UNIVERSITÀ CATTOLICA DEL SACRO CUORE

Sede di Piacenza

Scuola di Dottorato per il Sistema Agro-alimentare

Doctoral School on the Agro-Food System

cycle XXVIII

S.S.D.: AGR/01

ORGANIZATIONAL AND TRADE ISSUES IN THE SUPPLY CHAIN OF MAIZE AND SOYBEAN: THE ROLE OF GM AND NON-GM PRODUCTS

Candidate: Alessandro Varacca

Matr. n.: 4111063

Academic Year 2014/2015

UNIVERSITÀ
CATTOLICA
del Sacro Cuore

Scuola di Dottorato per il Sistema Agro-Alimentare
Doctoral School on the Agro-Food System

cycle XXVIII

S.S.D: AGR/01

Organizational and trade issues in the supply chain of maize and soybean: the role of GM and non-GM products

Coordinator: Ch.mo Prof. Antonio Albanese

Candidate: Alessandro Varacca
Matriculation n.: 4111063

Tutor: Prof. Paolo Sckokai

Academic Year 2014/2015

To my father, my relatives and all my friends,
without whom none of my achievements would have been possible.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The debate on the increasing adoption of genetically modified organisms (GMOs) in modern agriculture has been in vogue for the last twenty years. Whereas the European Union (EU) has always maintained an antagonistic attitude towards the use of biotechnology in feed and food production, most North and South American countries have largely embraced the use genetically engineered crops. In this regard, the differences between the EU and North/South America in terms of GMO legislations are supposedly due to the role of risk analysis: since the EU legislative process is firmly based on the so-called "Precautionary Principle", the approval of biotech crops for food and feed use has been typically sluggish, with a rather slow introduction of new varieties. These legislative discrepancies, along with the resulting difference in the rate of adoption of GM crops, pose two fundamental problems to the trade of agricultural products: on the one hand, the decreasing availability of non-GM raw materials rises the discussion of how the supply chains for such products cope with the higher probability of low level presence[1]; on the other hand, the trade of conventional products is also undermined by the possible occurrence of unauthorized GM events in overseas batches indented for export to the EU. In addition, the wide adoption of GM crops in North and Latin America poses the question of what effect, if any, the spreading of biotechnology in agriculture has exerted on real market prices. In this thesis, we try to answer these three research questions using maize and soybean as reference markets. First of all, we set up a case study for investigating how the Italian supply chain of non-GM soybean meal is framed and managed in order to reduce the risk of low level presence. Based on vis-á-vis interviews and transaction costs

---

[1] When used in relation to GM material, the term refers to the incidental presence of GM material in food, feed or grain at levels that are consistent with generally accepted agricultural and manufacturing practices.

economics, we conclude that hybrid organizations represent the best governance form. Next, we estimate the EU import demand for maize and soybean in order to assess the role of legislative diversities (in the matter of GMOs) on EU import decisions. Estimated cross-price elasticities suggest that dissimilarities in approval statuses between the EU and its major exporters do not influence imports. Therefore, we conclude that competition among exporters is based on price and seasonality. Last, a structural vector autoregression (SVAR) is set up to disentangle the role of GMOs adoption on the variability of US soybean market prices from 2000 to 2014. Results indicate that the introduction of biotech soybean reduces real soybean market prices in the short run, yet the effect is short lived and not much relevant.

1. INTRODUCTION

The debate about the swift spreading of biotechnology in modern agriculture, particularly when it comes to the adoption of genetically modified organisms (GMOs), has begun since the introduction of the first genetically engineered crops in the United States (US) during the nineties. After more than twenty years, however, the controversy has not diminished at all, at least in the European Union (EU). This is evidenced by two recent events that, in fact, reinforce the European position in relation to the use of GMOs in agriculture. The first one consists in the amendment of Directive 18/2001 concerning the release into the environment of GMOs, while the other coincides with the adoption of "GM-free" voluntary labelling schemes by an increasing number of member states (MS). Although both measures have in practice no immediate or dramatic market implications, they prove that the old continent has strengthened its stance against the use of genetic engineering in agriculture. The approval of Directive 412/2015[1] provides a quite new prospective to the cultivation of GM crops in the EU: whereas Directive 18/2001 allowed MS to forbid the cultivation of GM varieties deemed to be hazardous on the basis of new scientific evidence, with Directive 412/2015 MS can impose bans on GM crops under far weaker conditions. At the same time, France, Austria, Germany and The Netherlands have established framework laws allowing food retailers and manufacturers to introduce the so-called "negative labelling" for goods produced without the use of GMOs. In particular, these rules specify, on the one hand, the words that may be used to identify a product as "GMO-free" and, on the other hand, the thresholds for the accidental presence of GM raw material; thresholds are typically very low (from 0.5% to 0.1%) and, in general, positive limits are issued because of the impossibility to achieve 0% accidental presence.

---

[1] which amends Directive 18/2001 in article 26.

The reason for the current European anti-GM position is most likely the consequence of at least three cultural, scientific and political factors: first of all, the negative attitude of European consumers towards GMOs has almost surely limited farmers' incentives to adopt biotechnologies and, in general, it has addressed European policy makers accordingly; second, the uncertainty surrounding environmental and food safety issues have inspired a legislative process firmly based on the so-called "Precautionary Principle[2]"; third, the resistance of many MS to introduce major innovations in their agricultural systems may have significantly influenced European policy decisions in the last fifteen years.

Eurobarometer 2010 (European Commission, 2010) points out that, although European consumers are quite familiar with the concept GM food[3], only 27% of the respondents is supporting the adoption of GMOs. Globally, the European public sees GM food as unsafe, inadequate and worrying. Some authors believe that the reported absence of benefits originates from the lack of tangible consumers' benefits from the so called "first generation" of GM crops; indeed, this technological innovation gave birth to biotech agricultural products with characteristic mostly fitting farmers' needs. In addition, the country-level analysis on consumers' willingness to adopt GM crops clearly shows that in most MS the acceptance of GM crops has declined over time; in particular, results for Italy indicate that the share of consumers willing to encourage GM cultivation dropped from 51% in 1996 to 24% in 2010. This data reflect a trend common to all European countries with a GM crops' ban in place. In contrast, MS where GM crops are widely grown (i.e. Spain and Portugal) typically show highest levels of acceptance, which might suggest a link between private attitudes and public policies.

The discussion about the potential threats of genetic engineering to the environment and public health has reached no consensus yet. Based on the principle of substantial equivalence between GM varieties and conventional ones (Kuiper et al., 2001), most of the scientific community has already established the absence of food safety issues for genetically engineered crops (Snell et al. (2012), Hollingworth et al. (2003), Key

---

[2] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3Al32042 for details.

[3] EU survey shows that nearly half of the interviewed have heard about GMOs and searched for information as well. Only about 18% have not heard of it before the interviews.

et al. (2008) and European Commission (2015a))[4]; nevertheless, there seem to be still plenty of opponents in the public opinion. According to Herring (2008), the reluctance to accept the introduction of rDNA (recombinant DNA) technology in agriculture is mostly rooted in the asymmetries which characterize the complex network of interests and ideas surrounding genetic engineering. Whereas the debate about health concerns from the consumption of GMOs is largely outside the scope of this thesis[5], the issues arising from the introduction of biotech crops into the environment has fostered economic research concerning the sustainability of the so-called "coexistence[6] systems". The establishment of a coexistence strategies stems from the well known "Precautionary Principle" by which of all European policies regarding products potentially dangerous to humans, animals and environment should be draft on the basis of a comprehensive risk assessment analysis. Regulation 1829/2003 and 1830/2003 complement the legal framework about the marketing of GM food and feed products inside the EU; in particular, the two Regulation establish that only authorized products can be placed on the market and, if a food or feed product contains more than 0.9% of GM material, it must be labelled as "containing genetically modified organisms". Since the 2003 legislation de facto prohibited the presence of unauthorized GM varieties in food and feed products commercialized in the EU, this posed serious import problems to agricultural commodities originated from overseas countries like Argentina, Brazil and the US. If fact, both North

---

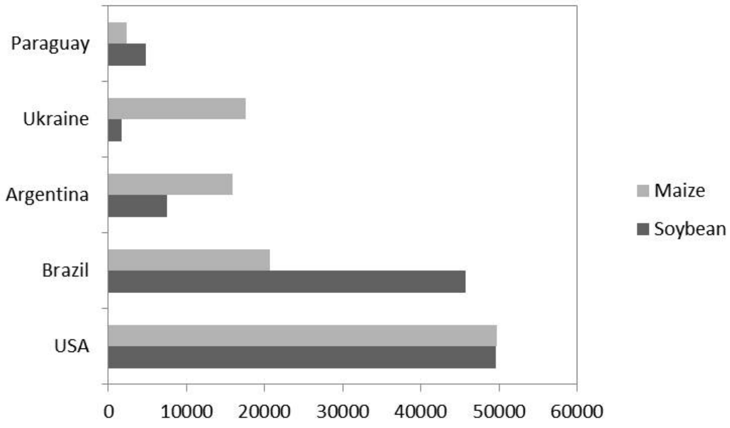
[4] There are however some "independent" works which recommend some caution when drawing conclusion from empirical methodologies: for example, Taleb et al. (2014) invoke the application of the Precautionary Principle, in light of systemic risk that might be associated to the cultivation and consumption of genetically engineered crops.

[5] Of course, this aspect is not secondary and is still particularly delicate; for example, the recent article by Séralini et al. (2012) received a lot of media attention before (and after) being retracted by the editor.

[6] The European Commission provides the following definition of coexistence: "Coexistence refers to the choice of consumers and farmers between conventional, organic and GM crop production, in compliance with the legal obligations for labelling defined in Community legislation. The possibility of adventitious presence of GM crops in non-GM crops cannot be excluded. Therefore, suitable measures are needed during cultivation, harvest, transport, storage and processing to ensure coexistence."

and South America have largely embraced the "GM side" and have rapidly adopted biotech maize and soybean varieties which are still pending for authorization in the European Union. Recognizing that trading commodities involves several steps which typically involve commingling and accidental admixtures, the EU realized that achieving 0% of unauthorized varieties in import batches was technically impossible. Therefore, Regulation 619/2011 sanctioned a 0.1% threshold as technical zero level for detected presence. Nevertheless, this tiny threshold still poses non trivial trade issues when it comes to agricultural commodities such as maize and soybean (Henseler et al. (2013), de Faria and Wieck (2015), Kalaitzandonakes (2011)). In fact, not only the major international maize and soybean exporters coincide with the world largest growers of GM varieties (see figure 1.1 and 1.2); but also the most relevant exporters of maize and soybean to the EU match with the countries presented in figure 1.2.

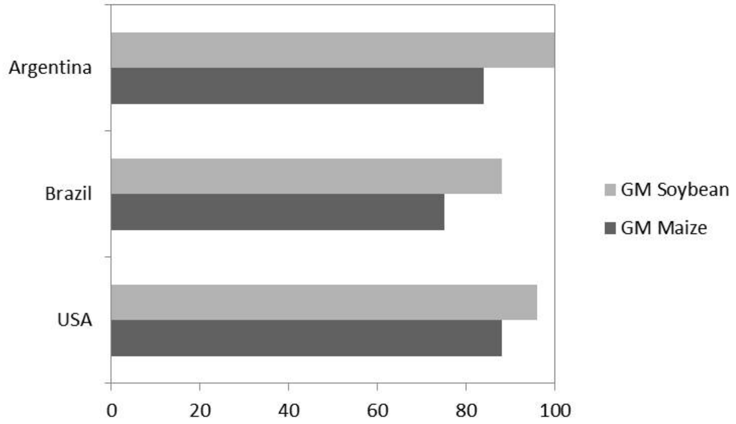
Fig. 1.1: World major maize and soybean exporter (2014, data in million of metric tons, MMT).



Source: UN Trade Statistics (2015).

The specific mention to maize and soybean is not casual: as shown in figure 1.3, these two products represent the most imported agricultural commodities within the European Union and, in general, they are among the most traded dry bulks on the international market. In particular, the European trade balance for soybeans and soybean meal is largely in deficit (UN Trade Statistics, 2015), meaning that the low self-sufficiency exposes

Fig. 1.2: Rate of adoption (land cultivated with GM varieties/total arable land) of GM maize and soybean in Argentina, Brazil and the US (2012).

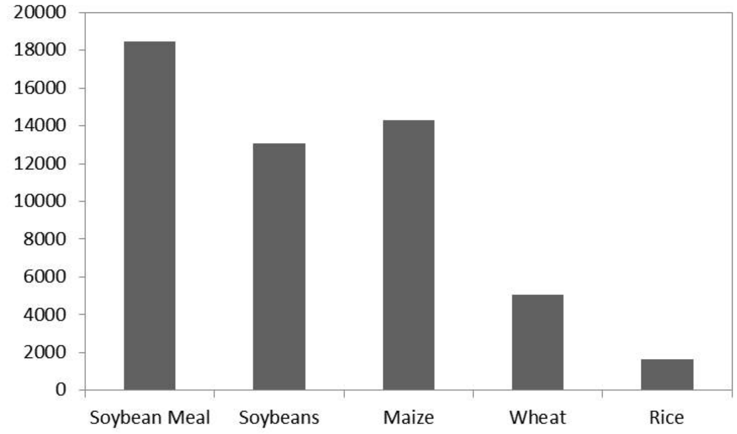


Source: James (2012), USDA, NASS (2015).

the EU to potential exogenous market shocks. In this regard, the predominance of the EU soybean imports over exports is due to at least three factors: first, the abolishment of import duties on oilseed crops (Dillon Round, 1962) and the contemporaneous ban of meat and bone meals in early 2000 has forced EU livestock breeders to switch to high-protein crops; second, the European predominance of continental weather has hindered the cultivation of soybean thereby fostering imports; third, the EU Common Agricultural Policy (CAP) reforms has strongly influenced farmers' decisions and addressed cropping choices towards other products (Bertheau and Davison, 2011).

There is no need to remark that the discrepancy between Europe and America regarding the adoption of GM crops poses the additional question of understanding what is the cost to European farmers and livestock breeders of being foreclosed to this particular product innovation. The literature on the matter is rather extensive and covers both the evaluation of welfare effects (for farmers and consumers) from adopting biotech crops (Lapan and Moschini (2004), Sobolevsky et al. (2005), Moschini et al. (2005)) and the direct impact of cultivating GM varieties on farmers' production costs (Fernandez-Cornejo et al. (2000), Fernandez-Cornejo et al. (2002), Bullock and Nitsi (2001)); in this respect,

Fig. 1.3: Most imported agricultural commodities in the European Union (2014, data in million of metric tons, MMT).



Source: UN Trade Statistics (2015).

however, results obtained through partial equilibrium and regression analysis are mixed. In addition, meta analysis indicate that significant differences in yields and profits are found when comparing herbicide tolerant with insect resistant GM crops and economic benefits, if any, are strictly dependent on geographical areas, marketing year and the GM trait adopted (Klümper and Qaim, 2014; Finger et al., 2011). Since the US represent the most important soybean exporter to the EU (Eurostat, 2015), understanding what effect the extensive adoption of biotech soybean has possibly exerted on US soybean real market prices is particularly relevant for the competitiveness of EU livestock breeders. Since GM crops have been cultivated in the US for nearly twenty years, there is now enough historical evidence to investigate this relationship empirically.

1.1 Research questions

Based on the arguments discussed so far, this thesis aims at addressing the following research questions:

1. Considering

    (a) the scarce acceptance of GM products by European consumers;
    (b) the introduction of a new stream of legislation supporting "GM-free" labels

   we investigate how non-GM supply chains are structured in order to cope with the risk of cross contamination between the GM and non-GM batches.

2. In light of

    (a) the importance of soybean and maize as raw materials in the European feed industry;
    (b) the huge adoption of GM varieties in the major exporting countries;
    (c) the tiny threshold allowed for EU-unauthorized GM events

   we estimate the European demand for maize and soybean under the assumption of geographically differentiated products. We expect, among others, that import decision might be significantly affected by differences in rate of adoption of GM crops.

3. Given the extensive adoption of GM soybean in the US since the early 2000s, we examine which role (if any) the spreading of herbicide resistant varieties has exerted on real soybean market price.

1.2 Methods

The following thesis is structured in three different self-standing chapters. Each chapter is linked to the other through the common ground of GM and non-GM maize and soybean international trade. In each chapter, one of the three research questions is specifically addressed using an appropriate empirical strategy; in this regard, our work will involve the use of both qualitative and quantitative analysis techniques. These methods are briefly introduced in the following paragraphs.

1.2.1 Chapter 2

In this chapter, we define the structure and assess the operation of the Italian supply chain for non-GM soybean meal. In particular, we develop a case study based on vis-á-vis interviews with industry representatives which provided the main input for the following economic analysis. Questionnaires were build to investigate the upstream and the downstream part of the supply chain separately: downstream respondents were representatives from the feed, retail, soybean crushing and livestock breeding industries, while those involved in upstream operations were primarily large international trading companies and port operators. We chose to frame and study these primary source information using the theory of hybrid organizations proposed by Williamson (1991) and Ménard (2004) within the broader field of Transaction Costs Economics (TCE). This stream of literature provides a useful conceptual framework for understanding how players in the supply chain behave when quality and market uncertainty are high enough to hinder the exploitation of vertical integration. Given the absence of reliable secondary data (i.e. time series observations) regarding the price and the trade volume of non-GM agricultural products, case studies represent perhaps the only instrument available to investigate scientifically the issues related to the marketing of non-GM products.

1.2.2 Chapter 3

In the second part of this thesis, we estimate the EU demand for maize and soybean grains in order to trace out any possible substitution and/or complementary relationship among different exporters. Under the well-known Armington's hypothesis (Armington, 1969), we consider products originating from different overseas countries as imperfect substitutes based on source-specific product characteristics such as nutritional value, product flow management and asynchronous approval of GM crop varieties. Demand analysis is carried out using the differential approach to demand theory proposed by Washington and Kilmer (2002b) and initially developed by Laitinen and Theil (1978). In particular, the EU derived demand for maize and soybeans is modelled through a Differential Factor Allocation Model (DFAM) which is derived from a general cost minimization problem. The production theory approach to international trade is preferred to traditional methodologies which consider imports as final goods entering the consumers' utility functions directly. This has at least three advantages: first, it is conceptually appropriate to the problem; second, it does not need the specification of a flexible functional form; third, it does not need aggregation across heterogeneous consumers. Moreover, since our data consists of quarterly times series for the past fifteen years, modelling demand in log-differences provides a useful way to wipe out non-stationarity in the data. Last, the model is flexible enough to include (temporal) fixed effects, and conditional Hicksian elasticities are very easy to compute.

1.2.3 Chapter 4

The last chapter of the thesis addresses the effect of GMOs adoption in the US on real soybean market prices using quarterly times series from year 2000 to 2014. We disentangle this relationship using a 5-dimensional structural vector autoregression (SVAR) where real soybean prices, energy prices, speculation activity on the soybean futures market, global demand of dry bulks and the rate of adoption[7] of biotech soybean in the US are simultaneously regressed on all endogenous variables and their lags. In particular, we use impulse response analysis to understand, among others, how market prices respond to a standard deviation shock in the share of GM soybean cultivated in the US. In addition, we perform forecast error variance decomposition to measure how much of the variability in soybean market prices is attributable to the rate of adoption of GM soybean within one or more quarters.

---

[7] This is measured as the ratio between the arable land cultivated with biotech soybean and the global area dedicated to soybean planting.

2. ECONOMIC ASPECTS OF SEGREGATION BETWEEN GM AND NON-GM CROPS IN ITALY

Paper by Varacca Alessandro, Boccaletti Stefano and Claudio Soregaroli, published in Agbioforum, Volume 17(2). 2014.

2.1 Background: the Italian market for non-GM products

The worldwide area dedicated to GM crops has been steadily increasing over the last 20 years and to date more than 150 million hectares are devoted to these varieties (Kalaitzandonakes, 2011). In countries where these technologies are available, the rate of adoption is generally high. According to the USDA, the United States, with 69.5 million hectares of GM crops planted in 2012, are the largest producer in the world. Brazil ranks second, with nearly 36.6 million hectares of GM maize, soybean and cotton in marketing year (hereafter MY) 2012/2013. The adoption rate of GM soybean reached 85% in MY 2011/2012 (21 million hectares), whereas the share of GM cotton was about 32% (490,000 hectares) and that of GM maize 67% (almost 10 million hectares). By July 2012, Brazil had 34 genetically engineered crops approved: 19 maize varieties, 9 cotton and 5 soybeans. Argentina, with 23.6 million hectares in 2011/2012, provides almost 15% of the total world production and is the third largest producer (Foreign Agricultural Service, 2012a). Although these data provide a clear picture of the adoption of GM crops around the world, more difficult is to assess the size of the non-GM production. This value is not simply the difference between the total production and the GM one, as a non-GM crop is defined according to specific labels requiring thresholds for GM admixture and certifications of compliance. Production data of Identity Preserved (IP) non-GM crops are even more difficult to derive: non-GM IP crops require stricter controls along the supply chain, third party certification and a stronger commitment of all the parties involved. Therefore, most estimates rely on trade data, although they mostly provide upper limits rather than ranges (Kalaitzandonakes, 2011). The demand for non-GM crops has three main destination markets (EU, South Korea and Japan) and remained stable over the last ten years. According to the European feed industry association (FEFAC), almost 15% of the EU compound feed production is certified non-GM. Poultry is the sector with the strongest demand for non-GM feed, as a significant part of poultry meat is sold under some sort of quality labels (i.e. organic) requiring non-GM feeding. Moreover, soybean meal for its characteristics is hardly replaceable in poultry, piglets and calves feeding, while cattle and mature animals can find more substitutes (Bertheau and Davison, 2011). The EU is almost self-sufficient for maize; only 10% of the internal consumption relies on imports, nearly 6.2 million of metric tons (MMt), 75% of which are non-GM, originating mainly from Ukraine and Brazil (Foreign Agricultural Service, 2012b). Instead, the EU is a net importer of soybeans and soybean meal, with non-GM varieties imported mainly from Brazil. Although the rate of adoption of GM maize and soybean crops in Brazil has been steadily increasing over the last few years, this country is still the largest world exporter of non-GM soybean and maize products addressed mainly to EU-27, Japan and South Korea. India and China are also large producers of non-GM soybean, but they do not contribute to trade: China does not export soybeans, mainly because of the large internal demand for protein feedstuff, while safety issues hinder India from exporting soybean meal (Tillie et al., 2012). Overall, the EU produces limited amounts of soybean and needs to import more than 30 MMt yearly of soybean and soybean meal to feed animals. Although Italy is the largest EU producer of soybeans (350,000 tons/year), the country is still a large net importer with imports that constitute over 90% of the total available soybean meal. Italian imports of soybean meal were up to 2.15 MMt in 2010, 7.5% of which non-GM hard IP[1]. Considering that the domestic production is

---

[1] In general, Hard-IP requires strict thresholds and segregation practices as well as tests performed by accredited laboratories all along feed/food supply chains. Definitions distinguish between Hard and Soft-IP. Some sources refer to Hard-IP product management systems as arrangements implying accurate

100% non-GM, total non-GM availability can be approximated at 13.8% of the total available soybean meal on the domestic market. Imports of non-GM soybeans in grains are generally zero; only in years of scarce domestic harvests imports may turn positive and significant. Italy imports non-GM soybean meal mostly from Brazil. Concerning maize, the Country is much more self-sufficient with imports that weight less than 20% of the total available maize on the domestic market. Roughly 95% of the imported maize (1.9 MMt in 2010) comes from other European countries where GM varieties are not allowed, with the largest share coming from Germany and France. Only 5% of imported maize is from Ukraine and Latin America and it is not clear whether this product is non-GM. The Italian market for non-GM feed is relatively small and both manufacturers and their customers are specialized enterprises in a specific supply chain, with livestock breeders being at most small-medium enterprises. That is, the competitive advantage for producers does not necessarily depend on the exploitation of economies of scale (Boccaletti et al., 2012), but rather on the slim and flexible structure and the capacity to respond promptly in terms of volumes sold, delivery schedules and just-in-time production to temporary supply shortages (Boccaletti et al., 2012). Moreover, unit costs are minimized at full capacity, a condition harder to achieve in large non-GM specialized facilities.

Since the availability of non-GM soybean is typically more problematic than the availability of non-GM maize, the rest of our discussion will focus on the economic aspects of segregation between GM and non-GM soybean in Italy.

2.2 Methodology

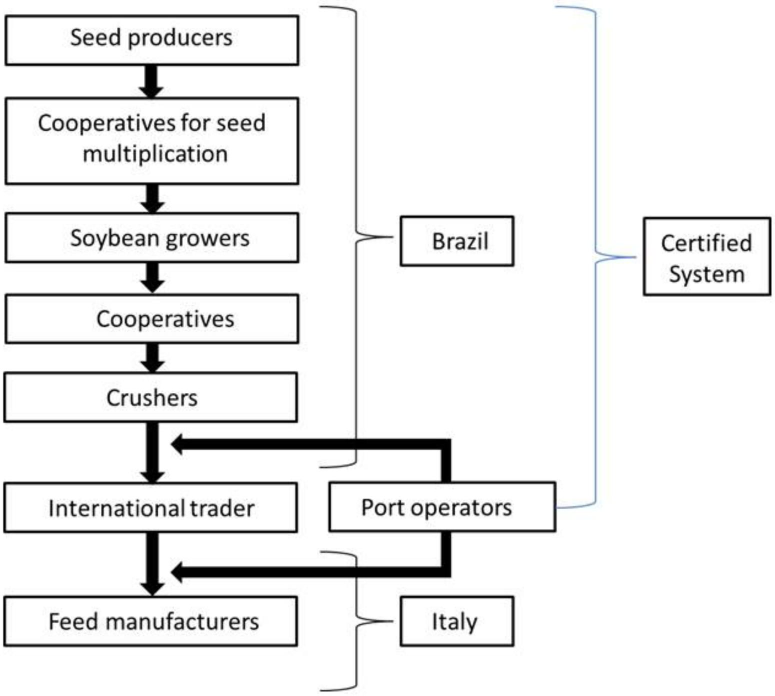
2.2.1 The survey

We investigated the structure of the Italian supply chain for maize and soybean through a number of vis-á-vis interviews with representatives from relevant enterprises. Each interview lasted between 2 and 3 hours; case by case, questions were organized in a

---

traceability; others define the difference between Hard and Soft-IP in terms of certification and auditing procedures. (Institut National de la Recherche Agronomique INRA, 2009) framework developed on the basis of a comprehensive review of the available literature regarding the structure, the organization and the governance of the supply chain (for GM and non-GM crops) (Boccaletti et al., 2012). This framework consisted of two structured questionnaires, addressed to investigate the upstream and the downstream part of the supply chain respectively. The full questionnaires are available in appendix A. Downstream respondents were from the feed, retail, soybean crushing and livestock breeding industries, those involved in upstream operations were primarily from large international trading companies and port operators. The questionnaire for the upstream operations has been more difficult to build and validate. Following the lack of information regarding how international trading companies organize their transactions and manage product and information flows, we faced a certain degree of uncertainty in drafting the framework. For example, we have not been able to pre-test it, and therefore we made progressive adjustments as the interviews proceeded. The questionnaire is structured into four sections. The first section identifies how the product and information flows are shaped, with emphasis on contractual arrangements and liabilities; the two following sections investigate the operations and responsibilities at the port level; whereas the final section refers to the physical transportation of the product from the origin to the destination country. The second questionnaire was revised after pre-testing with market experts from associations of producers, therefore with deep knowledge of the feed industry and its major trends. It is structured into six sections. The first section refers to the vertical and horizontal structures of the supply chain and asks also some preliminary details on market concentration and vertical integration. The second section considers the market for primary processed maize and soybean as well as the market for compound feed, listing questions on trade data and domestic production volumes. Sections three and four focus on the governance aspects of the upstream supply chain, including terms of trade among actors and pricing mechanisms. The last two sections are dedicated to the marketing and management of non-GM segregated products and to the role of certifiers. In this paper we decided to focus primarily on the upstream portion of the supply chain (figure 2.1). Based upon the information obtained from representatives of international trading companies, our aim was to assess the transactions between major overseas producers of non-GM soybean meal, international trading companies and domestic producers of non-GM feed. The management of product and the information flows from the field to the export terminal together with the following unloading and storage phases in dedicated facilities at the destination port are the key steps for segregation between GM and non-GM commodities (Pelaez et al., 2010; Bertheau, 2009). Therefore, we focused on two main transactions: the first between Brazilian selling companies (which aggregate non-GM soybeans and produce non-GM soybean meal) and the main international trading companies; the second between international trading companies and Italian feedstuff producers.

Fig. 2.1: The supply chain for soybean meal supplied to Italy.



Source: personal interviews, 2013

2.2.2 Theoretical framework

Building upon Williamson (1979, 1981, 1987, 1991), Ménard (2004, 2012), Ménard and Valceschini (2005), we arranged the information from the interviews using a Transaction Cost Economics (TCE) approach. The objective is to describe the nature of vertical relationships through the analysis of the determinants of economic organizational structures, namely asset specificity and different types of uncertainty. The core of the theory refers to whether a transaction is performed more efficiently within a hierarchical structure (i.e. within a firm) or by unrelated agents (i.e. market governance); the scope of the analysis relies on the transfer of goods and services. How this transfer occurs is the main outcome of interest. TCE also asserts that agents carrying out transactions are rationally bounded, risk neutral and in some cases they behave opportunistically in presence of asymmetric information. Although the neoclassical perspective of transactions considers market governance as more efficient than vertical integration because of the role played by competition and the reduced burden of bureaucracy, transaction characteristics and the behavioural problems of economic agents may lead to market failures. The specificity of the assets involved (transaction-specific assets), the frequency of the transaction and the level of uncertainty (which is mainly related to the bounded rationality and opportunistic behaviour of the agents involved) represent the three main dimensions which may cause markets to fail. Markets fail because transaction costs arise, making transactions through a simple market governance inefficient; these costs refer to search for ex-ante information, ex-ante and ex-post monitoring costs. Market failures suggest that, for some degree of asset specificity, uncertainty and frequency of the transaction, hierarchical structures could perform better than markets. Williamson defines three main economic organizations under which transactions can be established: market, hybrid forms and hierarchy. Hybrid forms are organizations between the market governance and hierarchical structures; according to the core of TCE, all hybrids share some common characteristics. In particular, Ménard (2004) emphasizes the following three:

- Resource pooling: whatever the hybrid form is, the agents involved converge in organizing their activities through inter-firm cooperation and coordination, so that investment decision relevant to the exchange are made jointly. The choice of the partner becomes a central issue.

- Contracting: coordination relies mostly on contracts, which differ by nature.

- Competition: parties within an hybrid form often compete against each other and also tend to compete with other arrangements. Formal mechanisms to discipline partners, solving conflicts and avoiding free-riding become crucial.

Ménard (2004, 2012) revisited the diversity of hybrid organizations proposed by Williamson, providing the idea that the decision to adopt one form of hybrid organization over another is linked to the logic of transaction costs (Réviron and Chappuis, 2005). Hybrid forms based on trust (which operates as a weak form of governance) are those which are closest to the market governance; on the other hand, formal governance includes hybrid forms sharing more characteristics with hierarchies than with market governance. Relationships characterized by trust fit with a low degree of assets specificity, while formal governance structures are associated with higher investments in transaction-specific assets. Between these two forms of hybrid organizations we may find relational networks and leadership: the former, differently from trust, presents formal rules defining the relationship, the latter is a hybrid form coordinated by a leader with a key position along the supply chain. Concerning the three dimensions which drive transaction costs, the classical TCE view (Williamson, 1991) emphasizes the predominant role of asset specificity in determining the properties of the economic organizations for transactions. Asset specificity refers to the degree to which the assets employed within a specific transaction can be redeployed for other uses without sacrificing productive value. According to the theory, as asset specificity increases, the ability to redeploy the assets gets lower and interdependency between parts increases, fuelling opportunistic behaviour under market governance. In his review on the diversity of hybrid forms, Ménard (2004) supports the hypothesis that the most important property affecting the form of alignment between parties is the degree of specificity of the assets involved. A second important dimension is uncertainty: this transaction costs determinant arises either when the relevant contingencies surrounding a transaction are to a large or small extent unpredictable to be formalized into an ex-ante contract, or when performances cannot be easily predicted and verified ex-post. The issue of uncertainty on quality is central to the supply chain for non-GM goods. Uncertainty in transactions where the quality of the goods involved is relevant originates from a problem of information asymmetry between agents; the lack of information affects primarily the buyer, unable to identify ”plums” from ”lemons”. According to Akerlof (1970), with information asymmetry the weak side of a transaction (the buyer) faces a ”moral hazard” problem and faces a higher risk of finding a bad partner. Additionally, information asymmetry protects bad partners if they cannot be easily separated from the good ones (Réviron and Chappuis, 2005). Some authors recognize several types of uncertainty: environmental uncertainty, behavioural uncertainty, technological uncertainty (i.e. uncertainty related to product quality) and volume uncertainty (Walker and Weber, 1984). Williamson (1991) also states that the role played by uncertainty on the degree of vertical integration or coordination depends on the degree of specificity of the assets. That is, increased uncertainty in presence of a non-trivial degree of asset specificity suggests that continuity between the transacting parties becomes important and adaptive capabilities are necessary, thus rendering market governance less preferable than other organized structures (i.e. firms or hybrids). Nonetheless, hybrid forms, in presence of transaction-specific assets, are perceived as less valuable as the degree of uncertainty increases. In fact, an hybrid form is bilateral in nature but mutual consent is hard to achieve with very high levels of uncertainty. However, there are several studies addressing the role of uncertainty without accounting for its interaction with asset specificity, or at least they do not focus on the combined effect of uncertainty and assets specificity. These studies try to explain whether uncertainty may cause either hierarchical or market oriented organizations independently from the specificity of the assets involved (Joshi and Stump, 1999; David and Han, 2004; Geyskens et al., 2006; Wei et al., 2012). In the case of segregated supply chains for non-GM goods, we expect uncertainty to play a key role in shaping the organizational forms by virtue of the higher transaction costs generated by both market conditions (price changes, total transaction volumes, characteristics of the demand) and agents' behaviour (suppliers' unpredictability, regulatory uncertainty) (David and Han, 2004). Consistently with TCE (Ménard, 2012), prior research (Jap, 1999; Klein et al., 1990) supported the effectiveness of hybrid forms of governance in presence of a nontrivial (but not very high) level of uncertainty; in fact, uncertainty makes both market governance and hierarchies less effective and the adoption of hybrid organizational structures may contribute to mitigating the problems of evaluation and monitoring caused by uncertain environments (Joshi and Stump, 1999; Lee et al., 2009). This is particularly true when it comes to uncertainty stemming from market turbulence and unpredictable demand and supply conditions (Joshi and Stump, 1999; Lee et al., 2009; Wei et al., 2012). Considering the uncertainty of quality under pure market conditions, the buyer bears the risk of acquiring a sub-optimal product whenever a minimum quality standard is required. Whereas different forms of signalling could help the buyer in a preliminary selection of the suppliers, the goodwill between transactors must be guaranteed with a specific organizational structure able to avoid opportunism and cheating (Reviron, 2000). In this case, non-trivial level of uncertainty calls for a tighter control of the buyer over the supplier. Transactions characterized by a very high level of uncertainty are less likely to be organized in hybrid forms, since mutual consent is generally not feasible (Lee et al., 2009). In fact, as uncertainty gets larger, hybrid organizations have to deal with some coordination issues: this translates into a higher effort for accommodating adaptation (in order to keep flexibility), control (in order to maintain the process unaffected) and incentives (to prevent opportunistic behaviour). In this case, either unilateral forms of governance (Wei et al., 2012) or market-oriented structures may solve the problem. However, some authors (Joshi and Stump, 1999) assert that, being the organizational structures dynamic, this sharp distinction is rather deceptive. In this work, we mainly focus on the role played by the different types of uncertainty in shaping the organizational structure of the transaction between Brazilian suppliers, international trading companies and Italian feedstuff producers.

2.3 Supply chains for Non-GM soybean meal

As to reduce quality-related uncertainty, Brazilian producers of non-GM soybean meal, the international trading company and feed manufacturers developed an organizational structure which relies on highly formalized contracts and provides for a traceability and certification system covering all the steps along the supply chain, from Brazilian growers to Italian port operators. The upstream part of the chain is built and validated by large international certification bodies in partnership with Brazilian crushers and it represents a necessary feature for the product to match the standards set by Italian feed manufacturers. In one of our case study, the Brazilian crusher established contracts with individual farmers and wholesalers implementing the segregation of non-GM soybeans. The certifier approves the soybean meal as non-GM by certifying each stage of the supply chain including: production and multiplication of seeds, grain production, industrial processing and delivery for export.

- At the seed production and multiplication stage, the crusher inspects and approves the entire process through a set of activities that ranges from the production of seeds by specialized cooperatives to the distribution of the seeds to soybean growers. The company is also in charge of monitoring the distribution of the seeds from the cooperatives to multipliers, seed planting, seed harvest and storage in dedicated silos (Pelaez et al., 2010).
- Grain production is also inspected and approved by the Brazilian crusher; at this stage the task is not limited to monitoring and includes testing procedures for the absence of GM events. Transportation of the harvested soybeans is a sensitive step of the production system and implies systematic strip testing on chronologically numerated batches. All the information is recorded and maintained for system certification (Pelaez et al., 2010).
- Industrial processing involves samples collection, as soybeans are unloaded into the

processing plant. Twice a week, composite samples are PCR-tested at an accredited laboratory (Pelaez et al., 2010).

- The crushing company's monitoring activity intensifies in the last stage, because the risk of admixture of non-GM products with other loads at the port terminal is very high. Certified procedures for export include: sampling when trucks are loaded; machinery and personnel cleaning before truck unloading or ship loading operations; daily physiochemical test on composite samples ; the issue of one Transaction Certificate of Compliance for each shipload; once the product is loaded on the ship, one further sample is taken for PCR analysis to certified laboratories: results are disclosed while the vessel is still on its way to Europe. The Brazilian crushing company forwards the certification papers to the trader, who requires such documents (in addition to any other formal document the company might require) when the payment is done (Pelaez et al., 2010).

On its part, the international trading company must deploy a system which guarantees the compliance with the GM threshold required by Italian customers for the non-GM product. The trader is responsible for ship's hold cleaning and inspection before the soybean meal is loaded and tested. Cooperation and coordination between the parts involved in these activities is crucial for achieving a low level of presence of GM events into the cargoes. Product management at the destination port is another critical step, and the implementation of best management practices helps to avoid commingling and adventitious presence. Therefore, it is important for international dealers to rely, on the one hand, on process-certified terminals and, on the other hand, to coordinate the activities of any actor involved in port operations, namely: grain terminals, shipping agents, port supervisors and finals customers. In particular, grain terminals are bound to employ dedicated cells, properly cleaned before non-GM soybean meal is being loaded; besides, terminals are also required to unload products using dedicated vacuums and blades. Last, terminal's operators (and any other port operators involved in handling these products) shall be trained in order to minimize commingling. Port elevating can be operated by the terminal itself or multinational trading companies can lease it to other structures: what is important is that GM and non-GM batches are stored in dedicated facilities with shipping documents kept separately in order to avoid products misplacement. When the product approaches Italy, the trading company makes arrangements to unload the non-GM holds in certified facilities. The trading company is liable if the product does not match the requirements, down to the loading on feed manufacturers' trucks. All the upstream documents are forwarded to the final customer and the imported product receives no further certifications. In the Italian case, in the main destination port of Ravenna the international trading company, together with port terminal managers, shipping agents, port supervisors and finals customers agreed on a common protocol for the management of non-GM covering from inbounding vessels to truck delivery. Final customers consider this protocol a valuable asset. Additional PCR tests are carried out when the meal is warehoused at the destination port; these cross tests are carried out on behalf of final customers and before the product leaves the port heading to final destinations (storage or processing facilities). Final customers are responsible for transportation from the port to the processing facilities and to any further stage.

2.4 Factors of uncertainty: hypothesis and results

2.4.1 Quality

We consider non-GM IP products as goods with higher quality compared to conventional ones. It is not our purpose to discuss whether the actual quality of non-GM IP soybean meal is effectively higher than its GM alternative; however, since the former requires higher investments in product quality management (i.e. coexistence measures at field level, segregation practices for harvesting, transportation, crushing, etc.), this extra costs must be matched by a price premium, which indicates the perception of a differentiated product. The uncertainty related to product quality refers to the risk of commingling the non-GM IP soybean meal with the GM one, which would cause a downgrade of the product, with negative economic consequences for the entire supply chain. Consistently with the theory concerning information asymmetry and product quality, we identify the following cases:

- Upstream risk of commingling. The main risks that international trading companies face are incurring in a batch with: 1) more than 0.9% of EU-approved GM events or, more often, a lower threshold (0.5% is the threshold level required by the international trader when purchasing non-GM soybean meal from Brazilian producers); 2) unapproved GM events. If tests for unapproved GM events are positive and the product was intended for the European market, the ship can still change its destination while surfing the ocean . The international trading company has to find a quick alternative, i.e. a non-European destination, in order to avoid a long stop at the dock (in-port daily costs are very high)possibly creating stock shortages downstream. On the other hand, if the product had already reached the port of destination, other measures shall be adopted and the economic impact changes accordingly . Since the amount of non-GM product is limited and specifically addressed to specialized feed manufacturers (which need to work at full capacity) and livestock breeders (mainly small-medium enterprises), any upstream stock shortage may cause serious problems, both from a legal and economic point of view. The downgraded product is usually sold at lower prices. The price may decrease further if a backup destination is not promptly available and the product needs to be sold as soon as possible. If the GM events in the batch are approved in the EU, then the product presenting values above thresholds is still marketable at lower prices. Unfortunately, the regular price would not cover the additional costs for the segregated non-GM supply chain.

- Downstream risk of commingling: the international trading company is still liable in case of non-compliance at destination. Even if the international trader purchased the product with a presence of GM events less than 0.9%, the threshold required by end-users is usually 0.5% (this way they want to keep safe from the legal threshold and the risk of GM labelling of feed). Consequently, the international trading company applies the lower limit of 0.5% to the Brazilian producers. If the content of GM events in the soybean meal batch in the destination port is above the legal threshold, the trader is bound to market the product as GM to other potential customers. If the product has already been unloaded, the trader has also the costs of stowing and maintaining the product. Feed manufacturers bear the risk of commingling after this point: if at the feed processing plant the legal limit is not respected and the manufacturer discovers it, the batch can be sold on the conventional market at lower prices. If the feed manufacturer is integrated downstream with the meat processor, the economic loss refers to a temporary shortage of feed; this might force the company to buy non-GM feed directly from the market at higher prices. If the feed manufacturer is not integrated, a non compliance might create losses of reputation and damage relationship with customers. Uncertainty related to product quality may cause relevant monetary and non-monetary losses borne by non-compliant agents, but with negative effects on the entire supply chain.

With reference to our methodological framework, we expect a non-trivial level of uncertainty to be controlled through hybrid organizational structures. However, as quality uncertainty changes from a non-trivial degree to a high one, the buyer has a strong incentive to adopt stricter organizational forms.

2.4.2 Environmental factors

Besides the uncertainty of quality, we recognize other types of uncertainty linked to environmental factors, i.e. to unanticipated changes in the circumstances surrounding the buying firm, with firms unable to write and enforce contracts which account for all future contingencies (Lee, Yeung, and Cheng 2009). We call this environmental uncertainty (Walker and Webber, 1984; David and Han, 2004):

- Supply-side uncertainty. As we already stated in the first section, the availability of non-GM soybeans has been steadily decreasing over the last decade, with the main international producer (Brazil) increasing the area cultivated with GM soybean varieties up to 80% of the total soybean area. The availability of non-GM soybean meal for international trading companies and domestic feed manufacturers is primarily related to the opportunity cost of producing GM soybean products by Brazilian farmers and processors. Several factors affect the choice, ranging from the management of the supply chain, to the surge of the conventional product price, resulting from an increasing demand for GM soybean, especially from China and India, and a steady supply. The availability of non-GM product generates an opportunity cost issue also for the international trading company. In fact, according to our interviewed traders the shrinking volumes will probably reduce the already low logistics efficiency along the supply chain of non-GM goods. This, together with the uncertainty at the demand level and an increasing demand for conventional products from developing countries, may support the decision to market GM soybean only. Domestic non-GM feed manufacturers are bound to their own (or retailer-driven) technical specifications and, more generally, to specific non-GM supply chains (Passuello et al., 2013). Being part of a non-GM supply chain may reduce the incentive for feed producers to switch to GM feed. However the choice also depends on the availability of substitutes for the non-GM IP Brazilian soybean meal. This issue is to date highly debated at the European level (Tillie et al., 2012).

- Demand-side uncertainty. The existing data regarding the awareness of European consumers towards both biotech crops and food derived from GM varieties are largely inconsistent across member states (Tille et al., 2012). This variability affects the incentive of downstream actors to abandon non-GM labelling since the monetary and organizational costs to maintain segregation might turn out unsustainable in the long run. In this uncertain scenario, the decision to abandon non-GM products could prevail and the market could shrink to a niche of producers.

- Price uncertainty. It results from demand-side and supply-side uncertainty. As regard to the upstream portion of the supply chain for non-GM soybean meal, the contract between the international trading company and the Brazilian supplier of non-GM soybean meal envisages a premium price for the non-GM standard;

> however, without a reference market for such premium, it is the results of a negotiation process based on several factors: the international price for soybean, the availability of non-GM soybean at the world level, the costs of the segregation techniques, the characteristics of the demand. The outcome of the negotiation is uncertain, although an estimate of the final premium is still possible. Clearly, price premiums have been increasing over the last few years in response to a shrinking global supply for non-GM soybean; besides the pure market effect of this contraction, one should also account for the reduction in logistics efficiency determined by lower volumes. Although the supply-side provides some insightful information regarding the trend of this premium price, the demand-side effects are less clear, in particular the willingness to pay for non-GM food. Moreover, estimates of the demand price elasticity for non-GM food are also missing and probably highly instable. Hand in hand with the attitude of European customers towards genetically modified organisms, food producers and more often retailers play a central role on the pricing mechanisms. Considering the actual price gap between non-GM and GM soybean meal, it is unlikely that this differential is fully transmitted to consumers, as the WTP would not be sufficient. Therefore, the price differential must be borne by some actors along the supply chain. These can be: 1) the producer of branded products or the retailer with its PL brand (in this case the labelling strategy could be considered as an investment in brand equity); 2) other upstream actors willing to accept lower margins to cope with downstream requirements achieving long term advantages from being part of a specialized supply chain.

Consistently with our methodological approach, we predict the appearance of hybrid forms of governance in presence of a non-trivial level of environmental uncertainty. Nonetheless, as uncertainty increases to a high level, according to theory hierarchical and hybrid governance forms are less suitable to the uncertain market conditions and a more market-oriented governance form is preferable.

2.5 Concluding remarks: organizational and managerial implications

The core of TCE identifies the most appropriate hybrid governance forms depending on both asset specificity and uncertainty. This work takes into consideration mainly uncertainty. As expected, the structure of the exchange between the upstream and downstream agents results from the combined effect of both environmental and quality-related uncertainty. A high degree of environmental uncertainty drives to a market-oriented governance form. In fact, both the upstream and downstream agents adopt a flexible framework based upon yearly contracts with a price premium for the non-GM standard re-negotiated on an annual basis. These contractual forms are expected to better manage upstream shortages. On the other hand, the uncertainty related to product quality is counterbalanced through a set of downstream-driven technical requirements enforced with process certification schemes. The buyer's monitoring of the supplier's performance is achieved through formalized contracts and process certification. Contracts between the international trading company and Brazilian producers are renewed yearly and transactors have been using them for many years, building upon trust and enduring personal relationships. In accordance with the literature on trust (Wei, Wong and Lai, 2012; Whan and Kwon, 2004) and transaction's long-term orientation (Joshi et al., 1999), we observe that the long-lasting trust-based relationships between local crushers and international trading company may serve as a flexible vertical coordination mechanism to reduce uncertainty and transaction costs. The main benefits of the relationship are:

- a stabilization of the price premium that the international trading company recognizes to Brazilian producers for non-GM soybean: this is of particular relevance, as there is no reference market for this premium;
- a secure market channel for Brazilian producers, i.e. a lower incentive to switch to GM crops;

- a stable and reliable supply of non-GM crops to the international trader.

The frequency of transactions between the international trading company and Brazilian crushers seems to play a key role in building trust. The exchange between the international trading company and feedstuff manufacturers is mainly managed through spot contracts. However, if we take into consideration the relationship between the trader and the main Italian customer, we cannot classify this transaction as pure market governance, where the identity of the transacting parties is irrelevant and no mutual dependency exists. What we notice is that the two parties maintain their autonomy but are bilaterally dependent in a nontrivial way: their identity matters and each of them cannot be replaced costlessly. The degree of uncertainty heavily affects the structure of the transaction: the volatility of demand and supply conditions may reduce the buyer's capacity to control the supplier. However, at this point of the supply chain, other economic determinants play a crucial role in shaping the transaction's governance form. The relatively small volumes of non-GM soybean meal necessary to satisfy the Italian demand resulted in a single international trader supplying the market. In this context, the buyer can control the supplier only through bilateral consent on product technical specifications and information/product management. This is usually done by large feed processors, such those integrated in the poultry sector, while relatively smaller feed manufacturers are more price and quality takers. Additionally, the feed manufacturer aims at establishing a trust-based and long-term oriented relationship with the international trader in order to curb the transaction costs arising from uncertainty. These are not necessarily specific to non-GM supply: as we observe from interviews, large Italian feed manufacturer have been doing business with one particular trading company, mainly because of the reputation of the upstream suppliers and the trust relationship between the two companies' staff[2].

---

[2] The importance of this trust relationship may be emphasized by some cases of product non-compliances, where the international trader claimed responsibility for it and paid the price gap between the GM and the non-GM final product

3. ANALYSIS OF THE EUROPEAN DEMAND FOR SOYBEAN GRAINS AND MAIZE

3.1 Background and objectives

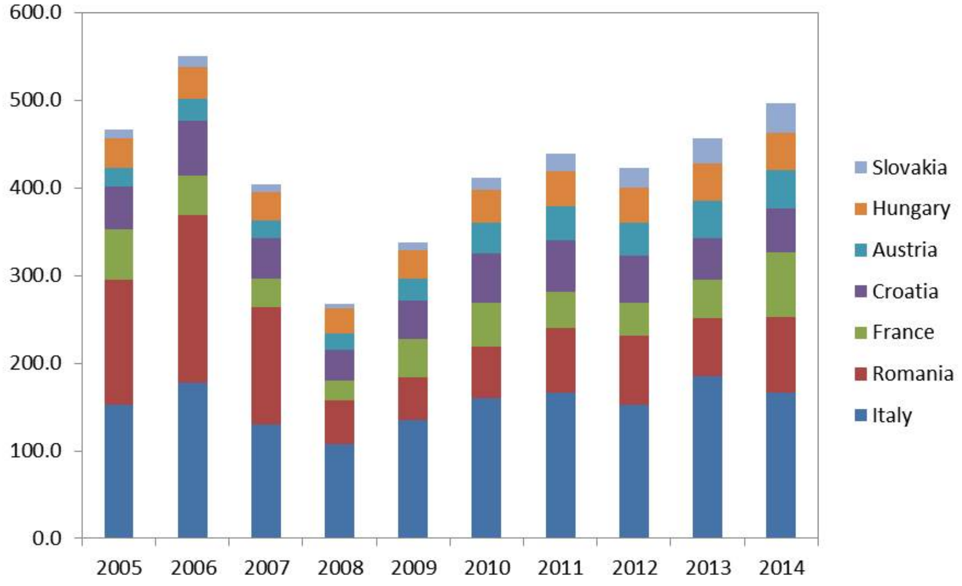
3.1.1 Background

Soybean

Soybean is currently the most important agricultural product traded on the international market, both in terms of volume and value. The reasons for the world-wide success of this leguminous plant can be substantially attributed to its remarkable protein content and the reduced fat fraction; these nutritional characteristics, along with its flexibility in feedstuff preparation, make soybean a preferable choice over most protein sources available for livestock breeding (Bertheau and Davison, 2011). Whereas soybean is not an essential feed for dairy and beef cattle, things change dramatically when it comes to poultry and hogs. Soybean meal is in fact a major source of highly disposable lysine, an essential amino acid which represents an important growth promoter and a limiting factor in pigs, chickens and turkeys (Tillie et al., 2012; De Visser et al., 2014).

Since the ban of high-protein meat and bone meals in early 2000, the abolishment of oilseeds import duties (Dillon round, 1962) and the hike in European domestic costs for feed grains, soybean has been largely introduced in European feedstuff formulations for intensively bred livestock (Bertheau and Davison, 2011). This escalation in demand has been mainly supported through imports: roughly 70% of protein-rich feed materials were imported into the EU in 2012 (64% of which is soybean meal), while only 3% of EU-27 arable land was dedicated to high-protein crops in 2013 (Bouxin, 2013; Häusling, 2011). It is clear that, up to now, the European agricultural sector cannot meet the compelling need for high-protein feed. The limited European supply of oilseeds has to do with two aspects: first, the unfavourable climate conditions in most member states hinder the cultivation of high-protein crops, in particular soybean; second, the frequent changes in the Common Agricultural Policy (CAP) have strongly influenced farmers' cropping decisions (Bertheau and Davison, 2011). Whereas continental climate with cool springs and dry early summer does not represent the best growing condition for soybean, political decisions had also influenced farmers' decision remarkably: with the 2005 Fischler Reform of the CAP, financial aids to European farmers became decoupled from production, thus aids were no longer related to oilseeds production and yields. The attempt was to link agricultural aid to environmental preservations and sustainability through the reinforcement the CAP's second pillar (Krautgartner et al., 2010; Bertheau and Davison, 2011). Since European farming is highly dependent on the CAP (Carlier et al., 2010; Cavaillès, 2009), these reforms have fuelled a shift in farmers' cultivation schemes since most crops (including soybean) are now driven by global market prices

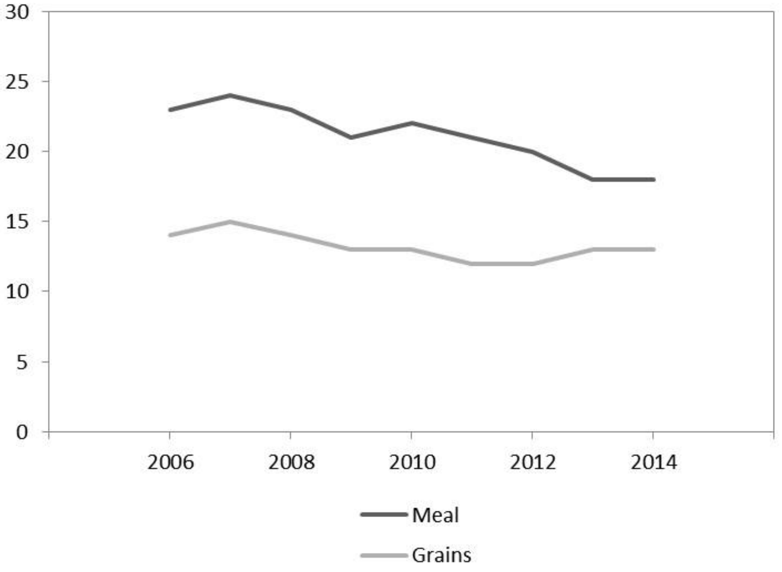
Fig. 3.1: Member States' soybean crop area (x 1000 ha).



Source: Eurostat (2015).

only. Italy is so far the European largest producer of soybeans (166 thousand of hectares in 2014, see figure 3.1 for details), followed by Romania (86 thousand of hectares in 2014), France (74.6 thousand of hectares in 2014), Croatia (50 thousand of hectares in 2014), Austria (43.8 thousand of hectares in 2014), Hungary (42.3 thousand of hectares in 2014) and Slovakia (33.4 thousand of hectares in 2014). As a result of the former USSR research in soybean breeding and the following adoption of these varieties within the former soviet block, eastern member states represents an important area for soybean cultivation; in particular, Romania and Hungary together invested over 125 thousand hectares in 2014, almost 26% of EU28 arable land dedicated to soybean.

Fig. 3.2: EU28 soybean import statistics (millions of metric tons).

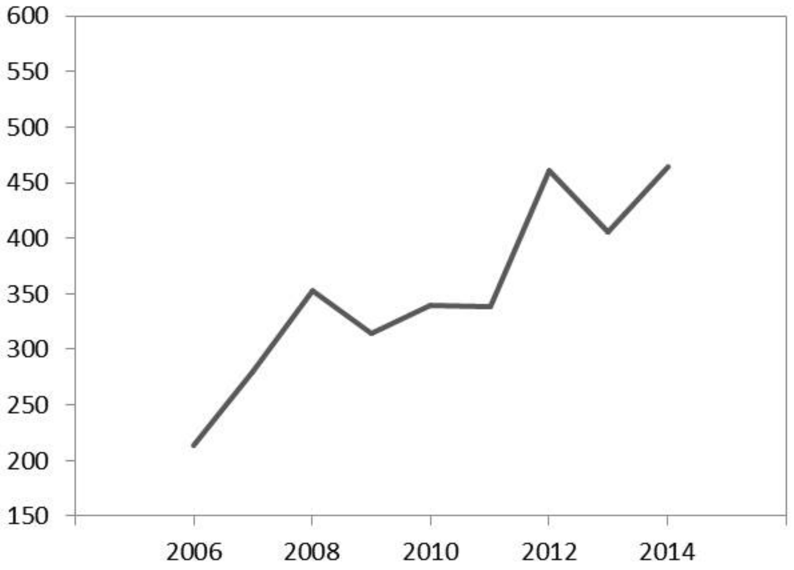


Source: Eurostat (2015).

The EU imports soybean as both crushed grains (soybean meal) and whole grains: official statistics indicate that Europe imported roughly 13 millions metric tons (MMT) of grains and 18 MMT of meal 2014, while the average import for the period 2006-2014 was 14.5 mmt and 21 mmt, respectively (see figure 3.2).

While the 15% decline in imported soybean meal is the likely consequence a remarkable soar in soybean's future prices in years 2008 through 2013 (see figure 3.3), the 10% drop in grain imports has also to do with the substantial decrease in European crushing capacity (De Visser et al., 2014). Since the EU imports soybean meal almost exclusively from Brazil and Argentina (Management Committee for the Common Organisation of Agricultural Markets, 2012), the following analysis will focus on the EU import of soybean grains (soybeans).

Fig. 3.3: Soybean World Price (expressed in Euro).



Source: World Bank (2015).

The EU soybeans import structure for 2014 is presented in table 3.1, while table 3.2 indicates the average soybeans import for the period 2000 through 2014. United States and Brazil are clearly the two nations which mostly contribute to European Union's international demand for soybean grains, followed by Paraguay and Canada. On the other hand, Argentina clearly plays a marginal role when we consider unprocessed soybean; therefore, we will not include Argentina in the analysis of the EU import structure.

It is now clear that the low self-sufficiency ratio and the consequent reliance on the international market, exposes the EU to possible trade distortions: scarcity, excess price volatility and problems of GMOs-related issues may undermine the sustainability of a significantly import-tied livestock sector.

Tab. 3.1: 2014 Soybeans import sources by volume (millions of metrics tons) and value (millions of Euro).

U.S.A.	Argentina	Brazil	Canada	Paraguay
Volume				
4.21	0.058	5.75	0.86	1.24
34.8%	*0.5%*	*47.5%*	*7%*	*10.2%*
Value				
1638	25	2364	316	509
33.8%	*0.5%*	*48.7%*	*6.5%*	*10.5%*

Source: Eurostat (2015).

Maize

Maize is currently cultivated on nearly 185 million hectares all over the world (FAO, 2015) and represents the most popular cereal in many developing countries such as Southern and Eastern Africa, Central America and Mexico (Ranum et al., 2014). In such geographical areas, maize is largely devoted to human consumption while its main use in developed countries has long been shifted to feed processing. However, with the fast economic growth which enabled most consumers to access animal produces such as milk, eggs and meat, the share of maize dedicated to livestock feed production in developing countries has recently soared (Shiferaw et al., 2011). This shift in maize allocation is particularly observed in Asian countries like China and India. At the global level, the use of maize as a source of food accounts for roughly 15% of the total demand but the share almost doubles when it comes to developing countries. On the other hand, roughly 63% of the global maize demand is absorbed by livestock breeders, while the amount of product dedicated to feed production declines to 56% in developing countries (Shiferaw et al., 2011). There are however significant variations in alternative uses at the country level across developing and developed world. According to the European Commission, roughly 64% of the maize imported/produced in the EU was employed to produce animal feed during the marketing

Tab. 3.2: Soybeans import sources by volume (millions of metric tons) and value (millions of Euro), 2000-2014 average.

U.S.A.	Argentina	Brazil	Canada	Paraguay
Volume				
3.86	0.25	7.37	0.61	1.07
30%	*2%*	*56%*	*4.7%*	*8%*
Value				
1,132	75	2,116	207	350
29%	*2%*	*55%*	*5%*	*9%*

Source: Eurostat (2015).

year (MY) 2013/2014. On the other hand, nearly 0.5% of the domestic supply was absorbed by the seed industry, while industrial use other than feed production (of which biofuel is the most relevant one) and human consumption were responsible for the 10% and 5.2% of domestic use (European Commission, 2015b). Table 3.3 reports the EU balance sheet for maize products from MY 2007/2008 to MY 2013/2014. The 16% increase in total supply that the EU experienced during the last seven years has been mainly driven by the hike in demand for maize feed products and maize for industrial uses (+14% and +39%, respectively). In particular, the soar in maize demand for industrial uses coincides with the rapid expansion of the European biofuel industry; in fact, the European balance sheet reports that the share of maize employed for bioethanol and/or biofuel production has increased by 79% since MY 2007/2008 (European Commission, 2015b). This trend is obviously not unique to the EU: nearly 50 developing countries have already established blending mandates and maize represents the primary feedstock within the famous US ”Corn Ethanol” program (Shiferaw et al., 2011). France is the European (EU28) largest producer of maize (3,259.9 thousand of hectares in 2014, see figure 3.4 for details), followed by Germany (2,573.9 thousand of hectares in 2014), Romania (2,552.4 thousand of hectares in 2014), Hungary (1,266 thousand of hectares in 2014), Poland

Tab. 3.3: European balance sheet for maize. Data reported in MMT. Total supply includes initial stocks.

	'07/'08	'08/'09	'09/'10	'10/'11	'11/'12	'12/'13	'13/'14
Production	48.3	63.1	57.6	57.1	68.6	58.3	66.4
Import	15.1	4	2.4	7.5	6.2	11	15
Total supply	79.2	81.4	77.8	79.4	88.3	86.1	94.6
Domestic uses							
Human consumption	4.7	4.7	4.8	4.8	4.8	4.8	4.9
Seed production	0.4	0.4	0.4	0.4	0.5	0.5	0.5
Industrial use	5.8	6.9	7.5	8.5	8.1	8.3	9.5
Animal feed	52.2	48.2	48.1	50.2	54	57	60.6

Source: European Commission (2015b).

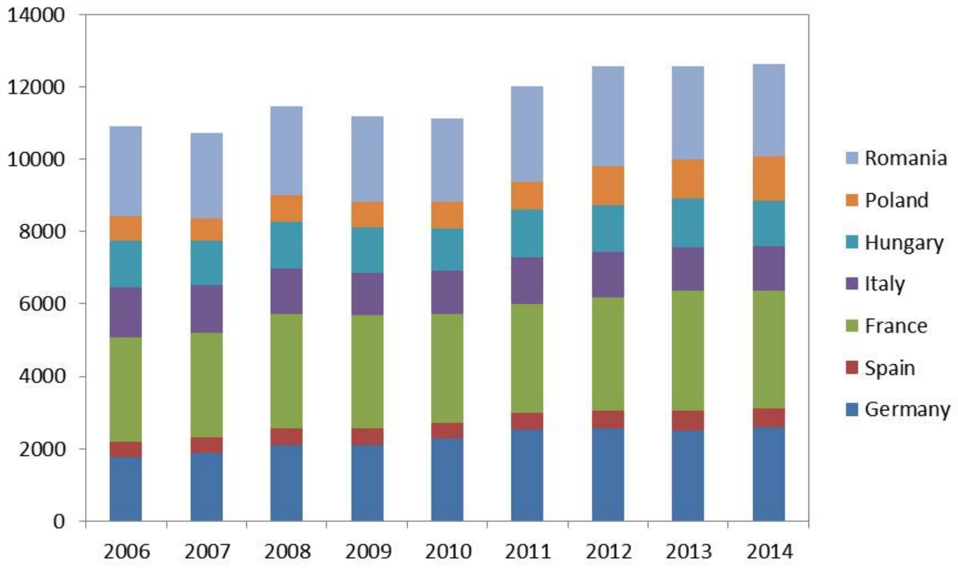
(1,219.5 thousand of hectares in 2014), Italy (1,215.9 thousand of hectares in 2014) and Spain (531.5 thousand of hectares in 2014).

Differently from soybean, the EU import of maize products[1] is not as compelling as it is for high-protein crops. Maize import represented only 10% (on average) of total European supply for the seven year period 2007/2008 to 2013/2014. In fact, maize can be easily grown in most EU member states thanks to favourable weather conditions and the remarkable supply of hybrids suitable to most pedoclimatic situations. In addition, World Trade Organization's (WTO) rules for the imposition of import duties on cereals depending on international market conditions. Even through the EU has set bound duties for all cereals under the GATT (General Agreement on Tariffs and Trade), for some cereals the rates imposed are different. This system dates back to the Blair House Agreement (November 1992) between the United States and the EU and consists of applying tariffs based on individual world reference prices for specific cereal products. The duty is computed as the difference between the effective EU intervention price multiplied

---

[1] The European Union imports maize as whole grains (we will hereafter refer to maize grains as simply "maize"), bran, starch, flour and distilled dried grains.

Fig. 3.4: Member States' maize crop area (x 1000 ha).



Source: Eurostat (2015).

by 1.55 and a representative CIF (i.e. cost, insurance and freight) import price at the Rotterdam port (European Commission, 2014). For example, in July 2014 the European Commission announced the introduction of an import duty on maize, sorghum and rye to be set at 5.32 Euro per tonne. The decision came in response to the troublesome situation on the international markets which resulted in particularly low prices.

3.1.2 Source differentiation

Even though soybean and maize are often referred as undifferentiated commodities, within an importing area like the EU imports from one source are likely to be perceived as imperfect substitutes for the same products from another exporter. If not, price ratios would be constant and elasticities of substitution between these supplies would be infinite (Armington, 1969). This imperfect substitution is typically due to a variety of source-specific features; for example, different countries may have different reputations for products' quality, quality consistency, reliability, supply chain management, etc. (Washington and Kilmer, 2002a). In this regard, soybean and maize do not make an exception for at least three reasons: first, soybean and maize originated from different overseas countries may show uneven nutritional characteristics; second, different exporting countries may show different authorization statuses for genetically modified (GM) events which have not yet been approved for food and feed use in the EU; third, products originating from countries with more efficient supply chain management are typically perceived as qualitatively superior[2] (Nakamura et al., 1998; Foster, 2008). Moreover, exporting countries' characteristics may change over time; that is, supply chain management may improve (Schwab et al., 2011), GMOs regulation and adoption may change (James, 2010) and the agricultural sector may evolve, particularly in areas such as South America and Asia. Additionally, soybean and maize quality and availability may differ from year to year consequently to transformations in the agricultural systems (Veeman and Gray, 2010) and bad/good growing seasons.

Nutritional Characteristics

Soybeans nutritional characteristics are highly dependent on country-specific features: transportation and storage conditions, management at the origination port, genetics and growing conditions are key parameters for quality (Northern Crops Institute, 2013). According to Grieshop and Fahey (2001), Karr-Lilienthal et al. (2004), and Park and Hurburgh Jr (2002), significant quality differences in soybeans and soybean meal originated from either South America, North America or Eastern Countries have been consistently found in several nutritional studies. In particular, the analysis performed by Grieshop and Fahey (2001) on soybeans harvested in different Brazilian, Chinese and North American states/provinces/regions showed that North American and Chinese samples had higher crude proteins (CP) and lysine levels. Similarly, Park and Hurburgh Jr (2002) results indicate that soybean meal originated from the US is more consistent and has higher feeding value (more digestible, higher in protein, and better quality protein) than meal from other geographic areas. However, Park and Hurburgh Jr (2002) analysis

---

[2] for example, the absence of unapproved GM goods at the ports' harbours would make such workflow a desirable country-specific feature (Pelaez et al., 2010).

is not performed on soybean grains but on soybean meal; in such a case, other factors pertaining to the oil extraction process might have influenced the nutritional features of the product. Karr-Lilienthal et al. (2004) also found that Chinese beans had a larger CP fraction and lysine level than South American (Brazil and Argentina) and US samples but, in this case, Brazil performed slightly better than North America. In addition, Ku et al. (2013) found that pigs fed with Korean soybean meal had greater final body weight than those fed with diets containing soybean meal originated from India or Brazil and, overall, that Korean meal had better quality than that imported from Brazil or India.

These empirical findings clearly show that soybean samples harvested in different geographic areas have heterogeneous qualitative attributes. This stream of literature is in line with the early works conducted by Rose (1988); Wolf et al. (1982) and Cure et al. (1982) who demonstrated that the amount of CP and oil can be the result, among the others, of different growing conditions such as rainfall (Rose, 1988), temperature (Wolf et al., 1982) and photo-period (Cure et al., 1982). Bellaloui and Mengistu (2008) also discuss how alternative irrigation regimes and cultivar differences may severely affect yields and seeds' composition under different environmental conditions; in particular, full season and/or reproductive stage irrigation schemes may or may not convey higher CP fractions depending on the cultivar adopted and the crop year. This implies that the availability of drought-resistant varieties, water and agricultural know-how is key for obtaining the "best" seed composition.

Consistently with the above literature, we will hereafter refer to (North) American soybean as the "highest quality" product with respect to its CP and lysine portions. By contrast, Brazilian soybean will be inevitably ranked below the US one. Unfortunately, there are no up to date empirical studies concerned with the assessment of Paraguayan or Canadian soybean quality. For example, the analysis by Mounts et al. (1990) provides some bits of evidence concerning Paraguay: the authors found that Paraguayan grains had overall higher CP levels then soybeans originated from the US and Brazil. However, these results are based on a single sample collected in 1988, 10 years before the time series we will use for our analysis.

Similarly, we found no up-to date studies concerning the assessment of nutritional characteristics of maize samples from different countries. Given this lack of information, we cannot make a-priori assumptions regarding maize grading across international suppliers.

GMOs and asynchronous approval

The rate of adoption of GM soybean and maize in most of world-major exporting countries has rapidly increased over the last decade (Tillie et al., 2012; James, 2010; Kalaitzandonakes, 2011), with a rather fast introduction of the newest varieties. Such phenomenon may undermine export opportunities toward the EU, where imported soybean and maize must be labelled as ”containing Genetically Modified Organisms” if the GM material exceeds the 0.9% threshold and such material must include only varieties approved by the EU legislation. Although globally traded, GMO’s approval for commercialization is still regulated by national legal schemes only. These regulations comprise, among others, approval for importing, cultivation, labelling policy and traceability. All these regulatory dimensions vary remarkably among different countries (Vigani et al., 2012; Davison, 2010; Berwald et al., 2006). This generates the well-known issue of asynchronous approval: since the authorization process in the major GM-producing countries is typically quicker than in the EU, it is common that newly approved GMOs in these countries still await for authorization in the EU, such that traces of these newly approved products cannot be present in imported batches because of the European ”zero tolerance policy” for unauthorized GM. Considering that a perfect segregation of approved and unapproved GM crops cannot be consistently achieved, then one should expect that a larger gap in the number of approved varieties should result in higher threaten of trade disruptions. Therefore, even if a complete segregation is not feasible in practice, an efficient upstream product management (especially at the ports’ harbours) is a key country-specific feature to minimize the risk of low level presence[3]. The

---

[3] The accidental presence of small amounts of biotech events that have undergone full safety assessment and have received regulatory approval for all possible uses in one or more countries but

”zero tolerance policy” has already challenged EU agricultural imports (Henseler et al., 2013) thereby fostering the economic research on the role of asynchronous approval as key trade determinant (Henseler et al., 2013; Kalaitzandonakes, 2011; Carter and Smith, 2007). Most of these works are aimed at assessing either ex-post market disruptions caused by non-compliant imports (Schmitz et al., 2005; Carter and Smith, 2007) or the potential economic turmoil caused by discontinued trade relationship (Philippidis, 2010; Magnier et al., 2009).

When discussing of any potential GMO-related trade issue, it is worth distinguishing between the whole amount of approved GM events and the share of approved GM events which are effectively commercialized for food and feed use. We want to provide a measure for this asynchronism using the Protectionism Index introduced by de Faria and Wieck (2015), which extends the Protectionism Index developed by Li and Beghin (2014) with a time dimension, in order to assess the extent of asynchronous approval over time. The Index is defined as follows:

$$AA_{jit} \equiv \frac{1}{M_t} \left(\sum_{m_t=1}^{M_t} \exp \frac{(R_{im_t} - R_{jm_t})}{\max(R_{m_t}) - \min(R_{m_t})} \right)$$

where the subscripts j, i and t indicate the importing country, the exporting country and the year, respectively[4]. Moreover, M denotes the total number of GMO events available for a given product (soybean or maize in this case), m indicates a particular GMO event, R_{m_t} defines the rank of the approval status for a GMO event m while R_{im_t} and R_{jm_t} represent the rank of approval for m in the exporting country i and the importing country j, respectively. Note that R_{m_t} can take on values from one (most restrictive approval status) to four (least restrictive approval status), with $R_{m_t} = 1$ indicating that event m is not approved for any use, $R_{m_t} = 2$ if m is approved for feed use only, $R_{m_t} = 3$ if m is approved for food use only and $R_{m_t} = 4$ is m is approved for both feed and food use. Since the present analysis considers only one importer (the European Union),

---

are still unauthorized in others due to regulatory asynchronicity or expiration of their approvals? (Kalaitzandonakes, 2011)

[4] In details: j = European Union, $i \in$ {U.S., Argentina, Brazil, Canada, Paraguay} and $t \in \{2000, 2003, 2006, 2009, 2012\}$.

the subscript j can be omitted so that $AA_{jit} = AA_{it}$. AA_{it} ranges from 0 to e with $AA_{it} = 1$ indicating no difference in approval statuses between the importing and the exporting countries, $AA_{it} \in [0, 1]$ if the importing country is less stringent than the exporting country and $AA_{it} \in [1, e]$ if the approval status of the importing country is more stringent than those of the exporting country. If the approval status in the EU is stricter than in country i, then AA_{it} will be non-decreasing in stringency[5]. The data employed for the Protectionism Index are obtained from de Faria and Wieck's dataset directly; in particular, the main sources regarding the approval status of GM events are the ISAAA GM Approval Database (ISAAA, 2013) and the CERA GM Crop Database (CERA, 2013), which provide names and codes of each GMO event as well as the countries that have already authorized the event, the first year of approval, and the type of approval (feed, food, feed and food and cultivation). Information about events currently marketed in at least one country is provided by the Biotechnology Industry Organization through the on-line Biotradestatus database (BIO, 2013).

As shown in table 3.4, when we consider soybeans imported from USA, Canada, Brazil and Paraguay, there are significant differences between North American and South American countries. Similarly, the maize Protectionism Index shows that whereas Ukraine and South American countries are on average as restrictive as or more restrictive than the EU, the US commercialize more GM varieties than the EU.

As de Faria and Wieck (2014, 2015) have recently shown, dissimilarity across country pairs (i.e.: EU vs major exporting countries) have been increasing over time in terms of globally approved events. Nevertheless, if the focus is shifted to commercialized events only, the study indicates a substantially synchronization between the EU and the major soybean and maize exporting countries. According to the authors, this could result from a strategic behaviour adopted by exporting countries in order to mitigate the impact of asynchronous approval and avoid potential trade disruption with key commercial partners. Nevertheless, the persistence of this sychronicity is highly dependent on the future discrepancies between

---

[5] Since the European Union has not approved any commercially available event for soybean, AA_{it} is always non-decreasing in stringency.

Tab. 3.4: Protectionism Indexes.

	USA	Brazil	Canada	Paraguay	Ukraine	Argentina
			Soybean			
Mean	2.23	1.58	2.23	1.13	-	-
Max	2.71	1.85	2.71	1.85	-	-
Min	0.85	0.84	0.84	0.52	-	-
Std.dev	0.71	0.4	0.71	0.4	-	-
			Maize			
Mean	1.68	0.85	-	-	0.70	0.96
Max	1.89	1.04	-	-	0.77	1.07
Min	1.53	0.64	-	-	0.64	0.85
Std.dev	0.14	0.17	-	-	0.04	0.08

Source: de Faria and Wieck (2014, 2015).

country pairs. These findings strengthen the hypothesis that asynchronous approval is a key feature when considering trade between GM-intensive countries and the European Union.

Efficiency of supply chain management

In order to assess differences in supply chain efficiency between USA, Canada, Brazil and Paraguay, we consider the Port Infrastructure Quality Index (PIQ hereafter) and the Overall Infrastructure Quality (OIQ hereafter) index provided by World Economic Forum's "The Global Competitiveness Report" (Sachs et al., 1999, 2000, 2002; Cornelius et al., 2003; Sala-i Martin et al., 2004, 2005; Lopez-Carlos et al., 2006, 2007; Porter et al., 2008; Porter and Schwab, 2009; Schwab, 2010, 2011, 2012, 2013) from 1999 to 2013, as suggested by Clark et al. (2004). These indexes are based on the so-called "Executive Opinion Survey" (Schwab, 2013) whose main goal is to achieve a quantitative assessment of those country-specific variables for which primary source data are scarce or, more frequently, unavailable. The survey is designed to capture the perceptions of business executives relatively to a broad range of countries' business dimensions: these include infrastructures, competition, labour market, institutions, etc. Respondents are asked to evaluate the conditions of the business environment they are competent about through a 1 to 7 ranking list, where 1 represents the worst operating situation, while 7 indicates excellence. To ensure results' consistency across countries, the World Economic Forum establishes collaborative agreements with a number of partner institutions in each nation included in the report; these partners are typically national universities, research centres and/or small/medium/large business organizations. The way country scores are computed is well described in each Report's issue; however, it is worth mentioning that by 2008 the World Economic Forum has introduced a new way to compute such indexes: from the 2007-2008 Report to the most recent releases, country scores are obtained using a moving average approach (Porter et al., 2008).

The reason why consider the PIQ and the OIQ indexes is that: since the major soybean and maize exporters are mainly located in North and South America, the smoothness of port operations, as well as the effectiveness of transaction procedures such as commingling, traceability, identity preservation, etc. represent remarkably important features for economies competing on the international market. In this regard, ports have historically been referred as bottlenecks in maritime transportation because of their complex internal organisation and the considerable number of companies or, more generally, agents in charge of moving goods between ships, from inbound vectors to loading sites or between warehouses (López and Poole, 1998). The provision of port services has therefore become crucial in modern international logistics and should provide a good indicator to assess how efficiently the product flow is managed. Table 3.5 reports the PIQ index for USA, Brazil, Canada, Paraguay, Ukraine and Argentina for the years 2000, 2006 and 2012:

Coherently with the available literature (Koopman and Laney, 2012; World Bank, 2010), Brazil is the country with the poorer port infrastructures, while Canada has performed better than both USA and South American countries. The data for Ukraine is less relevant as maize is mostly shipped to the EU by train or truck.

Tab. 3.5: Port infrastructure quality index for years 2000, 2006 and 2012.

	U.S.A.	Brazil	Canada	Paraguay	Ukraine	Argentina
PIQ 2000	6.0	3.3	6.1	NA	3.4	4.0
PIQ 2006	6.0	2.7	5.7	2.3	3.7	3.6
PIQ 2012	5.5	2.7	5.8	3.4	3.7	3.7

Source: The Global Competitiveness Report 2000, 2005-2006 and 2011-2012 (Sachs et al., 2000; Lopez-Carlos et al., 2006; Schwab, 2012).

We also consider the OIQ index in order to account for other supply chain physical components besides ports; in particular, the index encompasses the respondents' perceptions concerning, among the others, the quality of roads, railways, airports, telephone lines, internet access. Table 3.6 reports the OIQ index for USA, Brazil, Canada, Paraguay, Ukraine and Argentina for years 2000, 2006 and 2012.

Tab. 3.6: Overall infrastructure quality index for years 2000, 2006 and 2012.

	U.S.A.	Brazil	Canada	Paraguay	Ukraine	Argentina
OIQ 2000	6.6	3.1	6.3	NA	2.7	3.4
OIQ 2006	6.5	2.8	6.1	2.0	3.4	3.6
OIQ 2012	5.7	3.6	6.0	2.5	4.2	3.5

Source: The Global Competitiveness Report 2000, 2005-2006 and 2011-2012 (Sachs et al., 2000; Lopez-Carlos et al., 2006; Schwab, 2012).

Once again, the index highlights that USA and Canada are affine in terms of infrastructures' quality, while South American countries still lag behind.

3.1.3 Objectives

We aim at estimating the European soybean and maize import demand distinguished by country of origin in order to provide own-price and cross-price (i.e. cross-country) elasticities which are not currently available in the literature and might be supportive for further policy analysis. Cross-price elasticities will provide information about the presence of complementarity or substitution among different countries of origin. Depending on the sign of the estimated coefficients, demand dynamics might be dictated by source differentiation based on either pure product availability/price or, alternatively, on different country-specific product attributes (i.e. nutritional characteristics, asynchronous approval and supply chain efficiency). Although most import demand analysis are still performed through structural functional forms derived from consumer theory (Seale Jr et al., 2013; Mutondo and Henneberry, 2007; Boonsaeng et al., 2008), we proceed with the estimation of the European import allocation structure using a differential approach based on production theory.

3.2 Methodology

The methodology we use in the present analysis is based on Theil (1977); Laitinen and Theil (1978); Theil (1980); Davis and Jensen (1994); Washington and Kilmer (2002b,a). and Christou et al. (2005). The European derived demand for soybean grains is modelled through a Differential Factor Allocation Model (DFAM), following the differential approach to the theory of the firm initially proposed by Theil (1977) and Laitinen and Theil (1978). The production theory approach to international trade is preferred to traditional methodologies which consider imports as final goods entering the consumers' utility functions directly. Therefore, demand is not derived from utility maximization but from a two step profit maximization or cost minimization approach (Washington and Kilmer, 2002b; Laitinen and Theil, 1978).

3.2.1 Theoretical framework

The production theory approach to trade modelling was initially proposed by Burgess (1974a,b); Kohli (1978, 1991); Davis and Jensen (1994); Diewert (1986) and Truett and Truett (1998).

Early works recognized that most traded products are not delivered to the final consumers directly; rather, it is more appropriate to consider these goods as inputs of firms displaced at some point along of the supply chain [6]. Therefore, the proposal was to exploit production theory in order to estimate the domestic import demand through an industry-level profit maximization or cost-minimization approach (Burgess, 1974a; Kohli, 1978).

In particular, Davis and Jensen (1994) encompass the weaknesses of utility-maximization when dealing with imported inputs. First of all, the authors recognize the conceptual flaw by which most imported agricultural goods are not final products; indeed, it is acknowledged that most of imported products require further processing, handling, packaging, storing and retailing before they are delivered to the final consumer. It follows that the definition of first-stage utility aggregates may be often questionable because weak separability for agricultural commodities is not straightforward. As a consequence, elasticity estimates of these classes of models might not be structural parameters, thereby leading to erroneous interpretation of the estimated coefficients.

The assumption that import decision is made by profit maximizing/cost minimizing firms has several advantages: on the one hand, there is no need to specify a model for the final demand (through a specification of consumers' utility functional form) and, on the other hand, aggregation over consumers is also no longer necessary (Washington and Kilmer, 2002b; Kohli, 1991). Indeed, aggregation represents a substantial advantage of trade models derived from production theory with respect to consumers' utility-based models: given that import data are typically reported in the form of aggregate statistics, the derived demand we estimate is actually an industry-level derived demand or, in other words, a derived demand aggregated over firms. According to Mas-Colell et al. (1995), when considering firms' optimizing behaviour, properties derived from producer behaviour typically hold after aggregation over firms, whereas this is not always true when aggregating across consumers. The aggregate profit obtained when each producer maximizes its individual profit is the same that would be obtained if the whole industry

---

[6] These enterprises are typically international trading companies when it comes to agricultural commodities

would coordinate to take a joint profit-maximizing decision under the same set of input and prices. Analogously, the industry's cost of production for the joint output corresponds to the sum of each firm of individual total costs if each individual is a price taker. In other words, if G represent the number of firms in the industry, then the industry-aggregate cost function can be defined as (Chambers, 1988):

$$C\left(\mathbf{p},\mathbf{z}\right)=\sum_{g=1}^{G}c_g(\mathbf{p},\mathbf{z}_g)$$

where $c_g(\cdot)$ is the cost function associated to the g^{th} enterprise, $\mathbf{p}$ is the vector of input prices and $\mathbf{z}_g$ is the vector of output quantities for firm g. On the other hand, consumers' aggregate demand satisfies all the properties of the individual demand if and only if preferences and wealth are homogeneous across individuals; as many empirical studies have found, however, whenever homogeneity between individuals is not satisfied, symmetry does not typically hold (Mas-Colell et al., 1995; Washington and Kilmer, 2002b).

The more recent work proposed by Washington and Kilmer (2002b,a) and Muhammad and Kilmer (2008) employs a Differential Factor Allocation Model (DFAM, Laitinen and Theil (1978)) to specify the derived demand function of a variety of products in different countries. Following Davis and Jensen (1994) this methodology is consistent with a direct industry-level profit-maximization procedure.

General approach

Assume that a given industry has a inter-temporally separable and homothetically (weakly) separable transformation function in each time period; then, the industry-level technology can be indicated as:

$$\begin{aligned}F&=\{Z_l,Q_i;l=1,...,M;i=1,...,N\}\\&=F(Z_1,...,Z_M,Q_1,...,Q_N)=0\end{aligned}$$

where l indicates the output, i indicates the input, Z_l represents the aggregate outputs quantity and Q_i stands for aggregate inputs. Consider the set of indices of the input vector $\mathbf{I} = \{i\}_{i=1,...,N}$ and a subset $\mathbf{I} \supset \mathbf{I}^j = \{j\}_{j=1,...,J}$, then the aggregate inputs are defined as linearly homogeneous aggregation functions

$$Q_i = Q_i(\{q_{ij}; j = 1, ..., J\}) = Q_i(q_{i1}, ..., q_{iJ}), \qquad \forall i = 1, ..., N$$

where Q_i and q_{ij} are scalars representing the aggregate and disaggregate input quantities, respectively (Davis and Jensen, 1994). Similarly, consider the set of indeces of the output vector $\mathbf{L} = \{l\}_{l=1,...,M}$ and a subset $\mathbf{L} \supset \mathbf{L}^k = \{k\}_{k=1,...,K}$, then the aggregate outputs are dfined as linearly aggregation functions

$$Z_l = Z_l\left(\{z_{lk}; k = 1, \dots, K\}\right) = Z_l\left(z_{l1}, \dots, z_{lK}\right), \qquad \forall l = 1, \dots, M$$

Define now the industry-level aggregate profit maximization problem

$$\begin{aligned} &\underset{\mathbf{Z},\mathbf{Q}}{max} \quad \Pi = \mathbf{Z}\mathbf{W}' - \mathbf{P}\mathbf{Q}' \\ &\text{s.t.} \quad F(Z_1, ..., Z_M, Q_1, ..., Q_N) = F(\mathbf{Z}, \mathbf{Q}) \in \mathbb{Y} \end{aligned}$$

where $\mathbb{Y}$ is the production set, $\mathbf{Z}$ and $\mathbf{W}$ are $(1 \times M)$ vectors output quantities and prices while $\mathbf{Q}$ and $\mathbf{P}$ are $(1 \times N)$ vectors of aggregate input quantities and prices, respectively. As for Q_i and Z_l, P_i and W_l are defined as a linear homogeneous aggregation function:

$$P_i = P_i(p_{i1}, ..., p_{iJ}) \qquad \forall i = 1, ..., N$$

$$W_l = W_l(w_{l1}, ..., w_{lK}) \qquad \forall l = 1, ..., M$$

with p_{ij} representing the factor price corresponding to the disaggregate input q_{ij} and w_{lk} being the output price corresponding to the disaggregate input z_{lk}. Given a vector of solutions to the optimization problem, $\mathbf{Q}^*$, the aggregate profit function $\Pi^* = \mathbf{Z}\mathbf{W}' - \mathbf{P}\mathbf{Q}^{*'}$ is evaluated at the optimum bundle. The aggregate input demand is obtained though the Hotelling's lemma (Mas-Colell et al., 1995):

$$-\frac{\partial \Pi^*}{\partial P_i} = Q_i(\mathbf{W}, \mathbf{P}), \qquad \forall i = 1, ..., N$$

where $Q_i(\mathbf{W}, \mathbf{P})$ is the homogeneous of degree zero aggregate demand function for input i (Davis and Jensen, 1994). However, the aim of the present framework is to obtain disaggregate factor demands; for example, consider $\mathbf{I}^j$ to be the "oilseed" input partition, then $Q_i(\mathbf{W}, \mathbf{P})$ would represent the aggregate demand function for oilseeds and q_{ij} would be the disaggregate demand for soybean grains, for j = soybean grains. Disaggregate conditional Hicksian demand functions can be derived under the assumption of an homothetically separable transformation function in the $\mathbf{I}_j$ partition (Hotelling lemma). Differentiating the aggregate profit function Π^* with respect to disaggregated input prices p_{ij} (Davis and Jensen, 1994; Blackorby et al., 1978) leads to

$$\frac{\partial \Pi^*}{\partial p_{ij}} = \frac{\partial \Pi^*}{\partial p_{ij}} \frac{\partial P_i}{\partial p_{ij}} = -Q_i \frac{\partial P_i}{\partial p_{ij}}$$

Given the linear homogeneity of the aggregator function Q_i, then:

$$P_i(p_{i1}, ..., p_{iJ}) Q_i(q_{i1}, ..., q_{iJ}) = \sum_{s=1}^{J} p_{ij} q_{ij}, \qquad s \in \{j = 1, ..., J\} \tag{3.1}$$

Differentiating (3.1) with respect to q_{ij} gives:

$$P_i \frac{\partial Q_i}{\partial q_{ij}} = p_{ij}, \qquad \forall j = 1, ..., J \tag{3.2}$$

while differentiating (3.1) with respect to p_{ij} and re-arranging gives:

$$\frac{\partial P_i}{\partial p_{ij}} Q_i \equiv q_{ij} + \sum_{s=1}^{J} \left[p_{is} - P_i \frac{\partial Q_i}{\partial q_{is}} \right] \frac{\partial q_{is}}{\partial p_{ij}}, \qquad s \in \{j = 1, ..., J\} \tag{3.3}$$

Substituting (3.2) into (3.3) gives:

$$\frac{\partial P_i}{\partial p_{ij}} Q_i = q_{ij} \tag{3.4}$$

Therefore:

$$-\frac{\partial \Pi^*}{\partial p_{ij}} = Q_i \frac{\partial P_i}{\partial p_{ij}} = q_{ij}$$

Using duality, the optimal quantity q_{ij}^* can be also obtained through cost minimization. The problem

$$\begin{aligned} \underset{Q_i}{min} \quad & \mathbf{PQ'} \\ \text{s.t.} \quad & F\left(\mathbf{Z},\mathbf{Q}\right) \in \mathbb{Y} \\ & Q_i = Q_i(q_{i1}, ..., q_{iJ}) \end{aligned}$$

has solution at $\mathbf{Q}^*$. Analogously to Hotelling's lemma for the aggregate profit function, the aggregate input demand is obtained using Shephard's lemma (Mas-Colell et al., 1995); consider the aggregate cost function $C(\mathbf{P}, \mathbf{Z}) = \mathbf{PQ}(\mathbf{W}, \mathbf{P}) \equiv \mathbf{PQ}^* = C^*$, then:

$$\frac{\partial C^*}{\partial p_{ij}} = Q_i^*, \qquad \forall i = 1, ..., N$$

Under the assumption of a weakly-separable technology, the aggregate cost function is also weakly separable (Chambers, 1988) and differentiating C^* with respect to disaggregated input prices p_{ij} leads to (Shepard's lemma):

$$\frac{\partial C^*}{\partial p_{ij}} = \frac{\partial C^*}{\partial p_{ij}} \frac{\partial P_i}{\partial p_{ij}} = Q_i \frac{\partial P_i}{\partial p_{ij}}$$

Using (3.1) through (3.4) in the same fashion, we obtain:

$$\frac{\partial C^*}{\partial p_{ij}} = q_{ij}$$

which represents the conditional Hicksian demand function $q_{ij}^h(\mathbf{p}_i, Q_i)$, where $\mathbf{p}_i = (p_{i1}, \ldots, p_{iJ})'$. The term "conditional" is appropriate because q_{ij}^h is conditional on the aggregate input quantity Q_i. Following production theory, q_{ij}^h is homogeneous of degree zero in $\mathbf{p}_i$ (Mas-Colell et al., 1995). In the following application $\mathbf{I}^j$ will represent the "soybean grains" partition, while j will indicate the import source.

3.2.2 The Differential Factor Allocation Model

Laitinen and Theil (1978) developed a Differential Factor Allocation Model starting from the cost minimization problem of a multi-product firm. We formally derived the reference structural equations in Appendix B. The following expression indicates the multi-product firm's differential demand for input i, conditional on the Divisia volume index Q:

$$h_i d \log q_i^* = \theta_i d \log Q + \gamma \Psi_i - \psi \sum_{j=1}^{n} \theta_{i,j} d \left[\log \; p_j / \tilde{P} \right]$$

where $h_i \equiv p_i q_i / C$ indicates the share of the i^{th} input as a proportion of the total cost C, $d \log Q \equiv \sum_{i=1}^{n} h_i d \log q_i^*$ defines the Divisia volume index which captures the change in input elementary quantities[7], $\theta_{i,j}$ are the conditional own/cross-input price coefficients

---

[7] Q represents the total input decision

and $\tilde{P}$ is the Fisher's price index. Last, the term $\Psi_i \equiv \gamma \sum_{l=1}^{m} g_l \left(\theta_i^l - \theta_i\right) d\log z_l$ indicate the sample covariance between the amount of output l and input i's contribution to the marginal cost of that output. Therefore, whenever the change in output is positively correlated with the marginal share of the input, a change in the l^{th} output determines an increase in the demand for input i in excess of $\theta_i d\log Q$. As formally shown in appendix B, under the additional assumption of input-output separability, the contribution of the i^{th} input to the marginal cost of the l^{th} output does not change across outputs ($\theta_i^l = \theta_i$), hence $\Psi_i = 0$ and the model simplifies to:

$$h_i d\log q_i^* = \theta_i d\log Q - \psi \sum_{j=1}^{N} \theta_{i,j} d\left[\log\ p_j/\tilde{P}\right] \tag{3.5}$$

with $i, j \in \{1, \ldots, N\}$. From appendix B, $d\log Q$ can be also expressed as:

$$d\log Q = \gamma d\log Z$$

which indicates that the total input decision is γ proportional to the total output decision. Following the notation adopted in the previous section, equation (3.5) should be written as

$$h_{ij} d\log q_{ij}^* = \theta_{ij} d\log Q - \psi \sum_{s=1}^{N} \theta_{i_j,s} d\left[\log\ p_s/\tilde{P}\right]$$

with $s, j \in \{1, \ldots, N\}$. In this case, the consistency of model (3.5) with the definition of Hicksian demand function for the multi-product industry, $q_{ij}^h = q_{ij}\left(\mathbf{p}_i, Q_i(\mathbf{w}, \mathbf{P})\right)$ is easily verified. For notational easiness we will maintain the indexing used in equation (3.5) where $i, j = ij \in \{1, \ldots, N\}$.

Model (3.5) requires that the following parametric restrictions are met in order to satisfy the theoretical demand properties of homogeneity and symmetry, respectively:

$$\sum_{j=1}^{N} \theta_{ij} = 0$$

$$\theta_{ij} = \theta_{ji}$$

Moreover, conditional input prices and divisia index elasticities (hereafter ”divisia elasticities") can be specified as:

$$\begin{aligned}\varepsilon_{q_i p_j} &= \frac{\partial \log q_i^*}{\partial \log p_j} = -\psi(\Theta_{ij} - \theta_i \theta_j) h_i^{-1} = \theta_{ij} h_i^{-1} \\ \eta_{q_i Q} &= \frac{\partial \log q_i^*}{\partial \log Q} = \theta_i h_i^{-1}\end{aligned}$$

where, from appendix B, $\Theta_{ij} \in \boldsymbol{\Theta}$ and $\theta_i, \theta_{ij} \in \boldsymbol{\theta}$. More explicitly, $\varepsilon_{q_i p_j}$ measures the impact of input j's price on the conditional demand for input i (holding constant or, in other words, conditional to the total input decision Q) and $\eta_{q_i Q}$ captures how a change in the total input decision affects the conditional demand for input i.

Following Washington and Kilmer (2002b,a); Christou et al. (2005); Muhammad and Kilmer (2008), the model presented in this section is adopted to describe the input allocation decision of country i as a function of other countries' relative prices and the input Divisia index for soybeans and maize. Under the assumption that soybeans and maize are exclusively imported through international trading companies, then it is very likely that downstream enterprises will purchase the same product without any further transformation; if this is the case, the proportionality factor $\gamma = 1$ and $d \log Q = d \log Z$. What international traders may convey with soybeans and maize is a set of services which typically consists of storage, logistics, transportation, risk management, initial procurement and so on. Therefore, the output of these upstream firms (in volume) will equal the total quantity of the imported product (Q). Moreover, under (industry) profit aggregation and given prices, $q_i^* = \sum_{g=1}^{G} q_{ig}^*$ for all $g \in \{1, \ldots, G\}$, where q_{ig}^* is the optimal quantity for the g^{th} international trader.

Econometric specification

Consistently with Washington and Kilmer (2002b,a); Muhammad and Kilmer (2008); Christou et al. (2005), model (3.5) shall be properly specified for econometric estimation. Differential terms are thereby expressed in terms of finite log changes and the time component is also embedded in expression (3.5). The resulting system of demand equations can be written as:

$$\bar{h}_{it}\Delta q_{it} = \theta_i \Delta Q_t + \sum_{j=1}^{N} \pi_{i,j}\Delta p_{jt} + \varepsilon_{it} \tag{3.6}$$

where $\bar{h}_{it} = (h_{it} + h_{it-1})/2$, $h_{it} = V_{it}/\sum_{j=1}^{N} V_{jt}$ with V_{it} being import from country i, $\Delta q_{it} = \log q_{it} - \log q_{it-1}$ with q_{it} being the quantity imported from county i, $\Delta Q_t = Q_t - Q_{t-1}$, $Q_t = \sum_{i=1}^{N} \bar{h}_{it}\Delta q_{it}$, $\Delta p_{jt} = \log p_{jt} - \log p_{jt-1}$ with p_{jt} being the import price for soybean imported from country j.

Estimated conditional elasticities $\hat{\varepsilon}_{q_i p_j}$ and $\hat{\eta}_{q_i Q}$ are typically computed at the mean values of h_{it}: $\dot{h}_i = \sum_{t=1}^{T} h_{it}/T$, for all i. Elasticities' standard errors are computed as follows:

$$\text{s.e.}\left(\hat{\varepsilon}_{q_i p_j}\right) = \frac{\text{s.e.}\left(\pi_{i,j}\right)}{\dot{h}_i}$$

$$\text{s.e.}\left(\hat{\eta}_{q_i Q}\right) = \frac{\text{s.e.}\left(\theta_i\right)}{\dot{h}_i}$$

3.3 Data and estimation

The data we use to estimate model (3.6) are quarterly time series from 1999 to 2014 in the case of soybeans and from 2001 to 2014 for maize. We decided to employ two different timespan because data regarding maize imports from Brazil are incomplete throughout 1999 and 2000. All data employed to estimate model (3.6) are provided by the Eurostat's trade statistics dataset (Eurostat, 2015). Imported quantities and import values from each source are expressed in 100 Kg and Euro, respectively. Prices are artificially computed dividing the value of soybeans or maize imported from county j by the quantity (these prices are called "unit values" and are extensively used in trade analysis (Washington and Kilmer, 2002b,a; Muhammad and Kilmer, 2008)). The sources we consider in the present analysis are United States, Brazil, Canada and Paraguay for soybean grains and Argentina, Brazil, Ukraine and United States for maize. Summary statistics are presented in table 3.7.

Before proceeding with the estimation of model (3.6), we investigated the stationarity of ΔQ_t, $\bar{h}_{it}\Delta q_{it}$ and Δp_{it} for each $i \in \{1, \ldots, N\}$ using a seasonally-corrected Augmented

Tab. 3.7: Summary statistics.

		USA	Brazil	Canada	Paraguay	Ukraine	Argentina
				Soybeans			
Import Price (€/100Kg)	Mean	29.9	28.7	31.9	28.5	-	-
	Max	69.9	53.1	62.2	51.8	-	-
	Min	18	17.7	19.5	16.9	-	-
	S.D.	10	9	8.9	9.1	-	-
Quantity (mmt)	Mean	1.05	1.95	0.16	0.29	-	-
	Max	4.3	4.3	0.85	0.96	-	-
	Min	0.006	0.16	0.007	0.004	-	-
	S.D.	1.1	1.11	0.18	0.24	-	-
				Maize			
Import Price (€/100Kg)	Mean	37.3	18.54	-	-	15.72	19.0
	Max	91.0	49.6	-	-	23.8	31.26
	Min	13.52	10.8	-	-	7.9	10.35
	S.D.	19.6	7.7	-	-	4.5	6.2
Quantity (mmt)	Mean	0.05	0.43	-	-	0.49	0.32
	Max	0.05	4.2	-	-	4.4	2.1
	Min	0.0028	0.00003	-	-	0.00013	0.29
	S.D.	0.11	0.65	-	-	0.87	0.37
Divisia Index Soybeans		Mean	Max	Min	Std.dev.		
		0.116	0.815	-0.443	0.217		
Divisia Index Maize		Mean	Max	Min	Std.dev.		
		0.010	0.950	-0.770	0.337		

Source: own-elaboration based on based on Eurostat (2015) data

Dickey-Fuller (ADF) test (Said and Dickey, 1984) proposed by da Silva Lopes (2006). Although Wang and Tomek (2007) did not find any significant difference in ADF tests results with or without using seasonal dummies in the reference DF regression, the inclusion of deterministic seasonality in DF tests (Dickey and Fuller, 1979) is justified by the fact that, when the data generating process (DGP) contains seasonal unit roots, the test regression must at least include all the deterministic components of the DGP itself (da Silva Lopes, 2006). In other words, test results are conditional on the specification of the right-hand side of the reference DF equation[8] (Wang and Tomek, 2007). We test the presence of unit roots in each time series using the following nested specification of the classical ADF equation:

$$\Delta y_t = \sum_{i=1}^{4} \gamma_i D_{it} + \gamma t + \phi y_{t-1} + \sum_{q=1}^{q_{max}} \xi_q \Delta y_{t-q} + \epsilon_t \tag{3.7}$$

where y_t is the time series of interest, t is a linear time trend, $\sum_{i=1}^{4} D_{it}$ indicates a set of quarterly dummies (i.e. $D_{1t} = 1$ if $t = \{\text{January} - \text{March}\}$ and 0 otherwise) and ϵ_t represents a weakly stationary invertible ARMA(p, q) process in the innovation sequence defined as $\{\epsilon_t\} \sim iid(0, \sigma^2)$. We selected the lag truncation parameter q_{max} comparing the results given by Schwert (1989) "rule of thumb" criteria[9] and the "*t-sig* 5%" procedure proposed by Ng and Perron (2001) and others. The maximum number of lags is set to 4[10] but the value is adjusted equation by equation using the "*t-sig* 5%" criteria. Estimated test statistics for the autoregressive parameter in model (3.7) are reported in tables 3.8 and 3.9. As expected for variables in first differences, no evidences of unit root processes were detected in either time series.

Model (3.6) is estimated through an autocorrelation-robust system IFGLS (Iterative

---

[8] It is also worth to remark that the inclusion of quarterly dummy variables in the ADF equation with linear trend follows Ghysels et al. (1994) recommendation concerning tests for seasonal unit roots: the authors argue that the inclusion of this new test of controls in the ADF equation is a conservative strategy in applied econometrics when one has to test for either non-seasonal or seasonal unit roots.

[9] Schwert (1989) suggests a selection criteria based on the length of the times series: $q_{max} = \text{int}\{4(T/100)^{1/4}\}$ or $q_{max} = \text{int}\{12(T/100)^{1/4}\}$

[10] da Silva Lopes (2006) also suggests to use a "seasonally modified" deterministic rule for choosing q_{max}; in particular, for $T \in [48, 80)$, the author advocates $q_{max} = 4$

Tab. 3.8: Seasonally Augmented DF equations, OLS estimation results (Soybeans).

	US	Brazil	Canada	Paraguay
ADF test statistic				
Δp_{it}	-5.350	-4.546	-4.450	-4.720
$\bar{h}_{it}\Delta q_{it}$	-4.352	-5.422	-4.739	-4.085
ΔQ_t	-4.931			
Critical values				
1%	T=60, $q_{max} = 4$		-4.32	
5%	T=60, $q_{max} = 4$		-3.60	
10%	T=60, $q_{max} = 4$		-3.24	

Critical values provided by da Silva Lopes (2006).

Tab. 3.9: Seasonally Augmented DF equations, OLS estimation results (Maize).

	Argentina	Brazil	Ukraine	US
ADF test statistic				
Δp_{it}	-3.931	-5.621	-3.688	-4.124
$\bar{h}_{it}\Delta q_{it}$	-4.881	-3.827	-4.552	-4.443
ΔQ_t	-6.899			
Critical values				
1%	T=64, $q_{max} = 4$		-4.32	
5%	T=64, $q_{max} = 4$		-3.60	
10%	T=64, $q_{max} = 4$		-3.24	

Critical values provided by da Silva Lopes (2006).

Feasible Generalized Least Square), after imposing symmetry and homogeneity. This procedure employs an iterated fit of the system variance-covariance matrix to achieve efficiency (see Appendix C). As indicated by Kastens and Brester (1996) and Murphy et al. (2004), the forecasting ability of demand systems improves when theoretical properties are imposed rather then tested (even when rejected by appropriate testing procedures); therefore, we estimate model (3.6) under the restrictions presented in section 3.2, namely: $\sum_{j=1}^{N} \theta_{ij} = 0$ and $\theta_{ij} = \theta_{ji}$.

3.4 Results

3.4.1 Soybean

With the exception of Paraguay, all soybeans Divisia and own-price parameters have the expected sign (see table 3.10).

Tab. 3.10: Estimation results, soybeans.

Conditional own-price and cross-price coefficients					
	Div. Ind.	US	Brazil	Canada	Paraguay
US	0.4645***	**-1.2467*** **	1.3040***	-0.1846**	0.1274
(s.e.)	(0.1304)	(0.3714)	(0.3180)	(0.0780)	(0.0890)
Brazil	0.0625		**-1.5244*** **	0.4540***	-0.2336**
(s.e.)	(0.0992)		(0.2981)	(0.0855)	(0.0956)
Canada	0.0843***			**-0.3368*** **	0.0674
(s.e.)	(0.0225)			(0.0877)	(0.0535)
Paraguay	-0.0213				**0.0388**
(s.e.)	(0.0286)				(0.0641)

Note: *** for 1%, ** for 5% and * for 10%.

The Divisia index elasticities are significant only for the US and Canada and suggest that if the total soybeans imported in the EU increases by 1%, the amount of soybeans these two countries do export to the EU will increase by approximately 1.5%. Therefore, there is not a clear difference in terms of import benefit between the US and Canada. On the other hand, the negative Divisia elasticity for Paraguay indicates that soybeans from this source are considered inferior goods in the soybean supply chain (Washington and Kilmer, 2002). Conditional own-price elasticities are all negative and significant with the exception of Paraguay. Their absolute values are high, but in line with those found by Wilson (1994) for wheat; in particular, Canada turns out to be the most elastic soybean source followed by the US and Brazil. Paraguay is the only exporter showing an exceptionally low (and positive) value but, again, this is not statistically significant. The absolute magnitude of conditional own-price elasticities imply that Canada is the most price responsive soybeans source, while Brazil is less sensitive. Altogether, these large absolute values indicate that the European import structure is particularly price sensitive. Conditional cross-price elasticities suggest a complementarity relationship between Canada and the US, while Paraguay turns out

Tab. 3.11: Divisia and conditional price elasticities, soybeans.

Divisia, conditional own-price and cross-price elasticities					
	Divisia	Cross-price			
		US	Brazil	Canada	Paraguay
US	1.5880***	**-4.2623*** **	4.4581***	-0.6313**	0.4355
(s.e.)	(0.4458)	(1.2699)	(1.087)	(0.2668)	(0.304)
Brazil	0.1148	2.3951***	**-2.7999*** **	0.8340***	-0.4291**
(s.e.)	(0.1823)	(0.5841)	(0.5476)	(0.1570)	(0.1756)
Canada	1.5832 ***	-3.4660**	8.5222***	**-6.3215*** **	1.2653
(s.e.)	(0.4233)	(1.4651)	(1.6049)	(1.6474)	(1.0041)
Paraguay	-0.2428	1.4480	-2.6555**	0.7662	**0.4411**
(s.e.)	(0.3259)	(1.0127)	(1.0872)	(0.6081)	(0.7295)

Note: *** for 1%, ** for 5% and * for 10%.

to be a complement for Brazil. On the other hand, Brazil and Paraguay are substitutes for the US and Canada respectively. Under the geographical heterogeneity hypothesis (i.e. the Armington hypothesis) postulated in section 3.1, these results provide some clear indications regarding European import dynamics. For example, Canada shares a number of country-specific characteristics with the US, including most export routes towards the EU (i.e.: distance), the extent (and range) of commercialized GM soybean varieties (see table 3.4) and the perceived efficiency of handling infrastructures (see tables 3.5 and 3.6). The same argument is true for Paraguay and Brazil, although the similarities between these two countries are less trivial. Differently, South American and North American soybeans show contrasting nutritional features: as we have already discussed in section 3.1, US soybeans typically show higher crude protein and lysine concentration levels, while Brazilian grains are usually less nutritious but substantially cheaper (Karr-Lilienthal et al. (2004), Grieshop and Fahey (2001)). Moreover, Brazil and the US are characterized by distinct supply chains and GMO policies: the mean value of the Protectionism Index over the period 2000-2013 is 2.24 and 1.58 for the US and Brazil, respectively, while the PIQ and AIQ indexes are systematically larger for North American countries. These results indicate that conditional cross-price elasticities seem to put less weight on substitution/complementarity based on soybeans' country-specific characteristics (nutritional features, GMOs and supply chain efficiency) and place more emphasis on substitution/complementarity which might be dictated by seasonality or pure price competition. We verify this hypothesis by estimating model (3.6) with the inclusion of a set of quarterly dummy variables:

$$\bar{h}_{it}\Delta q_{it} = \theta_i \Delta Q_t + \sum_{j=1}^{N} \pi_{i,j} \Delta p_{jt} + \sum_{s=1}^{4} D_{st} + \varepsilon_{it} \tag{3.8}$$

Following Boonsaeng et al. (2008) the inclusion of fixed effects does not change the properties of the DFAM. Estimated Divisa, own-price and cross-price coefficients for model (3.8) are reported in table 3.12. The inclusion of quarterly dummies highlights that much of the soybeans demand dynamics are significantly attributable to seasonality. In fact, most of the estimated price parameters are no longer significant in equation (3.8),

Tab. 3.12: Estimation results with quarterly dummies, soybeans.

Conditional own-price and cross-price coefficients					
	Div. Ind.	US	Brazil	Canada	Paraguay
US	0.4858***	**-0.0743**	0.2581	-0.1670**	-0.01670
(s.e.)	(0.0858)	(0.1934)	(0.1776)	(0.0771)	(0.0715)
Brazil	0.0873		**-0.4978*** **	0.3187***	-0.0790
(s.e.)	(0.0596)		(0.1972)	(0.0936)	(0.0832)
Canada	0.0719**			**-0.2215** **	0.0698
(s.e.)	(0.0261)			(0.1014)	(0.0610)
Paraguay	-0.0478*				**0.0259**
(s.e.)	(0.0260)				(0.0674)
Quarter1		0.1322***	-0.0181	-0.0110	-0.0326***
(s.e.)		(0.0308)	(0.0214)	(0.0095)	(0.0094)
Quarter2		-0.3419***	0.2544***	0.0015	0.0527***
(s.e.)		(0.0290)	(0.0207)	(0.0099)	(0.0096)
Quarter3		0.0250	-0.0692***	0.0064	-0.0005
(s.e.)		(0.0277)	(0.0191)	(0.0083)	(0.0083)
Quarter4		0.1990***	-0.1743***	0.0211*	-0.0171
(s.e.)		(0.0348)	(0.0252)	(0.0124)	(0.0113)

Note: *** for 1%, ** for 5% and * for 10%.

while the coefficients of the quarterly dummies reveal that much of the variability is due to periodicity. In particualr, dummy variables show that the US export less soybeans to the EU during the second quarter (April, May, June), when imports from Brazil and Paraguay are the highest. This result indicates a clear seasonally-driven substitution between the US and Brazil/Paraguay: since planting in North America typically begins in mid April and lasts till June, imports from the US are lower and the product is therefore substituted by grains originated from either Brazil or Paraguay (where soybean is already being harvested and stored). Similarly, the availability of US' soybeans during the first, third and fourth quarter coincides with a reduction of the import from each other country, with the exception of Canada. Last, during the October, November and December quarter, soybean imports from North America are higher than imports from South America (although the parameter associated with Canada is not statistically significant), where soybean is typically being planted.

3.4.2 Maize

All maize Divisia and own-price parameters have the expected sign (see table 3.13).

Divisia, conditional own-price and cross-price elasticities for maize are reported in table 3.14. The Divisia index elasticities suggest that a 1% increase in the EU maize import drive Argentina's, Brazil's and Ukraine's export up by 0.55%, 0.76% and 0.60%, respectively. As expected, all conditional own-price elasticities are negative and significant at 1%. On the other hand, conditional cross-price elasticities are quite different from what we observed for soybeans; in fact, all maize sources seem to be one substitute for each other, with the exception of the United States (although the complementary between the US and Brazil is not statistically significant). Once again, this result suggests that the imperfect substitution among different exporters does not follow any clear pattern attributable to either nutritional characteristics, range of approved GMOs and/or efficiency of supply chain management. As displayed in table 3.15, the inclusion of quarterly dummy variables in model (3.6) does not trace out any seasonality in the European maize import structure: demand parameters remain substantially unchanged

Tab. 3.13: Estimation results, maize.

Conditional own-price and cross-price coefficients					
	Div. Ind.	Argentina	Brazil	Ukraine	US
Argentina	0.1024***	**-0.4412*** **	0.1583***	0.1972**	0.0856**
(s.e.)	(0.0180)	(0.0961)	(0.0538)	(0.0823)	(0.0339)
Brazil	0.0891***		**-0.3333*** **	0.1978***	-0.0227
(s.e.)	(0.0209)		(0.0692)	(0.0595)	(0.0260)
Ukraine	0.0647***			**-0.4488*** **	0.0537
(s.e.)	(0.0185)			(0.0993)	(0.0359)
US	-0.2623				**-0.1165*** **
(s.e.)	(0.0078)				(0.0229)

Note: *** for 1%, ** for 5% and * for 10%.

and significance is mostly unaffected. Only imports from Argentina seem to be quite sensitive to the crop's life cycle in south America, yet the negative sign in quarter 3 does not coincide with either planting or harvesting periods. Therefore, Argentina, Brazil, US and Ukraine most likely compete on price when it comes to commercialize maize on the European market. Finally, all maize conditional cross-country and own-price elasticities are smaller in absolute value than those we estimated for soybeans; this indicates that the European import structure for maize is less price sensitive than for soybeans.

3.5 Concluding remarks

In this work, we assess the European soybeans and maize import allocation structure using a producer-theory grounded demand system borrowed from the popular differential approach to the firm theory proposed by Laitinen and Theil (1978). This particular way of tackling derived demand analysis has several advantages over models (typically in levels) derived from cost minimization: first, intermediate goods are not assumed to enter consumers' utility functions directly; second, when the panel consists of high-frequency

Tab. 3.14: Divisia and conditional price elasticities, maize.

Divisia, conditional own-price and cross-price elasticities					
	Divisia	Cross-price			
		Argentina	Brazil	Ukraine	US
Argentina	0.5396***	__-2.3250***__	0.8342***	1.0395**	0.4512**
(s.e.)	(0.0949)	(0.5066)	(0.2838)	(0.4340)	(0.1790)
Brazil	0.7923***	1.4073***	__-2.9633***__	1.7586***	-0.2026
(s.e.)	(0.1858)	(0.4788)	(0.6153)	(0.5297)	(0.2317)
Ukraine	0.6173***	1.8801**	1.8851***	__-4.2776***__	0.5123
(s.e.)	(0.1766)	(0.7849)	(0.5678)	(0.7295)	(0.3423)
US	-0.2570	2.6105**	-0.6950	1.6388	__-3.5543***__
(s.e.)	(0.2395)	(1.0360)	(0.7956)	(1.0951)	(0.6996)

Note: *** for 1%, ** for 5% and * for 10%.

time series observation, first differentiation helps to get rid of non-stationarity if variables are integrated of order one; third, differential models are simple, general in their theoretical derivation (Clements and Gao, 2015) and easy to estimate. Conditional own-price and cross-price elasticities indicate that differences in supply chain efficiency, discrepancies in GMOs approval and other export-specific sources of product differentiation (i.e. nutritional characteristics) do not play a significant role in tracing out import demand dynamics for either maize or soybeans. In particular, soybeans cross-price elasticities do not highlight any complementarity between qualitatively different oilseeds (i.e. North America with respect to South America) nor substitution between similar products (i.e. US with respect to Canada and Brazil with respect to Paraguay). On the contrary, countries which share similar product characteristics turn out to be complements. In this regard, the inclusion of quarterly dummy variables in the structural model suggests that the the European soybeans import structure is mainly determined by seasonality. Moreover, own-price elasticities are particularly high, indicating a remarkable

Tab. 3.15: Estimation results with quarterly dummies, maize.

Conditional own-price and cross-price coefficients					
	Div. Ind.	Argentina	Brazil	Ukraine	US
Argentina	0.1111***	**-0.3287*** **	0.0499	0.1731**	0.1056***
(s.e.)	(0.0158)	(0.0912)	(0.0515)	(0.0794)	(0.0322)
Brazil	0.1080***		**-0.1711** **	0.1373**	-0.0160
(s.e.)	(0.0219)		(0.0698)	(0.0625)	(0.0280)
Ukraine	0.0465**			**-0.3332*** **	0.0227
(s.e.)	(0.0187)			(0.1008)	(0.0366)
US	-0.0030				**-0.1122*** **
(s.e.)	(0.0083)				(0.0238)
Quarter1		0.0121	-0.0063	0.0329*	0.0021
(s.e.)		(0.0164)	(0.0225)	(0.0188)	(0.0084)
Quarter2		0.0633***	-0.0103	-0.0169	-0.0008
(s.e.)		(0.0164)	(0.0227)	(0.0191)	(0.0086)
Quarter3		-0.0401**	0.0843***	-0.0319	0.0042
(s.e.)		(0.0169)	(0.0233)	(0.0199)	(0.0089)
Quarter4		-0.0426***	-0.0214	0.0285	-0.0205**
(s.e.)		(0.0163)	(0.0225)	(0.0194)	(0.0087)

Note: *** for 1%, ** for 5% and * for 10%.

price sensitiveness of the European import structure. Similarly, own-price and cross-price elasticities for maize reveal that all source are substitutes, and parameter's estimates do not change substantially after the inclusion of quarterly dummy variables in the structural model. This most likely implies that countries compete on price when it comes to export maize to the European Union. The fact that soybeans import is mainly driven by seasonality, while maize trade dynamics seems based on pure price competition reflects what we reported in section 3.1: since the EU is not self sufficient when it comes to high-protein feed sources, product availability is the key feature that differentiates North American soybens from South American soybeans. On the other hand, maize is widely grown in the EU and, although imports increased over the last seven years, it does not represent a limiting factor for the European livestock industry. Moreover, the largest maize suppliers (Argentina, Brazil and Ukraine) show similar supply chain and GMOs approval indicators and, if the hypothesis of price-competing countries is true, also nutritional characteristics (for which we were not able to find any specific analysis) should not differ too much.

4. ASSESSING THE IMPACT OF GMO POLICY ON US SOYBEAN PRICES

4.1 Background and motivation

During the past fifteen years, soybean prices have exhibited large fluctuations which accompanied a clear increasing that settled prices at twice the level registered at the beginning of 2000 (see figure 4.2, box 1). In particular, soybean prices rose sharply in early 2004 and fell steeply twelve months later. Then, prices suddenly hiked during the first quarter 2008 and decreased quite rapidly on the second half of the same year, with values remaining substantially higher than the levels recorded before the initial lift. Last, soybean prices rose remarkably in mid 2011, soared in late 2012 and settled at twice the 2000 price in late 2014, after plunging for several quarters. As already discussed in chapter 3, soybean is currently the most important agricultural commodity traded on the international market, both in terms of volume and value; therefore, disentangling the factors contributing to its price setting mechanism and understanding how their behaviour could affect market prices is crucial for undertaking policy decisions targeted at preserving farmers' income, food security and financial market stability. Based on the literature, we recognize at least four main drivers that may have significantly influenced soybean prices during the last decade: demand growth in emerging economies and, more generally, demand growth at the global level; price of energy, in particular crude oil prices; speculation on the financial markets; increased adoption of genetically modified (GM) organisms by the most important international producers (i.e. United States, Brazil and Argentina) (James, 2010).

Among the four drivers we consider in the present study, the amount of empirical and theoretical contributions concerning the effects of the quick spreading of GM varieties on soybean real market prices is rather scarce[1]. On the other hand, the stream of literature tackling the effect of the biotech revolution on the economic and environmental performances of the major agricultural commodities is quite extensive. For example, Fernandez-Cornejo et al. (2000), show that the increased adoption of herbicide-tolerant (HT) soybean[2] led to small (but significant) increases in yields and significant decreases in total herbicide use by US farmers. Similarly, Bullock and Nitsi (2001) report cost saving for GM soybean adopters by switching from more expensive herbicides to the cheap and user friendly glyphosate. According to the authors, there are four main sources of cost saving: first, glyphosate itself is relatively inexpensive and effective on a wide range of weeds; second, since glyphosate is easy to use, switching to GM soybean has several advantages in terms of resources management; third, a wide introduction of glyphosate resistant crops may lower other herbicides' prices through substitution effects; fourth, the introduction of GM may initially drive prices of conventional varieties down. However, given the price premium charged for patented GM soybean, it is argued that much of the cost saving is likely to be the consequence of a more efficient production program with lower management costs and reduced risk. Although several studies show that that gain in terms of profits is negligible when switching to HT soybean (Fernandez-Cornejo et al., 2002), evidence shows that farmers have decided to go for the biotech alternative anyway: data reported by the USDA show that the rate of adoption of genetically engineered soybean reached nearly 97% of the total soybean planted in 2014 (USDA, NASS, 2015). In this regard, Fernandez-Cornejo et al. (2002) corroborates Bullock and Nitsi (2001) and Carpenter and Gianessi (1999) thesis suggesting that the reason for the success of GM soybean could be indeed sought into the increased planting flexibility and simplicity of the weed management. Given the above contributions, we hypothesize that the introduction

---

[1] To our knowledge, only Sobolevsky et al. (2005) provide evidence concerning the effect of the adoption of GM soybean on real market prices.

[2] Note that the most widely adopted GM soybean in the United Sates is Monsanto's Roundup-Ready Soybean. This privately-patented genetically engineered crop is designed to be resistant to glyphosate, a particularly cheap and easy to use broad-band action herbicide.

(and the adoption) of biotech soyean has effectively enhanced the efficiency of US soybean cultivation thereby damping production costs. Under the assumption of competitive markets, we expect that the efficiency gain through the introduction of HT varieties will translate into reduction of real soybean market prices.

The literature regarding the effect of oil prices on commodity markets is also rather extensive. The primary relationship between these two economic dimensions is due to energy being an input in agricultural production. However, with the increased adoption of agricultural commodities in energy production during the past ten years, the linkage between the two markets have now become much stronger due to demand-side dynamics. In particular, soybean oil is largely employed in the production of biodiesel: according to the US Energy Information Administration (EIA, 2015), more than 4800 million litres of biodiesel[3] were produced in 2014, corresponding to a 246% increase with respect to 2009 (see table 4.1). As shown in table 4.2, the hike in biodiesel production had a great impact on the demand for soybean oil: production nearly tripled during the six-year period 2009-2014.

Tab. 4.1: US biodiesel production, sales and stocks (million of litres).

	Production	Sales B100	Sales B100 in blend	B100 stock change
2009	1,953	961	1,059	(53)
2010	1,298	950	336	0
2011	3,694	2,426	1,283	8
2012	3,668	2,850	919	68
2013	5,144	3,565	1,642	(41)
2014	4,807	2,998	1,858	(18)

Source: EIA (2015)

In this respect, Campiche et al. (2007) show empirically that soybean prices seem to be

---

[3] biodiesel can be either pure or blend; pure biodiesel is conventionally called B100, where 100 indicates 100% biodiesel. On the other hand, biodiesel blend contains both B100 and petroleum diesel fuel.

Tab. 4.2: US biodiesel feedstock inputs (million of pounds). Unavailable data (NA) are withheld to avoid disclosure of individual company data.

	Canola Oil	Corn Oil	Cottonseed Oil	Palm Oil	Soybean Oil
2009	NA	84	NA	NA	1,977
2010	246	112	NA	NA	1,141
2011	847	304	NA	NA	4,153
2012	787	571	NA	NA	4,023
2013	646	1,068	NA	632	5,507
2014	1,046	970	NA	63	4,802

Source: EIA (2015)

more correlated to crude oil prices than to corn prices, thanks to the biodiesel market. However, Harri et al. (2009), found no cointegration relationship between the market price of soybean and the price of crude oil from 2006 to 2008[4]. Similarly, Yu et al. (2006) concluded that the influence of crude oil price shocks on the variation in vegetable oil prices is relatively small.

The effect of speculation and investors' behaviour on agricultural commodity prices has been long discussed since the remarkable hike in commodity futures prices observed from 2005 to 2008, which followed a period of intense speculative activity primarily driven by index funds (McPhail et al., 2012). Although the legislator and the competent authority (the Commodity and Futures Trading Commission) took initiative to damp speculation through the limitation of non-hedging positions, empirical studies reached no consensus on whether the activity of index funds on futures markets did play any role on the dynamics of commodity prices. In particular, the comprehensive meta-analysis presented by Irwin and Sanders (2011) supports the idea that most investments in long-only commodity index funds did not seem to overwhelm the normal functioning of these markets, so the hike in commodity prices during the three-year period 2005-2008 was probably the result

---

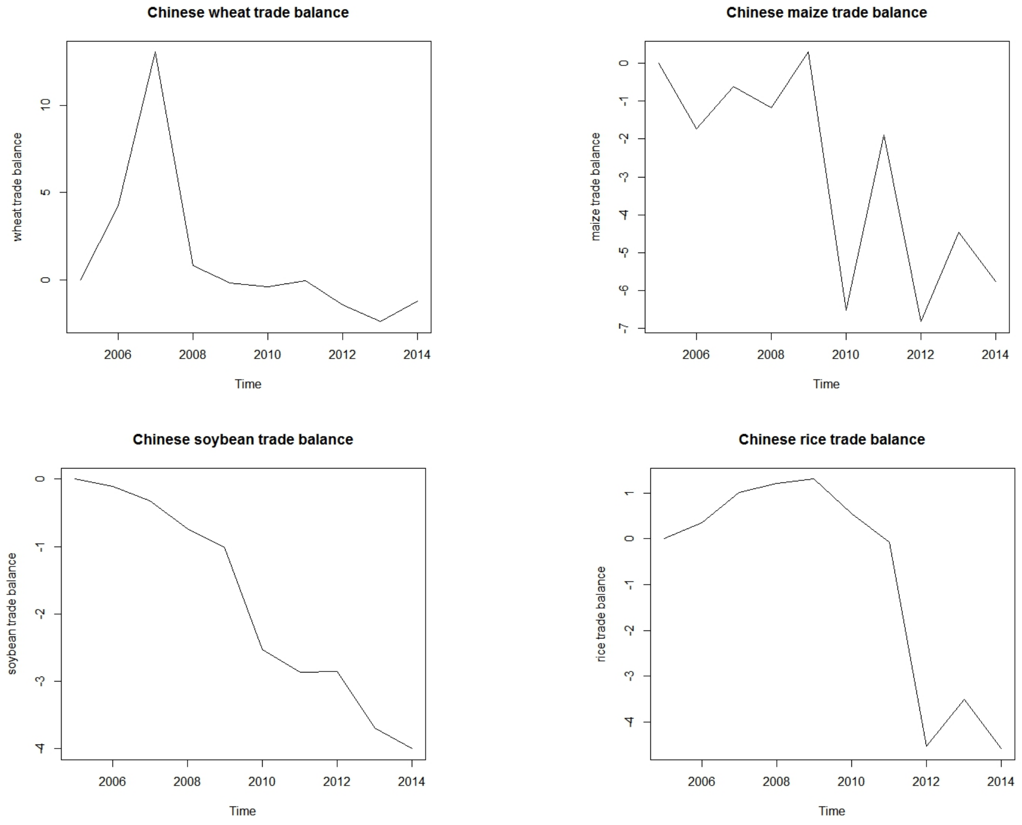
[4] they restricted their dataset to the period since April 2006 because that was the earliest period when a cointegrating relation between corn and crude oil was found

of mixed market conditions such as demand growth from China and other developing economies, biofuel policies, monetary policy, trade restrictions or supply shortfalls. The argument by which the demand surge in emerging markets such as China and other developing countries has positively contributed to high agricultural commodity prices is probably put forward assuming that the presence of global supply constraints limited the easiness of production responses. In this regard, the sensitiveness of agricultural commodity prices to international demand, supply and stocks might look straightforward from an economic point of view: higher levels of income should result in a more inelastic demand and prices of agricultural commodities more responsive to shifts in the supply curve. At the same time, under constrained supply conditions, a right shift in global demand would likewise drive commodity prices up more than proportionally. Although some authors argue that demand growth and income rise in developing countries are probably not responsible for agricultural prices escalation in recent years, this is not the case for soybean. For example, Carter et al. (2009) suggest that, whereas China remained a net exporter of corn, rice and wheat during the price spike period 2005-2008, the country did experience a rapid growth in soybean import. However, recent data show that the trade balance for wheat, rice, maize and soybean in China has turned negative even for those product whose export exceeded import in the four-year period 2005-2008 (see figure 4.1). This turnaround has been accompanied by a new sudden rise in agricultural commodity prices. These new pieces of information are currently unexploited and might provide a significant contribution in disentangling the effect of growing demand on the market price of agricultural products. Nevertheless, when the aim is to assess the role of demand-side dynamics on the price setting mechanism of agricultural commodities, one should also account for demand fluctuations in developed countries. Therefore, our analysis will employ a proxy for the global demand of agricultural commodities.

4.2 Methodology

We disentangle empirically the relative importance of global demand, price of energy, speculation and rate of adoption of genetically modified organisms (GMOs) in explaining

Fig. 4.1: Chinese agricultural commodities trade balance index (base 2005).



Source: UN Trade Statistics (2015).

the US Soybean price dynamics through a Structural Vector Autoregression (SVAR) model. Although these models have been important tools for analysing macroeconomic (monetary, fiscal, technological, etc.) shocks (Enders, 2004), the dynamic nature of agricultural commodity prices makes the SVAR methodology particularly suited for this kind of analysis. Indeed, the empirical literature addressing the impact of policy/market shocks on agricultural commodity prices though structural time series models have been rapidly growing over the last few years; these contributions include McPhail et al. (2012), McPhail and Babcock (2012), McPhail (2011), Mutuc et al. (2010), and Hausman et al. (2012).

The general structure of a standard SVAR is provided in Appendix D. SVAR models are typically preferred to VARs (Vector Autoregression) because the latter are nothing more than reduced form equations whose parameters are hardly interpreted without any clear link to an underlying economic model. By turning to SVAR, some economic structure is imposed by specifying contemporaneous movements in the set of selected variables; this allows to identify structural parameters and break down times series into economically meaningful shocks.

In our application, we define a 5-dimensional SVAR model ($K = 5$) that jointly explains the dynamics of the crude oil price (OIL_t), Baltic Dry Index (BDI_t), US soybean prices (P_t), Working (1960) speculative index ($SPEC_t$) and the rate of adoption of genetically modified soybean (ROA_t). Following McPhail et al. (2012), Trostle (2010) and Kilian (2006) the BDI is used as a proxy for the global demand of soybean. Since the BDI charter rates for shipping dry bulks such as grains, coal, steel and others, it can be interpreted as the equilibrium price of shipping raw materials throughout the globe. Given that the supply function of maritime transportation services is typically inelastic in the mid and short run, fluctuations in BDI are supposed to be largely explained by changes in the global demand for dry bulks (Kilian, 2006). Despite its popularity in the empirical literature, however, BDI is mainly adopted consequently to the limited (if any) availability of data for dry bulk and, in our specific case, for world soybean demand. The crude oil price is used to capture the effect of energy price shocks in the supply chain of soybean: high crude oil prices will inflate farmers' and processors' operative costs by boosting the expenditure in pesticides, fertilizers, fuel and transportation. Next, the Working (1960) speculative index is used to approximate speculation activity in the soybean futures market; in the present context, speculation indicates the investment in commodity futures for non-commercial (non-hedging) purposes (i.e. financial profits) through index funds and other financial instruments (McPhail et al., 2012). The index measures how much speculation exceeds the minimum level needed to offset commercial positions. Specifically, it is defined as the ratio of long and short speculative (non-hedging) position to the global amount of long and short hedging positions. In particular, let SS/SL indicate the speculative short/long positions and let HS/HL be the hedging short/long positions; then the Working (1960) speculative index can be defined as:

$$\begin{aligned} T &= 1 + \frac{SS}{HS + HL} \qquad \text{if} \qquad HS > HL \\ T &= 1 + \frac{SL}{HS + HL} \qquad \text{if} \qquad HS < HL \end{aligned}$$

If all position on the futures market are either hedging or speculative, then $HS + SS = HL + SL$ meaning that long and short positions offset each other. If this is not the case, speculation becomes necessary to take in the residual commercial positions. In the extreme case that $HS = 0$, the minimum level of speculation needed in the futures market is HL; if so, $SL = 0$ and $T = 1$. Lest, we measure the rate of adoption of GM soybean in the United States through the ratio between the amount of GM soybean planted in each marketing year and the whole amount of soybean cultivated during the same marketing year.

Before proceeding with the estimation of impulse response functions, we tested each time series for the presence of unit root processes. Using the seasonally-augmented ADF test presented in the previous chapter, we found that all but one (the Working's speculation index) variables did contain a unit root (see table 4.3). Order one integration (hereafter $I(1)$) was also verified by taking first differences of each non-stationary times series and repeating the same ADF test on transformed data. As reported in Table 4.3, all transformed variables are stationary hence all components of the random vector $\mathbf{y}_t$ are either $I(1)$ or $I(0)$. In this case, a natural way to proceed is to check if there exist any long run relationship between the $I(1)$ series. In other words, we want to test whether any of the $I(1)$ time series are cointegrated and how many cointegration relationships there are. We used the popular Johansen (1995) likelihood ratio approach to test the identifying long run restriction imposed on the cointegrating vectors. Since most series have trending and seasonal behaviour, both a linear trend and a set of quarterly dummy variables were included in the VAR specification employed for the testing procedure. Next, the lag order of the VAR was selected using the Akaike Information Criteria (AIC), assuming that the farthest lag should not be larger than 4^5. We selected one lag and used both the "trace"

---

[5] We decided to set the highest lag order to 4 based on data frequency and Schwert (1989) criteria.

Tab. 4.3: Seasonally Augmented DF equations, OLS estimation results.

ADF test statistic		
BDI_t	-2.175	
OIL_t	-2.467	
$SPEC_t$	-3.595	
ROA_t	-2.925	
P_t	-2.825	
Critical values		
1%	T=60, $q_{max} = 4$	-4.32
5%	T=60, $q_{max} = 4$	-3.60
10%	T=60, $q_{max} = 4$	-3.24

ADF test statistic		
ΔBDI_t	-5.498	
ΔOIL_t	-5.763	
ΔROA_t	-3.846	
ΔP_t	-5.999	
Critical values		
1%	T=60, $q_{max} = 4$	-4.32
5%	T=60, $q_{max} = 4$	-3.60
10%	T=60, $q_{max} = 4$	-3.24

Critical values provided by da Silva Lopes (2006).

and the "max-eigenvalue" test; furthermore, we introduced a dummy variable to control for the introduction of the 2005 Energy Policy Act, which introduced mandatory blending for fossil fuels. Results are reported in table 4.4 and table 4.5 both tests suggest that there are no long-run relationships in our set of time series. This result is consistent with Harri et al. (2009) and Yu et al. (2006), who found no cointegration relationship between soybean market prices and crude oil prices (these two variables were the most likely candidates to show a long-run joint behaviour).

Tab. 4.4: Johansen (1995) "trace" test, results.

H_0	H_1	Test statistic	Critical values		
			10%	5%	1%
$r \leq 3$	$r = 4$	3.68	10.49	12.25	16.26
$r \leq 2$	$r = 3$	14.32	22.76	25.32	30.45
$r \leq 1$	$r = 2$	31.06	39.06	42.44	48.45
$r = 0$	$r = 1$	60.70	59.14	62.99	70.05

Tab. 4.5: Johansen (1995) "max-eigenvalue" test, results.

H_0	H_1	Test statistic	Critical values		
			10%	5%	1%
$r \leq 3$	$r = 4$	3.68	10.49	12.25	16.26
$r \leq 2$	$r = 3$	10.64	16.85	18.96	23.65
$r \leq 1$	$r = 2$	16.74	23.11	25.54	30.34
$r = 0$	$r = 1$	29.64	29.12	31.46	36.65

Following appendix D, we take first differences of $I(1)$ variables in $\mathbf{y}_t$ and leave the $I(0)$ series unchanged. For notational easiness we use $\Delta\mathbf{y}_t$ to indicate the new random vector $(\Delta BDI_t, \Delta OIL_t, SPEC_t, \Delta ROA_t, \Delta P_t)$. The SVAR representation is then:

$$\begin{aligned}\mathbf{\Gamma}\Delta\mathbf{y}_t &= \mathbf{A}(L)\Delta\mathbf{y}_t + \varphi B_t + \boldsymbol{\varepsilon_t} \\ &= a + \sum_{i=1}^{p} \mathbf{A}_i \Delta\mathbf{y}_{t-i} + \varphi B_t + \boldsymbol{\varepsilon_t}\end{aligned} \tag{4.1}$$

where the off-diagonal elements of $\mathbf{\Gamma}$ capture the contemporaneous interactions across variables, p is the lag order, $\mathbf{A}_i$ captures the lagged effects of the endogenous variables, B_t is a dummy variable controlling for the introduction of the 2005 Energy Policy Act and $\boldsymbol{\varepsilon_t}$ is the vector of structural innovations with variance-covariance matrix $\mathbf{\Sigma}_\varepsilon = \mathbf{I}_K$. Our assumption is that soybean prices are driven by shocks in global demand (ε_t^{BDI}), oil prices (ε_t^{OIL}), speculation demand (ε_t^{SPEC}) and rate of adoption of genetically modified organisms (ε_t^{ROA}); on the other hand, soybean market shocks (ε_t^{P}) include all other shocks affecting soybean prices which are not captured by the first four innovation terms.

The reduced-from VAR representation of model (4.1) is the following:

$$\begin{aligned}\Delta\mathbf{y}_t &= \mathbf{\Gamma}^{-1}a + \sum_{i=1}^{p} \mathbf{\Gamma}^{-1}\mathbf{A}_i \Delta\mathbf{y}_{t-i} + \mathbf{\Gamma}^{-1}\varphi B_t + \mathbf{\Gamma}^{-1}\boldsymbol{\varepsilon_t} \\ &= a^* + \sum_{i=1}^{p} \mathbf{A}_i^* \Delta\mathbf{y}_{t-i} + \varphi^* B_t + \boldsymbol{e_t}\end{aligned} \tag{4.2}$$

In order to identify structural parameters, proper theoretical exclusion restrictions shall be placed on $\mathbf{\Gamma}^{-1}$; since $\Delta\mathbf{y}_t$ has dimension 5×1, we need to set $5(5-1)/2 = 10$

entries of $\mathbf{\Gamma}^{-1}$ to zero. For simplicity, we adopt the so-called "triangular identification" (Rubio-Ramirez et al., 2010) strategy to impose restrictions on $\mathbf{\Gamma}^{-1}$. These restrictions are chosen on the grounds of economic intuition. First of all, we assume that the global demand does not respond to a contemporaneous shock in crude oil price, speculation, rate of adoption of GMOs or soybean market price. Second, the price of crude oil is assumed to be not responding to a shock in speculation, rate of adoption of GMOs and price of soybean within the same quarter; however, oil prices may be sensible to shocks in global demand during the same quarter. These exclusion restrictions are quite straightforward: in fact, it is hard to think of global demand and oil prices readily responding to contemporaneous shocks in US-specific shocks like ε_t^{SPEC}, ε_t^{ROA} and ε_t^{P}. Next, we hypothesize that speculation does not react to a contemporaneous shock in the rate of adoption of GMOs or soybean market price, while the rate of adoption of GMOs is assumed to be not responding to shock in soybean real prices during the same quarter. We chose to restrict the contemporaneous relationship between e_t^{ROA} and ε_t^{P} under the assumption that farmers' decision to switch to GM soybean cannot be instantaneous: indeed, if conventional soybean was already being planted, farmers will have to wait the following growing season to revise their planting decisions. On the other hand, whereas the exclusion of ε_t^{ROA} from e_t^{SPEC} is obvious, the restriction of the γ_{35} parameter is more problematic: although McPhail et al. (2012) excludes the same parameter in a rather similar framework, their decision is actually less debatable because of the monthly frequency of the data. However, since triangularization of $\mathbf{\Gamma}^{-1}$ is needed to identify system (4.1), we set $\gamma_{35} = 0$ anyway and assume that speculation activity does not respond to a contemporaneous shock in real soybean market prices. These restrictions can be represented using the following matrix notation:

$$\mathbf{\Gamma}^{-1} = \begin{pmatrix} \gamma_{11} & 0 & 0 & 0 & 0 \\ \gamma_{21} & \gamma_{22} & 0 & 0 & 0 \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & 0 & 0 \\ \gamma_{41} & \gamma_{42} & \gamma_{43} & \gamma_{44} & 0 \\ \gamma_{51} & \gamma_{52} & \gamma_{53} & \gamma_{54} & \gamma_{55} \end{pmatrix}$$

hence

$$\mathbf{e}_t = \begin{pmatrix} e_t^{BDI} \\ e_t^{OIL} \\ e_t^{SPEC} \\ e_t^{ROA} \\ e_t^{P} \end{pmatrix} = \begin{pmatrix} \gamma_{11} & 0 & 0 & 0 & 0 \\ \gamma_{21} & \gamma_{22} & 0 & 0 & 0 \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & 0 & 0 \\ \gamma_{41} & \gamma_{42} & \gamma_{43} & \gamma_{44} & 0 \\ \gamma_{51} & \gamma_{52} & \gamma_{53} & \gamma_{54} & \gamma_{55} \end{pmatrix} \times \begin{pmatrix} \varepsilon_t^{BDI} \\ \varepsilon_t^{OIL} \\ \varepsilon_t^{SPEC} \\ \varepsilon_t^{ROA} \\ \varepsilon_t^{P} \end{pmatrix}$$

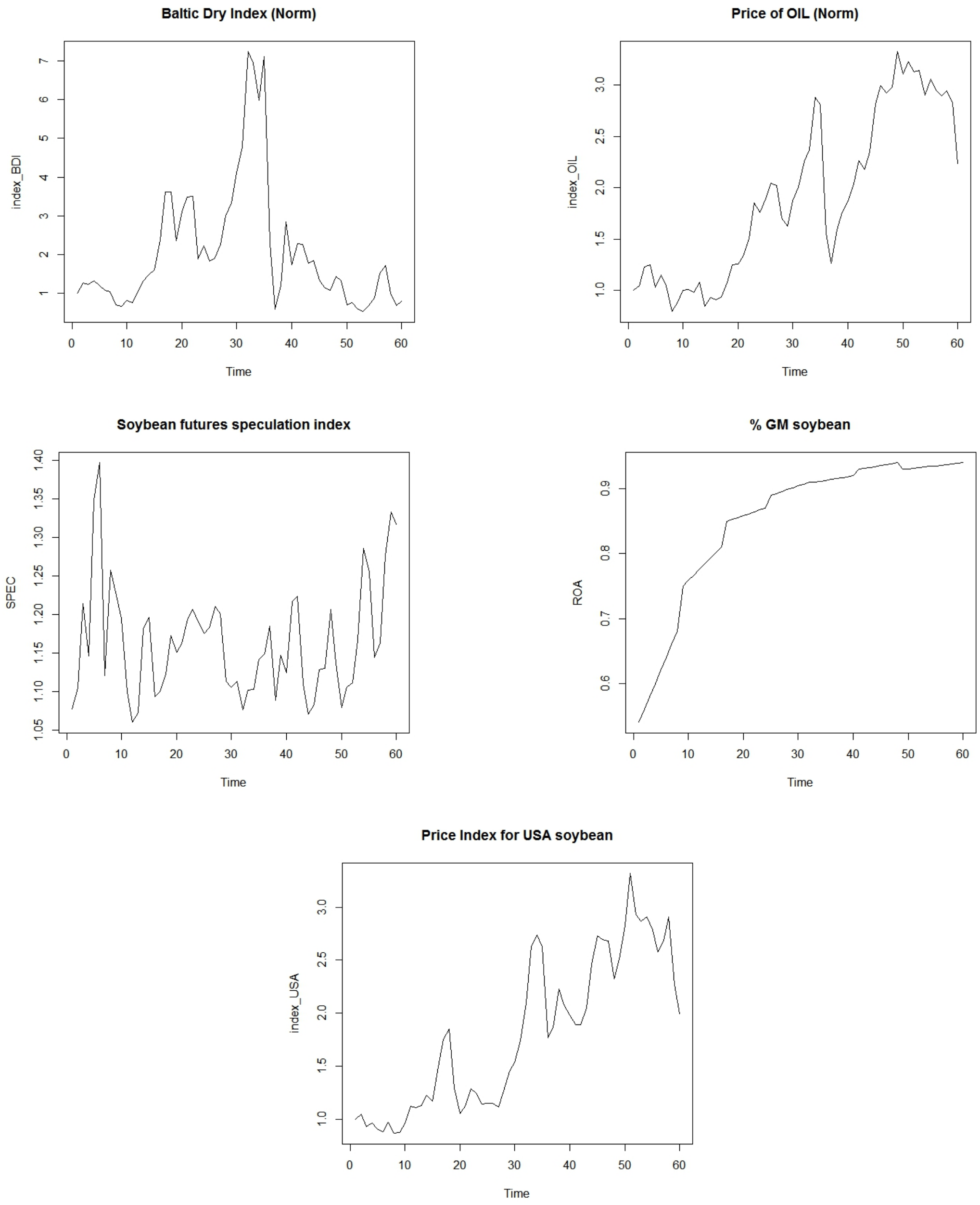
4.3 Data

We employed quarterly time series from 2000 to 2014 to estimate impulse response functions and perform variance decomposition; figure 4.2 shows data plots of each variable employed in model (4.1) against time. US soybean prices (P_t) are ”Soyabeans, No.1 Yellow” prices provided by USDA expressed in dollar cents per bushel. USDA also provides data regarding the rate of adoption of genetically modified soybean in the US (ROA_t): this share is computed as the ratio between the arable land cultivated with biotech soybean and the global area dedicated to soybean planting (USDA, NASS, 2015). BDI_t is provided by The Baltic Exchange using US dollars as the reference currency. Both US soybean prices and the BDI were retrieved from Datastream (Reuters, 2015). The price of crude oil is expressed in US dollars and is made available by the World Bank's Global Economic Monitor (World Bank, 2015). Last, the amount of hedging and speculating positions in the soybean futures market at Chicago Board of Trade is provided by the US Commodity Futures Trading Commission (CFTC) through the Historical Commitments of Trades reports (CFTC, 2015). Quarterly observations concerning the rate of adoption of biotech soybean in the US deserve to be discussed in more details. Since USDA provides tables with annual frequency only[6], we used a cubic spline interpolation for disaggregating annual data to quarterly time series in order to achieve the same frequency in all variables (Pollock et al., 1999). Data plots before and after disaggregation are shown in figure 4.3. We also created rather simple price indexes for BDI, crude oil price and US soybeans price by normalizing each time series using the $t = 1$ observation

---

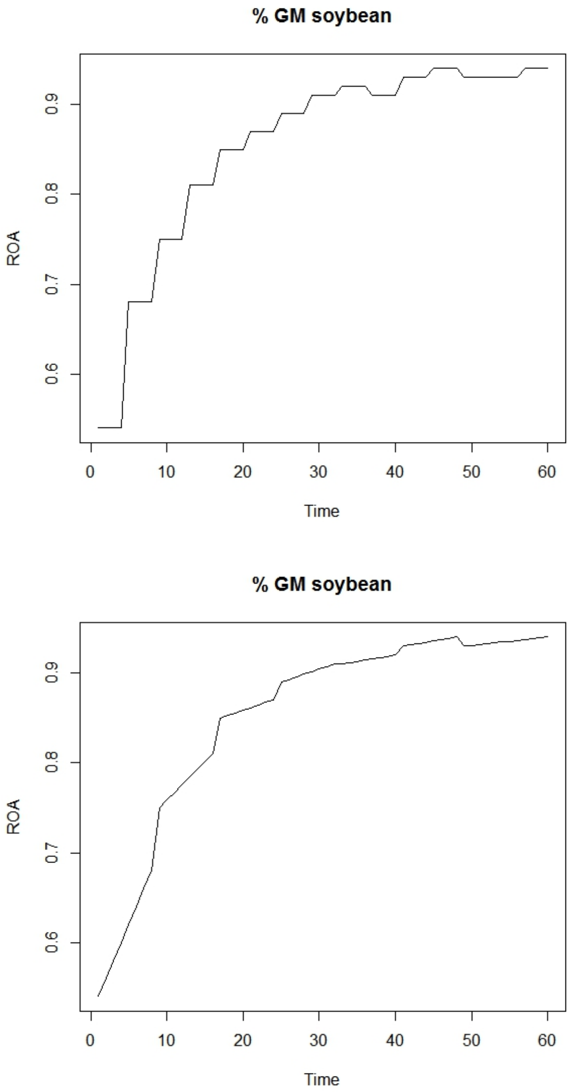
[6] This is natural because these observations are based on yearly planting decisions.

Fig. 4.2: Data plots for the components of the random vector $\mathbf{y}_t$.



Sources indicated in the text.

Fig. 4.3: Rate of adoption of GM soybean before and after cubic spline interpolation.



Source: USDA, NASS (2015)

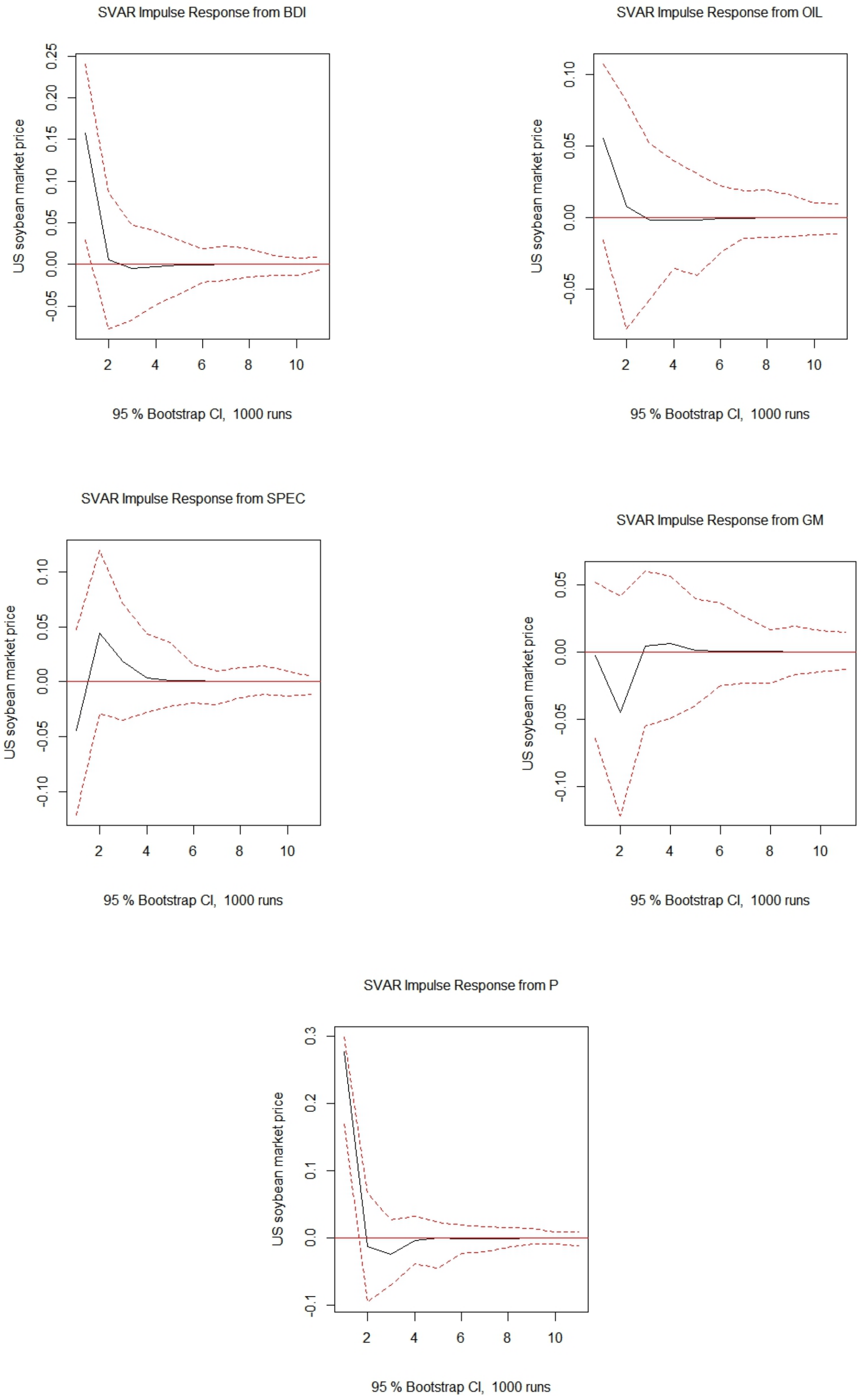
as numeraire.

4.4 Results

4.4.1 Impulse response analysis

We use impulse response analysis to assess the response of real soybean prices to shocks in global demand, crude oil prices, speculation and rate of adoption of GM soybean. Figure 4.4 depicts the dynamic response of soybean market prices from shock to quarter 10 with the corresponding 95% bootstrap confidence intervals (dotted lines). Responses of the dependent variable are obtained by considering one standard deviation shocks. As expected, a rise in global demand translates into an immediate, sharp and positive reaction of soybean market prices; this hike in soybean prices decreases rapidly during the first two quarters and begins to fade out gradually from the third quarter. What we observe implies that the supply-side response to a global demand shock would take at least six months to bring soybean prices back to the initial level. A similar pattern is recognized with a standard deviation shock in crude oil prices; however, in this case the initial response is less strong and the effect dies out less gradually. The interpretation is quite obvious: a rise in crude oil prices leads to higher transportation and energy costs, thereby making the soybean production process more expensive. Moreover, high crude oil prices might also drive the demand for biodiesel up thereby boosting the adoption of soybean by the oil industry. Globally, impulse response analysis shows that shocks in global demand and crude oil prices exert only temporary effects on soybean real prices. On the other hand, the impulse response of soybean market prices to a shock in Working (1960) speculation index is more subtle to interpret; however, our result is consistent (at least initially) with that observed by McPhail et al. (2012) for maize. One standard deviation shock in speculation generates an immediate negative response in soybean market prices, but the effect is reversed in the next two quarters and starts to decrease less steeply throughout the following four quarters. This result indicates that an hypothetical inflationary effect of speculation on soybean real prices, if any, is at least delayed by two

Fig. 4.4: Soybean market price impulse responses to each shock.



quarters. However, this effect does not persist for more than six quarters, indicating that the price reaction is a mid-term phenomenon. This corroborates the hypothesis put forward by Irwin et al. (2009) and Irwin and Sanders (2011) regarding the non-persistence of real price effects in periods of intense speculation on the futures market. A shock in the rate of adoption of GM soybean has initially no effect on soybean market prices. However, starting from quarter one, the effect becomes negative and persists for one additional quarter, while, starting from the second quarter, the effect begins to vanish more or less rapidly and eventually fades out after six quarters. Following Fernandez-Cornejo et al. (2000), Bullock and Nitsi (2001) and Klümper and Qaim (2014), depending on specific pedoclimatic conditions and the degree of spontaneous weeds infestations, the adoption of biotech soybean (mostly Monstanto's Roundup Ready soybean) leads, on the one hand, to a reduction of the operative/managerial costs and, on the other hand, it marginally increases yields. Therefore, the direction of the initial response is not surprising and might well indicate that a wider cultivation of GM soybean has allowed "GM farmers" to take advantage of reduced operative and managerial costs; furthermore, "conventional farmers" might have also taken advantage from a reduction in other herbicides and conventional seeds costs. However, the speed at which prices regress to the pre-shock levels might also suggest that the market effect of biotech soybean on substitute seeds and herbicides might exceed the cost saving for "GM farmers". In fact, although the shock in rate of adoption turns out to be the most persisting one, it still vanishes after only four-six quarters.

4.4.2 Variance decomposition

The procedure we follow to decompose the forecast error variance is discussed in Appendix D. Variance decomposition allows to measure the relative importance of each shock in explaining the fluctuation in soybean market prices. Table 4.6 shows the percentage of the variance of the error made in forecasting soybean prices attributable to a specific shock in global demand, crude oil prices, speculation and rate of adoption of GM soybean. These estimates are computed using historical averages for the whole time series since 2000 and, in general, the share of variance ascribable to different shocks differs from one

t observation to another. Results show that, within a quarter, more than 71% of the variability in soybean real prices is due to shocks which are not taken into consideration by model (4.1). Moreover, global demand shocks explain nearly 23% of the soybean price variation within a trimester, while oil shocks and speculation shocks represents roughly the 3% and 2% of the variability in soybean real prices, respectively. In addition, Table 4.6 indicates that the rate of adoption of GM soybean does not exert any significant effect on soybean real prices within one quarter. At six months, the contribution of the five shocks to the variability of soybean market prices remains substantially unchanged; the only noticeable difference lies in the rate of adoption of GM soybean. Although it remains quite small, the rate of adoption begins to significantly contribute to real prices variability in a two-quarters time horizon. This is consistent with the impulse repose analysis because the price effect related to the adoption of biotech soybean is not immediate. An increase in arable land dedicated to GM soybean requires at least six months to exert any damping effect on real market prices. From that moment onward, the relative contribution of each shock to soybean real price variation does not change any more. This indicates no clear cut between short-term and long-term effects of structural shocks on market price variance.

Tab. 4.6: Forecast error variance decomposition: percentage contribution of each shock to the variability in soybean market prices.

	Shocks				
Quarter(s)	Global demand	Oil price	Speculation	Rate of Adoption	Others
1	23.16	3.09	2.33	0.00	71.39
2	22.50	3.00	3.20	1.85	69.43
3	22.30	2.97	3.60	1.84	69.26
4	22.29	2.97	3.64	1.88	69.20
10	22.22	2.97	3.64	1.89	69.20
60	22.22	2.97	3.64	1.89	69.20

4.5 Concluding remarks

In this work, we measure the relative importance and the impact of global demand, energy prices, speculation and rate of adoption of genetically modified soybean on US soybean real prices. While there are many studies assessing the dynamics of agricultural commodity prices and their main determinants, most of the empirical evidence is presented using time series techniques which treat variables in isolation. Besides, most of the available research has focused on maize and, in particular, on the relationship between real prices, energy and ethanol using either univariate or multivariate time series models. Our aim was to model all contributing factors simultaneously through a structural vector autoregression (SVAR). Consistently with Sobolevsky et al. (2005), impulse response analysis indicate that a wider adoption of GM soybean leads to a decrease in soybean real prices. Following the available literature, this might reflect either a significant reduction of production costs (especially in terms of managerial costs), an increase in yields (Klümper and Qaim, 2014) or a substitution effect with conventional cultivation techniques. Although Bullock and Nitsi (2001) and Fernandez-Cornejo et al. (2002) argue that switching to GM soybean does not necessarily sort a positive effect on farmers' profits, our results suggest that, in the short run, the cost saving for "GM-farmers" should be initially larger than the profits' reduction due to the new (lower) equilibrium price[7]. Our findings are consistent with Klümper and Qaim (2014): albeit the authors indicate that switching to HT soybean leads to a substantial, yet not (statistically) significant hike in farmers' profits, they also show that, in general, the adoption of GM varieties produces enough economic benefits to at least balance out patented seeds' higher prices. Similar results are presented by Finger et al. (2011). In the mid/long-run, however, lower production costs (or higher profits) become attractive to conventional farmers that might choose to adopt the biotech program. In this case, the market equilibria would gradually reverse to the initial status, thereby bringing prices and profits back to the competitive

---

[7] Of course, this hypothesis requires the initial assumption of competitive markets with zero profits for conventional farmers.

level. This is what we observe from the second quarter of our impulse response function. In principle, however, the right tail of the impulse response function should have been less steep, indicating a smoother recovery of the initial equilibrium. In addition, variance decomposition shows that the impact of biotechnology adoption on soybean price variation over the period 2000-2014 is negligible in the very short run and remains low in the mid-long term. Another curious result is linked to the impulse response of soybean real prices to a shock in speculation: whereas the immediate reaction is negative, intense speculation drives market prices up after two quarters. Last, the shocks in oil prices and global demand exert an expected positive effects on soybean real prices, but the percentage contribution of an energy price shock to the variability in soybean market prices is limited. Moreover, the two positive effects are both short lived.

This work is certainly not free from critical issues. First of all, although the time series we employ to estimate our model should be long enough to achieve consistency, having too many years typically increases the risk of including structural breaks. In this regard, we control for the introduction of the 2005 Energy Policy Act but we fail to consider other major breaks such as the explosion of the ongoing economic crisis. Another major limitation lies in data frequency: on the one hand, quarterly observations are often not disaggregated enough to properly model short-term price dynamics while, on the other hand, the annual frequency of GM adoption data is hardly compatible with the other series. In particular, the inconsistency between annual and quarterly observations is particularly critical when it comes to lag selection. For this reason, we decided to disaggregate annual data using a cubic spline approximation, even though this procedure reduces the problem only marginally.

5. CONCLUSIONS

5.1 General conclusions

The purpose of this thesis is to investigate the role of GM and non-GM products on soybean and maize import, demand and prices in the EU. In particular, given the unavailability of reliable trade data for non-GM agricultural products, we assess how the governance of agricultural supply chains is framed under product segregation in order to cope with environmental and quality uncertainty. Using information gathered through vis-a'-vis questionnaires, we develop a case study for the most important non-GM commodity in the Italian (and European) feed industry: soybean meal. Since the literature indicates that the upstream product management is typically more problematic, we focus on the relationship between overseas soybean crushers and international trading companies. Conclusions are drawn based on the conceptual framework provided by Williamson (1991) and Ménard's (2004) theory of hybrid organizations. Whereas environmental uncertainty would require looser governance forms, quality uncertainty is better managed under vertical integration; since the management of non-GM soybean meal requires strong quality control mechanisms under non-trivial environmental uncertainty, we find that the supply chain governance relies on highly formalized yearly contracts. Although the structure of these contracts provides for strict operational standards and process certification, the yearly frequency enables the supply chain to adapt to uncertain market conditions. Moreover, we find that trust[1] is an interesting uncertainty control mechanism in the supply chain for non-GM soybean. The reason

---

[1] Trust is typically achieved through frequent transactions.

should be sought in: first, the high risk of adventitious presence[2]; second, the serious probability of exceeding the lower bound for authorized GM events; third, the opportunity for overseas exporters to stabilize price premiums and maintain a secure (niche) market channel to the EU.

It is also important to remark that, while quality uncertainty is probably less problematic because of its technical nature, understanding how environmental factors evolve is certainly more difficult and so is anticipating how the supply chain governance may evolve. Therefore, our findings are conditional on the availability on non-GM products, on the price premium corresponded for non-GM products and on the changes in demand. In this regard, the introduction of "GM-free" labelling schemes by some EU MS might create marketing opportunities for new overseas non-GM soybean producers. Obviously, the price premium paid for the non-GM status must be proportional to segregation costs, meaning that the adoption of "GM-free" labels must be eventually accompanied by consumers' willingness to pay (WTP) for the "extra quality". As consumers' WTP is at present insufficient to fill the price gap between GM and non-GM soybean meal, this price differential is pressuring some actors along the supply chain[3]. Therefore, if consumers were not ready to pay the toll of segregation, a wider introduction of non-GM products through the "GM-free" labelling schemes might pose further price pressure on the weakest actors of the chain.

The second result of our empirical analysis answers the question: "is the substitution/complementarity among overseas maize and soybeans exporters (to the EU) dictated by source-specific product characteristics[4]?". The estimated EU demand elasticities for maize and soybeans suggest that the answer is "no". In particular, soybeans cross-price elasticities highlight that countries with similar characteristics are

---

[2] Adventitious presence occurs when trace amounts of an agricultural biotech product that has not been approved for commercial use by any competent government authority, but is found in the commercial crop or food supply despite best agricultural and manufacturing practices.

[3] Most likely livestock breeders.

[4] These characteristics are: nutritional features, product management efficiency and asynchronous approval.

complements, while there is substitution between countries with different supply chain efficiency, approved GMOs and product's nutritional features. This result indicates that soybeans import demand must be regulated by other source-specific attributes; intuitively, the fact that complementarity is detected between US/Canada and Brazil/Paraguay while substitution is found between North American and South American countries[5] suggests that seasonality might play an important role on EU import decision. Using seasonal dummy variables, we are able to supports this hypothesis. In view of the negative EU trade balance for soybean and the importance of this product to the EU poultry and hog industry, the outcome is not surprising. For the opposite reason, seasonality should not be that important for maize and, in fact, estimated parameters for maize demand show that the inclusion of quarterly dummies does not trace out any periodicity in EU maize imports. Moreover, cross-price elasticities reveal that all maize sources are substitutes suggesting that, overall, Argentina, Brazil and Ukraine compete on price when it comes to commercialize maize on the European market. Last, our empirical analysis emphasizes that the debated issue of asynchronous approval does not play a crucial role on EU import decisions; this is probably due, on the one hand, to the EU dependence on soybean import and, on the other hand, to the substantial equivalence between the EU and Argentina, Ukraine and Brazil in terms of authorized GM maize varieties. In addition, as de Faria and Wieck (2015) suggest, the substantial synchronization between the EU and the major soybean and maize exporting countries might have mitigated this issue during the last fifteen years. Nevertheless, the structure of the EU import demand for soybean and maize might not be invariant to the introduction of new GM varieties (i.e. the so-called "second-generation" GMOs[6]). Since countries that have strong differences in their GM regulations trade significantly less (de Faria and Wieck (2015), Vigani et al. (2012)), the pure price competition we observe among overseas maize exporters might no longer be true if some of these countries decide to introduce (and commercialize) new GM varieties.

---

[5] In other words, we find substitution between Brazil/US, Brazil/Canada, Paraguay/US and Paraguay/Canada (see table 3.11).

[6] The second wave of genetic modification in agricultural crops focuses on output traits such as improved nutritional features and processing characteristics (Stegelin et al., 2011)

That is, regulation asymmetries would ultimately undermine the substantial equivalence between products originated from Argentina, Brazil, Ukraine or the US. As a consequence, EU livestock breeders might be challenged with higher raw material prices unless the EU approval process for newly released genetically engineered crops is fastened or domestic production is boosted. On the other hand, as long as the gap between the EU soybean demand and supply is filled through imports (Eurostat, 2015), seasonality will constantly play a leading role in determining the EU import decision; in this case, the response to the adoption of new GM varieties by overseas exporters will be mild.

In our last chapter, we use a structural vector autoregression (SVAR) to show that the adoption of herbicide resistant (GM) soybean exerts a negative, yet short-lived, effect on real soybean market prices. Following the literature, we conclude that the price reduction follows the introduction of the GM soybean in a perfectly competitive market, where only conventional soybean is initially cultivated. In the short-run, innovating farmers (i.e. GMOs adopters) would earn positive profits due to lower production costs while, in the mid/long-run, lower production costs would attract conventional farmers, thereby bringing profits back to zero and the equilibrium price back to the initial level. However, the effect of the innovation shock on soybean real prices does not persist for more than few quarters, with a rather fast recovery of the pre-GM equilibrium. Moreover, this effect of the GM innovation does not contribute much to the soybean price variability, meaning that a spreading of biotech soybean has only a limited impact on market prices. As we will discuss in the next section, however, the rapid vanishing of the price reduction might be linked to the AIC-based lag selection mechanisms; if so, our result might be biased and the true impulse response might be smoother.

5.2 Methodologies and data

The use of empirical research methods to properly analyse the international market of non-GM agricultural products is seriously limited by the lack of reliable data on trade flows and price premiums. Nevertheless, case studies may provide a useful tool for understanding supply chain mechanisms as the analysis provided in chapter two. Given the narrow scope of our analysis (i.e. the supply chain on non-GM soybean in Italy), the use of a case study allows for a detailed investigation of all economic agents involved and, using transaction cost economics as theoretical framework, information gathered through vis-á-vis interviews can be effectively framed. As a result, conclusion are be based on a firm economic ground. Nonetheless, case studies are often hardly replicable and do not allow to quantitatively assess the effects of changing demand or supply conditions. Also, vis-á-vis interviews are extremely time consuming and most of the times respondents do not provide all the expected information. In our opinion, however, the use of targeted questionnaires, paired with the appropriate economic theory, remains the most appropriate way to study niche markets, particularly when detailed secondary source data are unavailable or too expensive to collect.

In chapter three, we presented the main advantages of modelling import demand using a functional from derived from production theory (the so-called differential factor allocation model, DFAM). Here we want to stress that, although the differences between this approach and the modelling based on consumer theory might seem negligible from a mathematical point of view, the conceptual implications are not trivial. In particular, the use of production theory provides, first, a useful shortcut to avoid aggregation across heterogeneous consumers and, second, a straightforward way to avoid intermediate goods entering consumer's utility functions directly. Moreover, using a demand system derived from the differential approach to the firm theory, the specification of a cost/profit function is no longer necessary to derive a ready-to-estimate functional form. From an empirical point of view, models in (log) first differences have several advantages over demand systems in levels, the most relevant being the invariance to order-one integrated data. In other words, first differentiating has no conceptual implications on estimated parameters because it derives from the logarithmic specification of the total differential. Moreover, since these models are linear in the parameters, structural coefficients can be easily estimated with using standard least squares technique; since our dataset consists of a rather long time series of quarterly observations, we decided to include autocorrelation in the standard variance-covariance matrix of the popular ISUR estimator. The data we used to estimate the empirical model deserve a separate discussion: although Eurostat provides monthly observation regarding EU import statistics, prices are forcedly calculated as value divided by volume[7]. Even though unit values are often used in trade analysis (Washington and Kilmer, 2002b), Schott (2004) asserts that Free on Board (FOB) prices should be used when analysing the trade of differentiated goods. Unfortunately, FOB prices were not available for all exporters presented in chapter three, therefore we were forced to proceed with the analysis using unit values.

When discussing the SVAR methodology employed in chapter four, it is worth dwelling on two very important issues: first, the model identification through the so-called "triangular identification" (Christiano et al., 1996); second, the lag choice. Identification in SVAR models is typically achieved by imposing exclusion restrictions on the inverse contemporaneous coefficients matrix and, indeed, this is what we did in our work. Sometimes, however, this identification strategy may not be fully consistent with the economic theory; in fact, some parameters might be restricted just for the sake of obtaining a lower triangular matrix. For example, the restriction of the contemporaneous coefficient between the reduced form speculation innovation and the structural price innovation might be highly questionable when using quarterly data. Although we decided to stick with the standard (and easier) triangular identification strategy and restrict this parameter anyway, we might need to re-estimated the model using alternative identification methods (such as non-triangular techniques (Rubio-Ramirez et al., 2010)) and compare the results. The second issue has to do with the lag choice in the structural model. Consistently with most of the applied literature, we selected the lag truncation parameter using the Schwert (1989) criteria; although this method is widely adopted in empirical analysis, we believe that the use of the spline-interpolated rate of adoption data might generate a lag selection problem. In fact, despite the quarterly frequency, the structure of the time series has remained substantially unchanged and it might still incorporate yearly fluctuations. In this case, Schwert (1989) criteria would give a different result and identifying the correct number of lags in the structural model through AIC

---

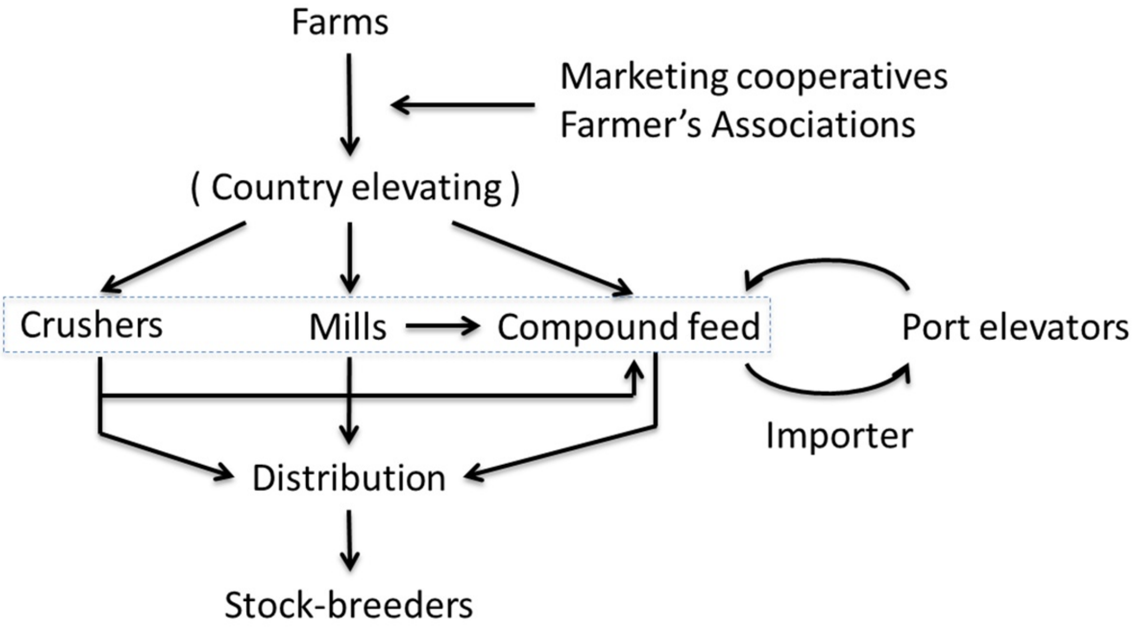
[7] Values reported by Eurostat are Cost, Insurance and Freight (CIF).

would be rather demanding. Unfortunately, there is no clear solution to this problem because the frequency of data regarding the cultivation of GM soybean is annual by definition. One alternative way of extracting information from rate of adoption data would consist of using yearly observations for all other variables; on the one hand, this shortcut would probably solve the lag selection problem, on other hand, the price to pay in terms of reduction of the sample size would be rather high.

APPENDIX

Appendix A

Questionnaire to the experts of the market for compound feed products



Structure of the supply chain. Note that the country elevating activity (included related services for drying, blending, etc.) could be often carried out by Farms, Cooperatives, Crushers, Mills and Feed Producers. Again, activities for primary processing products (namely: Crushing and milling) and compound feed processing might be carried out within the same plant.

I. The structure of the supply chain

(This section is common tot the questionnaire for mills and crushers)

(1) Consider the flow chart above: how is this representative of the supply chain in your country? If not, could you redraw it in a way that best represents your national supply chain? Note: you might need to draw more than one chart, since different supply chain structures could be in place (es: soybean vs. maize, SME?s vs multinational firms,...).

Note: the flow charts resulting from this first question should serve as a basis to guide the remaining questions of this questionnaire.

(2) We now talk about the level of vertical integration of firms (i.e. how a firm deals with the actors upstream or downstream to the supply chain).

    (a) What are the most common forms of vertical integration? (e.g. M&A, long-term contracting, joint ventures, strategic alliances, formal cooperation,...)

    (b) What level of the supply chain are these forms of vertical integration adopted at? Which are the actors involved?

    (c) Generally, is there a leading actor (farms, elevators, mills, crushers, compound feed processors, distributors) taking action in order to get integrated?

    (d) At each level of the supply chain, can you assess the relative importance of the forms of vertical integration you described above compared to the non-integrated activities?

(3) We now talk about the size of the firms operating at the different levels of the supply chain and the resulting level of market concentration (i.e. the share of the most important firms over the size of the relevant market).

    (a) At each level of the supply chain, is there a relevant share of sizeable firm? Could you name the first four firms and assess their market share at that supply chain level? (note: the same firm, if integrated, can appear at more than one step of the supply chain)

(4) Who are the most important importers for soybeans and maize products in your country? Are those importers Domestic Aggregators or International Marketing Companies? Make a distinction between the two different organizations.

    (Domestic Aggregators can buy products either FOB from foreign export elevators at the origination port directly, or they can buy products CIF at the destination port from international marketing companies. They then sell the product FOB to international customers facilities and deliver the product to

the facilities themselves)

(5) What are the reference international ports for soybeans and maize import and export in your country?

II. The compound feed market

From the above section we expect to know the level of concentration of the industry and the names of market leaders: here we want some more details.

(6) What is the share of nationally sourced maize used by compound feed producers? Do they import maize as grains, by-products, or products of primary processing?

(7) What is the share of nationally sourced soybean used by compound feed producers? Do they import soybean as grains, by-products, or products of primary processing?

(8) Can you assess the relative share of national compound feed producers with respect to the multinational ones? Which are the most important national compound feed producers? Which are the most important multinational ones? Are there specific ones for soybeans or maize?

(Please provide the names and a brief description of who they are ? property structure, main activities)

(9) What are the national compound feed processors' main suppliers? Cold you distinguish between national and international ones?

(Please provide the names and a brief description of who they are ? property structure, main activities, moreover distinguish the level and form of integration the suppliers have with compound feed processors)

(10) What is the share of farms and elevators dealing with compound feed producers directly?

(11) We now talk about the compound feed market and trade:

(a) Distinguishing between maize and soybean based products, what is the share of exported output (towards European Union) for the compound feed industry?

(b) Distinguishing between maize and soybean based products, which are the most relevant export categories?

(c) Which are the most important European and International suppliers (nations) of soybean meal/oil and Maize flour/CGF (Corn Gluten Feed)/CGM (Corn Gluten Meal)? Which are the structures (mills, crushers, elevators,...) supplying these goods?

III. Supply Chain Deals

(12) How do the compound feed producers deal with their suppliers? Is there any typical deal between compound feed producers and its supplier for the supply of soybean and maize? Do they aggregate in doing same activities?
(Please distinguish these deals considering the different form of supplier: farms, mills or crushers, importers)

(13) Excluding price, what are the main items of the deal? (e.g. how are volumes and delivering time managed?)

(14) How does the relationship between compound feed producers and foreign suppliers work? In particular, could explain the dynamics of the purchasing mechanism when dealing with multinational importer? How do deliveries work?

(15) How do the compound feed producer deal with their customers? Is there any typical deal between compound feed producers and its customers for the supply of compound feed? Do they aggregate in doing same activities?
(Please distinguish these deals considering the different form of customers: distributors, stock-breeders?)

IV. Pricing mechanism

(16) How does the price setting work when compound feed producer deal with

mills/crushers/cooperatives/farms or elevators (the upstream stakeholders)? *(Please distinguish between contracts with integrated and non-integrated players ? i.e. market vs. coordination)*

(17) 17. How does the price setting work when compound feed producer deal with distributors/stock-breeders (the downstream stakeholders)?
(please distinguish between contracts with integrated and non-integrated players ? i.e. market vs. coordination)

(18) How does the pricing setting described in the two questions above change when dealing with foreign suppliers or national ones?

(19) What is the premium price paid (on average) for certified gm-free soybeans/soybean meal/CGM/CGF/Maize grains/Maize flour?

(20) According to your opinion, what is the competition mostly focused onto? Is it focused on prices, differentiation or on the services offered?

(21) Are there any reference prices for maize and soybean inputs used by the compound feed producer? Where are they fixed? Is there a difference between national and international prices?

(22) Is there any e-procurement program to help processors in finding national or international maize or soybean suppliers?

(23) In your opinion, which are the factors effecting the fluctuation of feed prices?

(24) Do compound feed producers tend to align their pricing strategies?

V. GM products, non-GM products and segregation

(25) Can you make a distinction between national and multinational players regarding the segregation and/or identity preservation of gm-free products? Is the segregation/IP feasibility strongly influenced by the scale and/or by the structures of the supply chain?
(Please distinguish between maize and soybean and between national and imported products)

(26) Do national compound feed producers implement segregation/identity preservation systems for ensuring the supply of gm-free products? What about the multinational ones?

(Please distinguish between maize and soybean and between national and imported products)

(27) Which are the mostly adopted techniques for segregating products and/or ensuring Identity Preservation used by compound feed producers?

(Please distinguish between maize and soybean and between national and imported products)

  (a) Do these measures eventually affect the feed prices?
  (b) Is vertical integration a feasible point for these procedures?

VI. Certifiers and certifications

(28) Who are the certifiers involved in endorsing segregated and identity preserved gm-free products?

(29) Which form of monitoring is the mostly adopted by non-integrated compound feed producers to control their suppliers? Which is the one mostly adopted for integrated compound feed producers? Is there any regional/national plan to inspect for gm products at this stage of the supply chain?

(30) Do the compound feed producers require any GM-free certification to their national and international suppliers? Can you name three of the more common certification required to suppliers?

(31) Are the compound feed producers required to certify the identity preservation of their GM-free product? Can you name three of the more common certification for processors?

(32) Is the processing activity the most problematic phase for the identity preservation of GM-free products? If not, which is in your opinion the most critical phase?

Questionnaire to the experts of the market primary processing products

This questionnaire shares both the sketch and the first section with the previous one; what changes is the structure and the number of questions listed in sections II though VI.

II. The market of primary processed maize and soybean

From the above section we expect to know the level of concentration of the industry and the names of market leaders: here we want some more details.

(6) What is the share of nationally sourced maize used by Italian maize mills? Do they import maize as only dried grains do they import maize by-products as well?

(7) What is the share of nationally sourced soybean used by [Country] soybean crushers?

(8) Can you assess the relative share of national maize mills and soybeans crushers with respect to the multinational ones (we mostly refer to the primary processing activity eventually integrated by large multinational feed industries)? Which are the most important national producers of maize and soybean primary processing products (we refer to soybean meal, soybean oil, maize flour, maize starch, distilled dried grains, corn gluten feed, corn gluten meal)? Which are the most important multinational ones?
(Please provide the names and a brief description of who they are ? property structure, main activities)

(9) Which are the national maize mills' and soybean crushers' main suppliers (downstream integrated firms shall be considered)? Cold you distinguish between national and international ones?
(Please provide the names and a brief description of who they are ? property structure, main activities..., moreover distinguish the level and form of integration the suppliers have with compound feed processors)

(10) We now talk about the primary processing products? international trade:

  (a) Distinguishing between maize and soybean primary processing products, what is the share of exported output towards European Union?
  (b) Distinguishing between maize and soybean primary processing products, which are the most relevant export categories?
  (c) Which are the most important European and International suppliers (nations) of soybean and Maize inputs for the primary processing industry? Which are the structures (international marketing companies, domestic aggregators, small exporters, large European farms/cooperatives/elevators,...) supplying these goods?

III. Supply chain deals

(11) How do the maize mills and the soybean crushers deal with their suppliers? How are deliveries managed in order to address the crushing/milling process? *(Please distinguish these deals considering the different form of supplier: farms, elevators, importers,...)*

(12) Excluding price, what are the main items of the deal? (e.g. how are volumes and delivering time managed?)

(13) How does the relationship between the maize mills and the soybean crushers work when dealing with foreign suppliers? In particular, could explain the dynamics of the purchasing mechanism when dealing with multinational importer? How do deliveries work?

(14) How the maize mills and soybean crushers deal with their customers? Is there any typical deal between primary processing products? producers and either customer for the supply of maize and soybean derivatives? Do they aggregate in doing same activities?

(Please distinguish these deals considering the different form of customers: distributors, stock-breeders, compound feed producers,...)

(15) If possible, try to assess which is the difference between the share of primary processing products sold to the compound feed industry and the share directly sold to the final consumer.

IV. Pricing mechanism

(16) How does the price setting work when maize mills/soybean crushers deal with cooperatives/farms or elevators (the upstream stakeholders)?
(Please distinguish between contracts with integrated and non-integrated players ? i.e. market vs. coordination)

(17) How does the price setting work when maize mills/soybean crushers deal with distributors/stock-breeders/compound feed producers (the downstream stakeholders)?
(Please distinguish between contracts with integrated and non-integrated players ? i.e. market vs. coordination)

(18) How does the pricing setting described in the two questions above change when dealing with foreign suppliers (international marketing companies, aggregators,...) or national ones?

(19) What is the premium price paid (on average) for certified GM-free maize and soybean inputs for primary processing?

(20) According to your opinion, what is the competition mostly focused onto? Is it focused on prices, differentiation or on the services offered?

(21) Are there any reference prices for maize and soybean inputs used by mills/crushers? Where are they fixed? Is there a difference between national and international prices?

(22) Is there any e-procurement program to help processors in finding national or international maize or soybean suppliers?

(23) In your opinion, which are the factors effecting the fluctuation of the prices of primary processing products (make a distinction between maize and soybeans)?

V. GM products, non-GM products and segregation

(24) Can you make a distinction between national and multinational players regarding the segregation and/or identity preservation of gm-free products? Is the segregation/IP feasibility strongly influenced by the scale and/or by the structures of the supply chain?

(Please distinguish between maize and soybean and between national and imported products)

(25) Do national maize mills and soybean crushers implement segregation/identity preservation systems for ensuring the supply of gm-free products? What about the multinational ones?

(Please distinguish between maize and soybean and between national and imported products)

(26) Which are the mostly adopted techniques for segregating products and/or ensuring Identity Preservation used by maize mills and soybean crushers?

(Please distinguish between maize and soybean and between national and imported products)

  (a) Do these measures eventually affect the feed prices?

  (b) Is vertical integration a feasible point for these procedures?

VI. Certifiers and certifications

(27) Who are the certifiers involved in endorsing segregated and identity preserved gm-free products?

(28) Which form of monitoring is the mostly adopted by non-integrated mills/crushers to control their suppliers? Which is the one mostly adopted for integrated mills/crushers? Is there any regional/national plan to inspect for gm products at this stage of the supply chain?

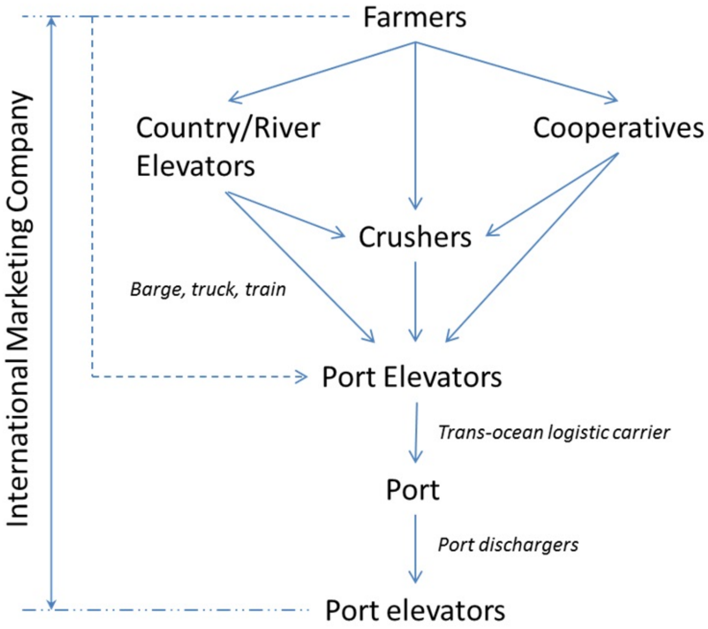
(29) Do the mills/crushers require any GM-free certification to their national and international suppliers? Can you name three of the more common certification

required to suppliers?

(30) Are the mills/crushers required to certify the identity preservation of their GM-free product? Can you name three of the more common certification for processors?

(31) Is the crushing/milling activity the most problematic phase for the identity preservation of GM-free products? If not, which is in your opinion the most critical phase?

Questionnaire to importers and/or international traders



Structure of the intenrational supply chain. This figure depicts a sketch of the international supply chain for maize and soybean raw material

I. Product and information flow

(1) Consider the flow chart above: how is this representative of the supply chain, from the origination country to the destination country, importers deal with? If not, could you redraw it in a way that best represents it?

(2) Consider the flow chart above: to what extent of the soybean supply chain are International Marketing Companies integrated?

  (a) Do they have control over the upstream activities like crushing, elevating or farming?

  (b) Do they have control over any downstream activity as well (crushing, transportation)?

   (c) Which is the most common form of vertical integration/coordination International Marketing Companies adopt to deal with the actors upstream or downstream the supply chain? (Hierarchy, M&A, long-term contracting, joint ventures, strategic alliances, formal cooperation,...)

(3) Consider now foreign buyer willing to purchase a soybean products from an importer (it cloud be either an International Marketing Cooperative or a domestic Aggregator): could you describe how the dealing begins? Please focus, among other things, on the role of brokers in international trade for soybeans and its derivatives.

   (a) Could you describe how many and which are the actors involved in the purchasing/selling activity?

(4) Could you assess what share of soybean products is delivered through FOB contracts and what share is delivered through CIF contracts, instead?

   (a) Could you make a distinction between the characteristics of enterprises willing to buy products CIF and the characteristics of firms buying products through FOB contracts?

   (b) Is there a distinction when considering either soybean meal or soybean grains?

(5) We now consider that the foreign buyer signed a sales contract with the importer. We want to understand how the information is transmitted upstream in order to have the right product (in terms of volume and qualitative attributes) reaching its destination.

   (a) In particular, could you explain which are the offices and departments (namely: origination offices, international marketing offices, destination offices, satellite offices, etc.) involved in the information flow and the specific role they play in the information flow management (i.e. who is the information transmitted to?).

(b) Could you also indicate also which information is required to be forwarded and how long it takes before the product is shipped?

(c) Last, could you describe the differences, if any, between the information flow management for regular products and that for Identity Preserved Products?

(6) Suppose now that the order was fully processed:

(a) Could you explain how is the product delivered and which information goes along with the product through the different offices from the origination country to the destination port?

(b) In particular, could you describe the delivery modes (CIF, FOB, other) through each subsequent step along the product flow from the origination country to the destination port?

(c) Based on the origination port it is shipped from: how long does the product take to reach the destination port?

(d) Again, could you make a difference between the procedures followed for regular products and those followed for Identity Preserved products?

II. Actors involved, operations and responsibilities at the origination port

textitWe now consider which dynamics take place at the origination port before and while the products are inbound. In particular, we want to describe how and by whom the products are loaded on trans-ocean logistic carriers? vessels and then shipped to the destination port.

(7) Could you explain what relationships international marketing companies (IMC) establish with origination port?s operators?
(A detailed description of all the operations run by these two port operators is needed. Besides, a detailed description about what the international marketing companies require, in terms of procedures and guarantees, from the dischargers and the elevators shall be given as well)

   (a) Are port activities usually integrated by international marketing companies?
   (b) If we were talking about Identity Preserved GM-free products:
      (i) Could you explain how these relationships change in terms of both relevance and procedures adopted (from a technical/ bureaucratic point of view and from a liability point of view) for avoiding commingling and adventitious presence?
      (ii) When would the product be tested (along this process chain) and who would be responsible for testing?
      (iii) What would be the role of GM-free products? certifiers during these operations?

(8) We are still talking about products which need to be Identity Preserved but more precisely, we now refer to GM-free products:
   (a) Which point of the port logistic network are the tests for detecting GM events carried out at?
   (b) How many tests are carried out?
   (c) Who is responsible of testing the products (namely: the IMC, the foreign buyer, the port operators)?
   (d) What is (if any) the role of certifiers in product testing?
   (e) Suppose that one result from the product testing showed a GM threshold above 0,9%. Based on the point along the port?s logistic network (from the inbound vessel to the outbound truck/train) the tests were carried out, who would be liable for the adventitious presence if any product was found positive to the presence of GM material over an agreed threshold?

(9) Which are the most important certifiers for international flows of GM-free IP products?

(10) How is the relationship between international marketing companies (or other importers) and certifiers form IP products? Is certification managed at the

corporate level or should every single office work to get the product he is charged to handle certified?

III. Actors involved, operations and responsibilities at the destination port

We now consider which dynamics take place at the destination port before, while and after the products are inbound.

(11) Suppose an inbound soybean cargo has reached the destination port: how are the batches coming from non-EU countries managed when dealing with the issue of maintaining Identity Preservation at the port?

  (a) Which are the actors involved in discharging and storing?
  (A detailed description of all the bureaucratic procedures run by these two port operators is needed.)

  (b) Which is/are the most problematic phase/s when managing identity preserved GM-free products at this level of the supply chain?

(12) Could you explain what relationships international marketing companies (IMC) establish with ports? operators?

  (a) How do IMC deal with port dischargers and port elevators?
  (A detailed description about what the international marketing companies require, in terms of bureaucratic procedures and guarantees, from the dischargers and the elevators shall be given)

  (b) Could you also explain how these relationships change in terms of both relevance and procedures adopted (from a technical point of view and from a liability point of view) when dealing with IP products?

  (c) Are port activities usually integrated by international marketing companies?

(13) We now talk about products which need to be Identity Preserved but more precisely, we now refer to GM-free products:

    (a) How many tests are carried out after the vessel reached the destination port?
    (b) Which point of the port logistic network are those tests carried out at?
    (c) Who is responsible of testing the products (namely: the Importer, the buyer, the port operators)? In particular, what is (if any) the role of certifiers?
    (d) Are tests certified by the same certifiers who endorsed the products from the foreign farm to the destination port?
    (e) Suppose that one result from the product testing showed a GM threshold above 0,9%. Based on the point along the port?s logistic network (from the inbound vessel to the outbound truck/train) the tests were carried out, who would be liable for the adventitious presence if any product was found positive to the presence of GM material over an agreed threshold?

(14) Which are the most important certifiers for international flows of GM-free IP products?

IV. Physical transportation: trans-ocean logistic carriers and International Trading Companies

First of all, we need to know who are the most important logistic carriers involved in dry-bulk overseas transportation and their relevance across soybean origination and destination areas. Furthermore we need to describe some of the most important characteristics of the trans-oceanic logistic industry (Is that industry concentrated? What is the competition based upon?).

(15) How do IMC or other importers relate with those trans-ocean logistic companies for shipping their products around the world?

    (a) Is there any international marketing company integrating the trans-ocean logistic?

(16) How much is (on average) the freight rate for shipping dry-bulk products

(soybean meal and soybean grains) form USA/Brazil/Argentina to your country?

(17) How much does the freight rate change when switching from regular commodities to IP products?

(18) How many overseas logistic carriers can ensure products? Identity Preservation?

    (a) Could you name at least three of the most common logistic carriers for IP products?

Appendix B

Under the assumption of an inter-temporally separable, twice continuously differentiable and homothetic industry-level transformation function, we assume that the transformation function is:

$$f(\mathbf{q}, \mathbf{z}) = 0$$

where $\mathbf{q} = (q_1, \ldots, q_N)$ is a vector of inputs and $\mathbf{z} = (z_1, \ldots, z_M)$ is a vector of outputs. The transformation function satisfies

$$\sum_{l=1}^{M} \frac{\partial f}{\partial log z_l} \equiv -1$$

The firm's objective can be state as the following minimization problem:

$$\begin{aligned} \min_{\mathbf{q}} \quad & \mathbf{p}\mathbf{q}^T \\ \text{s.t.} \quad & f(\mathbf{q}, \mathbf{z}) = 0 \end{aligned}$$

We construct with corresponding Lagrangian function

$$\mathscr{L}(\mathbf{q}, \lambda) = \mathbf{p}\mathbf{q}^T - \lambda f(\mathbf{q}, \mathbf{z}) = \sum_{i=1}^{n} p_i q_i - \lambda f(\mathbf{q}, \mathbf{z})$$

Differentiation this expression with respect to $log q_i$ and re-arranging leads to:

$$p_i q_i - \lambda \frac{\partial f}{\partial log q_i} = 0, \qquad \forall i = 1, \ldots, N \tag{B.1}$$

with solution at $\mathbf{q}^*(\mathbf{z}, \mathbf{p}) = \{q_i^*(\mathbf{z}, \mathbf{p}); i = 1, \ldots, N\}$ and $\lambda > 0$.

Total cost and Marginal Cost

Define the total cost function as:

$$\mathbf{p}^T\mathbf{q}^* = C(\mathbf{p}, \mathbf{q}^*) = C(\mathbf{p}, \mathbf{q}^*(\mathbf{z}, \mathbf{p})) = \sum_{i=1}^{N} p_i q_i^*(\mathbf{z}, \mathbf{p}) \equiv C$$

Define also the *contribution of the* i^{th} *input to the total cost* as:

$$C(\mathbf{p}, \mathbf{q}^*) [p_i q_i^*]^{-1} = h_i \tag{B.2}$$

This quantity measures the relative importance of each input to the multi-product firm in terms of its contribution to the total cost.

Now, the Marginal cost of the l^{th} output is:

$$\frac{\partial C\left(\mathbf{p},\mathbf{q}^*\right)}{\partial z_r}=\frac{\partial \sum_{i=1}^{N} p_i q_i^*}{\partial z_l}=\sum_{i=1}^{N} p_i \frac{\partial q_i^*}{\partial z_l}=\frac{C}{z_l}\sum_{i=1}^{N} h_i \frac{\partial \log q_i^*}{\partial \log z_l}$$

The differentiation of $f(\mathbf{q}^*,\mathbf{z})=0$ with respect to $\log z_l$ leads to:

$$\frac{\partial f\left(\mathbf{q}^*,\mathbf{z}\right)}{\partial \log z_l}=\nabla_{\log \mathbf{q}} f\left(\mathbf{q}^*,\mathbf{z}\right)\begin{pmatrix}\dfrac{\partial \log {q_1}^*}{\partial \log z_l}\\ \vdots \\ \dfrac{\partial \log {q_n}^*}{\partial \log z_l}\end{pmatrix}+\frac{\partial f\left(\mathbf{q}^*,\mathbf{z}\right)}{\partial \log z_l}\frac{\partial \log z_l}{\partial \log z_l}=0$$

where the first vector product can be also written as:

$$\sum_{i=1}^{N}\frac{\partial f}{\partial \log q_i}\frac{\partial \log q_i}{\partial \log z_l}$$

where, using (B.1), $\frac{\partial f}{\partial \log q_i}$ is equal to $\frac{p_i q_i}{\lambda}$ and, using (B.2), $p_i q_i = C/h_i$. Therefore:

$$\sum_{i=1}^{N}\frac{\partial f}{\partial \log q_i}\frac{\partial \log q_i}{\partial \log z_l}=\sum_{i=1}^{N}\frac{p_i q_i}{\lambda}\frac{\partial \log q_i}{\partial \log z_l}=\sum_{i=1}^{N}\frac{\frac{C}{h_i}}{\lambda}\frac{\partial \log q_i}{\partial \log z_l}=\frac{C}{\lambda}\sum_{i=1}^{N} h_i\frac{\partial \log q_i}{\partial \log z_l}$$

It follows that:

$$\frac{\partial f\left(\mathbf{q}^*,\mathbf{z}\right)}{\partial \log z_l}=\frac{C}{\lambda}\sum_{i=1}^{N} h_i\frac{\partial \log q_i}{\partial \log z_l}+\frac{\partial f\left(\mathbf{q}^*,\mathbf{z}\right)}{\partial \log z_l}=0$$

Now, since

$$\frac{\partial C}{\partial z_l}\frac{z_l}{\lambda}=\frac{z_l}{\lambda}\frac{C}{z_l}\sum_{i=1}^{N} h_i\frac{\partial \log q_i}{\partial \log z_l}$$

then:

$$\frac{\partial C}{\partial z_l}\frac{z_l}{\lambda}+\frac{\partial f\left(\mathbf{q}^*,\mathbf{z}\right)}{\partial \log z_l}=0$$

Therefore, the summation over l gives:

$$\sum_{l=1}^{M}\left[\frac{\partial C}{\partial z_l}\frac{z_l}{\lambda}+\frac{\partial f\left(\mathbf{q}^*,\mathbf{z}\right)}{\partial \log z_l}\right]=\sum_{l=1}^{M}\frac{\partial C}{\partial z_l}\frac{z_l}{\lambda}+\sum_{l=1}^{M}\frac{\partial f\left(\mathbf{q}^*,\mathbf{z}\right)}{\partial \log z_l}=\sum_{l=1}^{M}\frac{\partial C}{\partial z_l}\frac{z_l}{\lambda}-1=0$$

hence

$$\lambda=\sum_{l=1}^{M}\frac{\partial C}{\partial z_l}z_l$$

This indicates that, for the multi-product firm, λ corresponds to the marginal cost of a proportionate increase in the outputs or, in other words, the total marginal cost (each input being evaluated at its marginal cost). Sticking with the total marginal cost interpretation of λ, it is possible to define

$$g_l = \frac{z_l}{\lambda}\frac{\partial C}{\partial z_l} \qquad \forall l = 1, \ldots, m$$

which corresponds to the contribution of the l^{th} output to the total marginal cost. Therefore, an aggregate output index may be defied by allpying the Divisia decomposition to the definition of λ:

$$d(\log Z) \equiv \sum_{l=1}^{M} g_l d(\log z_l)$$

which implies $Z \equiv \sum_{l=1}^{m} g_l z_l$. Furthermore, from the definition of g_l it is easy to see that:

$$\frac{\partial C}{\partial z_l}\frac{z_l}{\lambda} + \frac{\partial f\left(\mathbf{q}^*, \mathbf{z}\right)}{\partial \log z_l} = g_l + \frac{\partial f\left(\mathbf{q}^*, \mathbf{z}\right)}{\partial \log z_l} = 0$$

hence

$$\frac{\partial f\left(\mathbf{q}^*, \mathbf{z}\right)}{\partial \log z_l} = -g_l$$

Proportionate output elasticities

The total differential of $f\left(\mathbf{q}^*, \mathbf{z}\right)$ is given by (in vector notation):

$$\nabla_{\log \mathbf{q}} f\left(\mathbf{q}^*, \mathbf{z}\right) d\log \mathbf{q} + \nabla_{\log \mathbf{z}} f\left(\mathbf{q}^*, \mathbf{z}\right) d\log \mathbf{z}$$

Since the $f\left(\mathbf{q}^*, \mathbf{z}\right) = 0$, $\left(\mathbf{q}^*, \mathbf{z}\right)$ lies on the transformation frontier of the productions set hence (Mas-Colell et al., 1995)

$$\nabla_{\log \mathbf{q}} f\left(\mathbf{q}^*, \mathbf{z}\right) d\log \mathbf{q} + \nabla_{\log \mathbf{z}} f\left(\mathbf{q}^*, \mathbf{z}\right) d\log \mathbf{z} = 0 \tag{B.4}$$

This can be also expressed in the form

$$\sum_{i=1}^{n} \frac{\partial f}{\partial \log q_i} dl \log q_i + \sum_{l=1}^{m} \frac{\partial f}{\partial \log z_l} d\log z_l = 0$$

Under the assumption that inputs and outputs change proportionately, then $d\log q_i$ and $d\log z_l$ can be placed out of the summations:

$$d\log q_i \sum_{i=1}^{N} \frac{\partial f}{\partial \log q_i} + d\log z_l \sum_{l=1}^{M} \frac{\partial f}{\partial \log z_l} = 0 \tag{B.3}$$

Using

$$\sum_{i=1}^{N} \frac{\partial f}{\partial \log q_i} = \sum_{i=1}^{N} \frac{p_i q_i^*}{\lambda} = \frac{C}{\lambda}$$

$$\sum_{l=1}^{M} \frac{\partial f}{\partial \log z_l} = -1$$

equation (B.3) can be re-written as

$$d\log q_i \frac{C}{\lambda} - d\log z_l = 0 \qquad \Longleftrightarrow \qquad \frac{C}{\lambda} = \frac{\partial f(\mathbf{q},\mathbf{z})}{\partial \log q_i} = \frac{d\log z_l}{d\log q_i}$$

Letting the outputs change proportionately and letting the inputs do the same, $\frac{C}{\lambda}$ can be generalized for each l and i. This ratio represents the elasticity of proportionate output with respect to a proportionate input, at $\mathbf{q}^*$. Another interpretation is that of elasticity of scale of a multi-product firm at $\mathbf{q}^*$.

On the other hand, the reciprocal of the former ratio represents the elasticity of (total) cost with respect to a proportionate (global) output increase:

$$\frac{\lambda}{C} = \frac{\sum_{l=i}^{M} \frac{\partial C}{\partial z_l}}{C} = \sum_{l=1}^{M} \frac{\partial \log C}{\partial \log z_l} \equiv \gamma$$

Last, from the f.o.c. $p_i q_i - \lambda \frac{\partial f(\mathbf{b},\mathbf{z})}{\partial \log q_i}$, $C = \sum_{i=1}^{n} p_i q_i^*$ and $h_i = \frac{p_i q_i}{C}$ we can obtain $C h_i q_i = p_i q_i$ and the following identity:

$$\frac{p_i q_i}{\lambda} = \frac{h_i C}{\lambda} = \frac{\partial f(\mathbf{q},\mathbf{z})}{\partial \log q_i}$$

Since $\gamma = \left(\frac{\lambda}{C}\right)^{-1}$, then

$$\frac{\partial f(\mathbf{q},\mathbf{z})}{\partial \log q_i} = h_i \gamma^{-1}$$

This in turn implies that:

$$h_i \gamma^{-1} = \frac{\partial f(\mathbf{q},\mathbf{z})}{\partial \log q_i} = \frac{d\log z_l}{d\log q_i}$$

However, the interpretation of $h_i\gamma^{-1}$ is different from $\frac{C}{\lambda}$: the first expression implies that we keep all inputs constant and we let input i vary, hence it represents the elasticity of proportionate (global) output with respect to the i^{th} input, at $\mathbf{q}^*$. In conclusion, $\frac{\partial f(\mathbf{q},\mathbf{z})}{\partial \log q_i}$ has two different interpretations depending on whether we assume inputs proportionate or not.

Demand for inputs, preliminary

First of all, consider the second-order logarithmic derivatives of $f(\mathbf{q},\mathbf{z}) = 0$

$$\mathbf{H} = \frac{\partial^2 f(\mathbf{q},\mathbf{z})}{\partial \log \mathbf{q}\, \partial \log \mathbf{q}^T} \qquad (N \times N)$$
$$\mathbf{H}^* = \frac{\partial^2 f(\mathbf{q},\mathbf{z})}{\partial \log \mathbf{q}\, \partial \log \mathbf{z}^T} \qquad (N \times M)$$

Additionally, given the total differential defined in (B.4):

$$\mathbf{H}^* \boldsymbol{\iota} = 0$$

where $\boldsymbol{\iota}$ is an $(M \times 1)$ vector of ones.

Consider now the Lagrangian function of the cost minimization problem evaluated at the solution $\mathbf{q}^*(\mathbf{p},\mathbf{z})$ and $\lambda^*(\mathbf{p},\mathbf{z})$:

$$\begin{aligned}\mathscr{L}(\mathbf{q}^*(\mathbf{p},\mathbf{z}), \lambda^*(\mathbf{p},\mathbf{z})) &= \mathbf{p}\mathbf{q}^{*'}(\mathbf{p},\mathbf{z}) - \lambda^*(\mathbf{p},\mathbf{z}) f(\mathbf{q}^*(\mathbf{p},\mathbf{z}),\mathbf{z}) \\ &= \sum_{i=1}^{n} p_i q_i^*(\mathbf{p},\mathbf{z}) - \lambda^*(\mathbf{p},\mathbf{z}) f(\mathbf{q}^*(\mathbf{p},\mathbf{z}),\mathbf{z})\end{aligned}$$

The f.o.c. evaluated at $\mathbf{q}^*(\mathbf{p},\mathbf{z})$ and $\lambda^*(\mathbf{p},\mathbf{z})$ is therefore:

$$p_i q_i^*(\mathbf{p},\mathbf{z}) - \lambda^*(\mathbf{p},\mathbf{z}) \frac{\partial f(\mathbf{p},\mathbf{z})}{\partial log q_i} = 0, \qquad \forall i = 1,...,n$$

The partial derivative of this expression with respect to $\log z_l$ is:

$$p_i q_i^* \frac{\partial \log q_i^*}{\partial \log z_l} - \lambda^* \frac{\partial \log \lambda^*}{\partial \log z_l} \frac{\partial \log f}{\partial \log q_i} - \lambda^* \sum_{j=1}^{N} \frac{\partial^2 f}{\partial \log q_i \partial \log q_j} \frac{\partial \log q_j^*}{?\partial \log z_l} - \lambda^* \frac{\partial^2 f}{\partial \log q_i \partial \log z_l} = 0$$

or, given $-p_i q_i \frac{\partial \lambda^*}{\partial \log z_l} = -\lambda^* \frac{\partial \log \lambda^*}{\partial \log z_l} \frac{\partial \log f}{\partial \log q_i}$:

$$p_i q_i^* \frac{\partial \log q_i^*}{\partial \log z_l} - p_i q_i \frac{\partial \lambda^*}{\partial \log z_l} - \lambda^* \sum_{j=1}^{N} \frac{\partial^2 f}{\partial \log q_i \partial \log q_j} \frac{\partial \log q_j^*}{?\partial \log z_l} - \lambda^* \frac{\partial^2 f}{\partial \log q_i \partial \log z_l} = 0$$

Laitinen and Theil (1978) shows that if all i, l pairs are be divided by C, then one can use $\gamma = \frac{\lambda}{C}$ and $h_i = \frac{p_i q_i}{C}$ to get the following expression:

$$(\mathbf{F} - \gamma \mathbf{H}) \frac{\partial \log \mathbf{q}^* (\mathbf{z}, \mathbf{p})}{\partial \log \mathbf{z}'} - \mathbf{F} \boldsymbol{\iota} \frac{\partial \log \lambda^* (\mathbf{z}, \mathbf{p})}{\partial \log \mathbf{z}'} = \gamma \mathbf{H}$$

where $\mathbf{F} \equiv diag(h_i)$.

The f.o.c. evaluated at the optimum can be also differentiated with respect to p_j, for $i \neq j$, and q_i. The second-order partial derivative of the Lagrangian function evaluated at $\mathbf{q}^*$ and λ^* with respect to p_j, for $i \neq j$, divided by C is:

$$h_i \frac{\partial \log q_i^*}{\partial \log p_j} - h_i \frac{\partial \log \lambda^*}{\partial \log p_j} - \gamma \sum_{k=1}^{n} \frac{\partial^2 f}{\partial \log q_i \partial \log q_k} \frac{\partial \log q_k^*}{\partial \log p_j} = 0$$

with $i, j, k \in \{1, \ldots, N\}$. On the other hand, the partial derivative of the f.o.c. at $\mathbf{q}^*$ and λ^* with respect to $\log q_i$, divided by C is:

$$(\mathbf{F} - \gamma \mathbf{H}) \frac{\partial \log \mathbf{q}^* (\mathbf{z}, \mathbf{p})}{\partial \log \mathbf{p}'} - \mathbf{F} \boldsymbol{\iota} \frac{\partial \log \lambda^* (\mathbf{z}, \mathbf{p})}{\partial \log \mathbf{p}'} = -F$$

Now take the value function $f(\mathbf{q}^*(\mathbf{p}, \mathbf{z}), \mathbf{z})$ and differentiate it with respect to $\mathbf{p}$ and $\mathbf{q}$:

$$\begin{aligned} \frac{\partial f (\mathbf{q}^* (\mathbf{p}, \mathbf{z}), \mathbf{z})}{\partial \log \mathbf{z}'} = 0 \qquad &\Rightarrow \qquad \boldsymbol{\iota} \mathbf{F} \frac{\partial \log \mathbf{q}^*}{\partial \log \mathbf{z}'} = \gamma \mathbf{g}' \\ \frac{\partial f (\mathbf{q}^* (\mathbf{p}, \mathbf{z}), \mathbf{z})}{\partial \log \mathbf{p}'} = 0 \qquad &\Rightarrow \qquad \boldsymbol{\iota} \mathbf{F} \frac{\partial \log \mathbf{q}^*}{\partial \log \mathbf{p}'} = 0 \end{aligned}$$

where $\mathbf{g} = (g_1, \ldots, g_m)$.

These results can be put together to obtain the following system of equations:

$$\begin{cases} (\mathbf{F} - \gamma \mathbf{H}) \frac{\partial \log \mathbf{q}^* (\mathbf{z}, \mathbf{p})}{\partial \log \mathbf{z}'} - F \boldsymbol{\iota} \frac{\partial \log \lambda^* (\mathbf{z}, \mathbf{p})}{\partial \log \mathbf{z}'} = \gamma \mathbf{H} = \gamma \mathbf{H} \\ h_i \frac{\partial \log q_i^*}{\partial \log p_j} - h_i \frac{\partial \log \lambda^*}{\partial \log p_j} - \gamma \sum_{k=1}^{n} \frac{\partial^2 f}{\partial \log q_i \partial \log q_k} \frac{\partial \log q_k^*}{\partial \log p_j} = 0 \\ (\mathbf{F} - \gamma \mathbf{H}) \frac{\partial \log \mathbf{q}^* (\mathbf{z}, \mathbf{p})}{\partial \log \mathbf{p}'} - \mathbf{F} \boldsymbol{\iota} \frac{\partial \log \lambda^* (\mathbf{z}, \mathbf{p})}{\partial \log \mathbf{p}'} - \mathbf{F} \\ \boldsymbol{\iota} \mathbf{F} \frac{\partial \log \mathbf{q}^*}{\partial \log \mathbf{z}'} = \gamma \mathbf{g}' \\ \boldsymbol{\iota} F \frac{\partial \log \mathbf{q}^*}{\partial \log \mathbf{p}'} = 0 \end{cases}$$

which can be expressed in matrix notations as:

$$\begin{pmatrix} \mathbf{F}^{-1}\left(\mathbf{F}-\gamma\mathbf{H}\right)\mathbf{F}^{-1} & \boldsymbol{\iota} \\ \boldsymbol{\iota}' & 0 \end{pmatrix} \begin{pmatrix} \mathbf{F}\dfrac{\partial\log\mathbf{q}^*\left(\mathbf{z},\mathbf{p}\right)}{\partial\log\mathbf{z}'} & \dfrac{\partial\log\mathbf{q}^*\left(\mathbf{z},\mathbf{p}\right)}{\partial\log\mathbf{p}'} \\ -\dfrac{\partial\log\lambda^*}{\partial\log\mathbf{z}'} & -\dfrac{\partial\log\lambda^*}{\partial\log\mathbf{p}'} \end{pmatrix} = \begin{pmatrix} \gamma\mathbf{F}^{-1}\mathbf{H}^* & -\mathbf{I} \\ \gamma\mathbf{g}' & \mathbf{0} \end{pmatrix}$$

or

$$\mathbf{AB} = \mathbf{C}$$

Since $\mathbf{H}$ is assumed to be a symmetric and positive-definite matrix, $\mathbf{F}$ is a constant matrix and γ is a constant, then $\mathbf{A}$ is also symmetric and positive-definite. Define the inverse of $\mathbf{A}$ as:

$$\mathbf{A}^{-1} = \begin{pmatrix} \psi(\boldsymbol{\Theta}-\boldsymbol{\theta}\boldsymbol{\theta}^T) & \boldsymbol{\theta} \\ \boldsymbol{\theta}' & -\frac{1}{\psi} \end{pmatrix}$$

where:

$$\begin{aligned} &\psi = \boldsymbol{\iota}\mathbf{F}(\mathbf{F}-\gamma\mathbf{H})^{-1}\mathbf{F}\boldsymbol{\iota} > 0 && \text{is a scalar} \\ &\boldsymbol{\Theta} = \frac{1}{\psi}\mathbf{F}(\mathbf{F}-\gamma\mathbf{H})^{-1}\mathbf{F} && \text{is a vector} \\ &\boldsymbol{\theta} = \boldsymbol{\Theta}\boldsymbol{\iota} = \frac{1}{\psi}\mathbf{F}(\mathbf{F}-\gamma\mathbf{H})^{-1}\mathbf{F}\boldsymbol{\iota} && \text{is a scalar} \end{aligned}$$

If $\mathbf{A}$ is invertible, the system has a solution in:

$$\mathbf{B} = \mathbf{A}^{-1}\mathbf{C}$$

where

$$\mathbf{B} = \begin{pmatrix} \gamma\boldsymbol{\theta}\mathbf{g}' + \gamma\psi(\boldsymbol{\Theta}-\boldsymbol{\theta}\boldsymbol{\theta}')\mathbf{F}^{-1}\mathbf{H}^* & -\psi(\boldsymbol{\Theta}-\boldsymbol{\theta}\boldsymbol{\theta}') \\ \frac{\gamma}{\psi}\mathbf{g}' - \gamma\boldsymbol{\theta}' f^{-1}\mathbf{H}^* & \boldsymbol{\theta}' \end{pmatrix}$$

hence

$$\begin{pmatrix} \gamma\boldsymbol{\theta}\mathbf{g}' + \gamma\psi(\boldsymbol{\Theta}-\boldsymbol{\theta}\boldsymbol{\theta}')\mathbf{F}^{-1}\mathbf{H}^* & -\psi(\boldsymbol{\Theta}-\boldsymbol{\theta}\boldsymbol{\theta}') \\ \frac{\gamma}{\psi}\mathbf{g}' - \gamma\boldsymbol{\theta}' F^{-1}\mathbf{H}^* & \boldsymbol{\theta}' \end{pmatrix} = \begin{pmatrix} \mathbf{F}\frac{\partial\log\mathbf{q}^*}{\partial\log\mathbf{z}'} & \mathbf{F}\frac{\partial\log\mathbf{q}^*}{\partial\log\mathbf{p}'} \\ -\frac{\partial\log\lambda^*}{\partial\log\mathbf{z}'} & -\frac{\partial\log\lambda^*}{\partial\log\mathbf{p}'} \end{pmatrix}$$

Let now $\mathbf{q}^*$ be the demand of input for the multi-product firm, then the total differential (in logarithms) pre-multiplied by $\mathbf{F}$ is given by:

$$\mathbf{F}d\log\mathbf{q}^* = \mathbf{F}\frac{\partial\log\mathbf{q}^*}{\partial\log\mathbf{z}'}d\log\mathbf{z} + \mathbf{F}\frac{\partial\log\mathbf{q}^*}{\partial\log\mathbf{p}'}d\log\mathbf{p}$$

since $\mathbf{F}\frac{\partial \log \mathbf{q}^*}{\partial \log \mathbf{z}'} = \gamma\boldsymbol{\theta}\mathbf{g}' + \gamma\psi(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}')\mathbf{F}^{-1}\mathbf{H}^*$, $\mathbf{F}\frac{\partial \log \mathbf{q}^*}{\partial \log \mathbf{p}'} = -\psi(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}')$, $\mathbf{g}' = \boldsymbol{\iota}'\mathbf{G}$ and $\mathbf{G} \equiv diag(g_l)$ for $l = 1, \dots, M$, this expression becomes:

$$\mathbf{F}d\log\mathbf{q}^* = \gamma\left[\boldsymbol{\theta}'\boldsymbol{\iota}' + \gamma\psi\left(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}'\right)\mathbf{F}^{-1}\mathbf{H}^*\mathbf{G}^{-1}\right] d\log\mathbf{z} - \psi\left(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}'\right)] d\log\mathbf{p}$$

the i^{th} element of the vector $\mathbf{F}d\log\mathbf{q}^*$, $h_i d\log q_i^*$, represents the quantity component of the change in the i^{th} factor share h_i or, in other words, the change in the contribution of input i to total cost due to a change in the quantity of q_i. This can be verified by taking the differential of $h_i = \frac{p_i q_i}{C}$:

$$dh_i = h_i d\log p_i + h_i d\log q_i - h_i d\log C$$

Any change in h_i is therefore related to a change in either q_i, p_i or C.

Marginal share of the inputs: recall the definition of the Lagrange multiplier for the multi-product firm:

$$\lambda = \sum_{l=1}^{M} \frac{\partial C}{\partial z_l} z_l$$

which corresponds to

$$\lambda = \sum_{l=1}^{M} \frac{\partial C}{\partial \log z_l} = \sum_{i=1}^{N} \left[\sum_{l=1}^{M} \frac{\partial (p_i q_i^*)}{\partial \log z_l}\right]$$

If we multiply both sides by $\frac{1}{\lambda}$ and disaggregate across i we get:

$$\theta_i = \frac{1}{\lambda} \sum_{l=1}^{M} \frac{\partial (p_i q_i^*)}{\partial \log z_l}$$

where $\theta_i \in \boldsymbol{\theta}$ is the share of the i^{th} input in the total marginal cost. To see why this is the case, re-write the right-hand side as

$$\frac{1}{\lambda} \sum_{l=1}^{m} \frac{\partial (p_i q_i^*)}{\partial \log z_l} = \frac{C}{\lambda} \sum_{l=1}^{m} h_i \frac{\partial q_i^*}{\partial \log z_l} = \frac{1}{\gamma} \sum_{l=1}^{m} h_i \frac{\partial q_i^*}{\partial \log z_l} \in \gamma^{-1} F \frac{\partial \log \mathbf{q}^*}{\partial \log \mathbf{z}} \boldsymbol{\iota}$$

Since $\mathbf{F}\frac{\partial \log \mathbf{q}^*}{\partial \log \mathbf{z}'} = \gamma\boldsymbol{\theta}\mathbf{g}' + \gamma\psi(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}')\mathbf{F}^{-1}\mathbf{H}^*$, $\mathbf{g}'\boldsymbol{\iota} = 1$, $\mathbf{H}^*\boldsymbol{\iota} = \mathbf{0}$ and $\mathbf{H}^{**}\boldsymbol{\iota} = \mathbf{0}$ then

$$\left[\gamma\boldsymbol{\theta}\mathbf{g}' + \gamma\psi(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}')\mathbf{F}^{-1}\mathbf{H}^*\right] \boldsymbol{\iota} = \boldsymbol{\theta}$$

We may also define the share of the i^{th} input in the marginal cost of each individual output as:

$$\theta_i^l = \frac{\partial(p_iq_i^*)/\partial z_l}{\partial C/\partial z_l} \qquad \forall l = 1, \dots, M;\ i = 1, \dots, N$$

Such that $\sum_{l=1}^{M} g_l\theta_i^l = \theta_i$. To prove this note that, given the definitions of g_l and γ

$$\frac{\partial(p_iq_i^*)/\partial z_l}{\partial C/\partial z_l} = \frac{p_iq_i}{\partial C/\partial z_l}\frac{\partial \log q_i^*}{\partial \log z_l}\frac{1}{z_l} = \frac{Ch_i}{\lambda g_l}\frac{\partial \log q_i^*}{\partial \log z_l} = \frac{h_i}{\gamma g_l}\frac{\partial \log q_i^*}{\partial \log z_l}$$

The latter member of this expression is an element of the $(M \times N)$ matrix $\gamma^{-1}\mathbf{F}(\partial \log \mathbf{q}^*)/(\partial \log \mathbf{z})\mathbf{G}^{-1}$. Given that $\mathbf{F}\frac{\partial \log \mathbf{q}^*}{\partial \log \mathbf{z}'} = \gamma\boldsymbol{\theta}\mathbf{g}' + \gamma\psi(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}')\mathbf{F}^{-1}\mathbf{H}^*$ and $\mathbf{g}'G^{-1} = \boldsymbol{\iota}'$, then

$$\gamma^{-1}\left[\gamma\boldsymbol{\theta}\mathbf{g}' + \gamma\psi(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}')\mathbf{F}^{-1}\mathbf{H}^*\right]\mathbf{G}^{-1} = \psi(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}')F\mathbf{F}^{-1}\mathbf{H}^*\mathbf{G}^{-1}$$

where

$$\begin{aligned} &\psi(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}')\mathbf{F}^{-1}\mathbf{H}^*\mathbf{G}^{-1} = \left(\boldsymbol{\theta}^1 - \boldsymbol{\theta} \ \dots \ \boldsymbol{\theta}^m - \boldsymbol{\theta}\right) \\ &\boldsymbol{\theta}^l = (\theta_1^l \ \dots \ \theta_n^l) \end{aligned} \tag{B.5}$$

Now, the post-multiplication of this expression by $\mathbf{g}$ gives

$$\sum_{l=1}^{M} g_l\theta_i^l = \theta_i \qquad \forall l = 1, \dots, M;\ \forall i = 1, \dots, N$$

A first input demand specification: given the results obtained in the previous paragraph and recalling that

$$\mathbf{F}d\log \mathbf{q}^* = \gamma\left[\boldsymbol{\theta}'\boldsymbol{\iota}' + \gamma\psi\left(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}'\right)\mathbf{F}^{-1}\mathbf{H}^*\mathbf{G}^{-1}\right]d\log \mathbf{z} - \psi\left(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}'\right)]d\log \mathbf{p}$$

it is easy to see that

$$\left[\boldsymbol{\theta}'\boldsymbol{\iota}' + \gamma\psi\left(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}'\right)\mathbf{F}^{-1}\mathbf{H}^*G^{-1}\right] = \left(\boldsymbol{\theta}^1 \ \dots \ \boldsymbol{\theta}^m\right)$$

therefore:

$$h_i d\log q_i^* = \gamma\sum_{l=1}^{M}\theta_i^l g_l d\log z_l + \ \textit{price term}$$

where the price term is the i^{th} entry of $-\psi\left(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}'\right)d\log \mathbf{p}$. Since $\boldsymbol{\theta} = \boldsymbol{\Theta}\boldsymbol{\iota} = \psi^{-1}\mathbf{F}(\mathbf{F} - \gamma\mathbf{H}^{-1}\mathbf{F})\boldsymbol{\iota}$, then $(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}') = \boldsymbol{\Theta}\left(I - \boldsymbol{\iota}\boldsymbol{\theta}'\right)$ and the i^{th} entry of $-\psi\left(\boldsymbol{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}'\right)d\log \mathbf{p} = -\psi\boldsymbol{\Theta}\left(I - \boldsymbol{\iota}\boldsymbol{\theta}'\right)d\log \mathbf{p}$ is

$$-\psi\sum_{j=1}^{N}\theta_{i,j}\left[d\log p_j - d\log\sum_{i=1}^{N}\theta_i p_i\right]$$

or

$$-\psi \sum_{j=1}^{N} \theta_{i,j} \left[d \log p_j - d \log \tilde{P} \right]$$

where $\tilde{P}$ is the Fisher input price index and $j, i \in \{1, \ldots, N\}$. Therefore, the differential demand for the i^{th} input is given by:

$$\begin{aligned} h_i d \log q_i^* &= \gamma \sum_{l=1}^{M} \theta_i^l g_l d \log z_l - \psi \sum_{j=1}^{N} \theta_{i,j} \left[d \log p_j - d \log \tilde{P} \right] \\ &= \gamma \sum_{l=1}^{M} \theta_i^l g_l d \log z_l - \psi \sum_{j=1}^{N} \theta_{i,j} d \left[\log \frac{p_j}{\tilde{P}} \right] \end{aligned}$$

The coefficient $\theta_{i,j}$ is an element in the $(N \times N)$ symmetric positive definite matrix $\boldsymbol{\Theta}$, while $\psi\theta_{i,j}$ is the coefficient associated with the j^{th} relative price.

This expression describes the change in input's i demand in terms of a global output change and the change in own/cross-input prices corrected by the Fisher's price index. Moreover, given $\boldsymbol{\theta} = \boldsymbol{\Theta}\boldsymbol{\iota} = \psi^{-1}\mathbf{F}(\mathbf{F} - \gamma\mathbf{H}^{-1}\mathbf{F})\boldsymbol{\iota}$ and $\boldsymbol{\iota}'\boldsymbol{\theta} = 1$, the above demand satisfies

$$\sum_{j=1}^{N} \theta_{i,j} = \theta_i$$

$$\sum_{i=1}^{N} \sum_{j=1}^{N} \theta_{i,j} = 1$$

Input-output separability, input allocation decision and demand for inputs

Input-output separability: The assumption of input-output separability can be captured through the following notation:

$$f(\mathbf{q}, \mathbf{z}) = f_z(\mathbf{z}) - f_q(\mathbf{q}) = 0$$

This condition imposes an additional constraint on $\mathbf{H}^*$: Laitinen and Theil (1978) show that

$$F^{-1}H^* = \boldsymbol{\iota}\mathbf{a}'$$

where $\mathbf{a}'$ is an M-dimensional row tuple. This result implies that $\mathbf{F}^{-1}\mathbf{H}^*$ consists of identical rows if input-output separability holds.

Input-output separability has an implication on the parameters θ_i^l, i.e. the contributions of the i^{th} input to the marginal cost of the l^{th} output. In fact, the marginal share of each input is the same across outputs, namely:

$$\theta_i^l = \theta_i$$

for each pair (i, l). To verify this, recall the expression $\psi(\mathbf{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}')\mathbf{F}^{-1}\mathbf{H}^*\mathbf{G}^{-1}$; given $\mathbf{F}^{-1}\mathbf{H}^* = \boldsymbol{\iota}\mathbf{a}'$, then

$$\psi(\mathbf{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}')\mathbf{F}^{-1}\mathbf{H}^*\mathbf{G}^{-1} = \psi(\mathbf{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}')\boldsymbol{\iota}\mathbf{a}'$$

Since $\boldsymbol{\theta} = \mathbf{\Theta}\boldsymbol{\iota} = \frac{1}{\psi}\mathbf{F}(\mathbf{F} - \gamma\mathbf{H})^{-1}\mathbf{F}\boldsymbol{\iota}$ and $\boldsymbol{\theta}'\boldsymbol{\iota} = 1$, then

$$(\mathbf{\Theta} - \boldsymbol{\theta}\boldsymbol{\theta}')\boldsymbol{\iota} = 0$$

In light of (B.5), it is easily seen that

$$\big(\boldsymbol{\theta}^1 - \boldsymbol{\theta} \ ... \ \boldsymbol{\theta}^M - \boldsymbol{\theta}\big) = \mathbf{0}$$

which implies $\theta_i^l = \theta_i$ and

$$\sum_{i=1}^{n} \theta_i^l = 1$$

Input allocation decision: The separation of input allocation decision from the total-input decision adds more structure to the differential demand equation and provides additional information. In order to specify the model accordingly, we first need to define the Divisia volume index for the inputs

$$d\log Q = \sum_{i=1}^{N} h_i d\log q_i^* = F d\log \mathbf{q}^*$$

It is easy to see that $h_i d\log q_i^*$ is the contribution of the i^{th} input to this index. Therefore

$$\sum_{i=1}^{N} [h_i d\log q_i^*] = \sum_{i=1}^{N} \left[\gamma \sum_{l=1}^{M} \theta_i^l g_l d\log z_l - \psi \sum_{j=1}^{N} \theta_{i,j} d\left(\log \frac{p_j}{\tilde{P}}\right)\right]$$

corresponds to

$$d\log Q = \gamma \sum_{i=1}^{N}\sum_{l=1}^{M} \theta_i^l g_l d\log z_l - \psi \sum_{i=1}^{N}\sum_{j=1}^{M} \theta_{i,j} d\left(\log \frac{p_j}{\tilde{P}}\right)$$

since $\sum_{l=1}^{M} g_l\theta_i^l = \theta_i$, $\forall l = 1, \ldots, M$, $\sum_{i=1}^{N} \theta_i = 1$ and $\sum_{i=1}^{N}\sum_{j=1}^{M} \theta_{i,j} = 1$, then

$$d\log Q = \gamma \sum_{l=1}^{M} d\log z_l - \psi \sum_{j=1}^{M} d\left(\log \frac{p_j}{\tilde{P}}\right)$$

where $\sum_{l=1}^{M} d\log z_l = d\log Z$ is the Divisia volume index of the output and $\sum_{j=1}^{M} d\left(\log p_j/\tilde{P}\right) = 0$. Therefore:

$$d\log Q = \gamma d\log Z$$

Note that, if we assumed input-output separability, $\sum_{i=1}^{N} \theta_i^l = 1$ and $\sum_{i=1}^{N}\sum_{j=1}^{M} \theta_{i,j} = 1$ would have been sufficient.

The above expression indicates that the total input decision is proportional to the Divisia volume index of the output by a factor γ. Therefore, input prices play no role in determining the total input decision.

Demand for inputs: the pre-multiplication of $d\log Q = \gamma d\log Z$ by θ_i gives the following expression:

$$\theta_i \sum_{i=1}^{N} h_i d\log q_i^* = \theta_i\gamma \sum_{l=1}^{M} g_l d\log z_l \qquad \Longleftrightarrow \qquad \theta_i d\log Q = \theta_i\gamma d\log Z \tag{B.6}$$

Substituting equation (B.6) into $h_i d\log q_i^* = \gamma \sum_{l=1}^{M} \theta_i^l g_l d\log z_l - \psi \sum_{j=1}^{N} \theta_{i,j} d\left[\log\ p_j/\tilde{P}\right]$ and re-arranging produces

$$h_i d\log q_i^* = \theta_i d\log Q + \gamma\Psi_i - \psi \sum_{j=1}^{N} \theta_{i,j} d\left[\log\ p_j/\tilde{P}\right]$$

where $\Psi_i = \gamma \sum_{l=1}^{M} g_l \left(\theta_i^l - \theta_i\right) d\log z_l$. Since $d\log Z = \sum_{l=1}^{M} g_l d\log z_l$ and $\theta_i = \sum_{l=1}^{M} g_l\theta_i^l$, $d\log Z$ and θ_i can be interpreted as weighted averages of $\log z_l$ and θ_i^l respectively. It follows that an alternative way to specify this term is

$$\Psi_i = \sum_{l=1}^{M} g_l \left(\theta_i^l - \theta_i\right)\left(d\log z_l - d\log Z\right)$$

Therefore, Ψ_i is interpreted as the sample covariance between the amount of output l and the contribution of input i to the marginal cost of that particular output. The reason to include Ψ_i in the equation is quite straightforward: a change in the l^{th} output determines an increase in the demand for input i in excess of $\theta_i d \log Q$ when the change in output is positively correlated with marginal share of the input (i.e., when $d \log z_l$ and θ_i^l are positively correlated). Note that, if we assumed input-output separability, the term $\gamma \sum_{l=1}^{M} g_l \left(\theta_i^l - \theta_i\right) d \log z_l$ would disappear because $\theta_i^l = \theta_i$; therefore, under such assumption:

$$h_i d \log q_i^* = \theta_i d \log Q - \psi \sum_{j=1}^{N} \theta_{i,j} d \left[\log \ p_j / \tilde{P}\right]$$

This implies that the input allocation decision is independent of the change in output.

Appendix C

Let $\boldsymbol{\Omega}$ be the $NT \times NT$ variance-covariance matrix of the $NT \times 1$ stacked random vector $\boldsymbol{\varepsilon}$ such that $E\left[\boldsymbol{\varepsilon}\boldsymbol{\varepsilon}^T \middle| \mathbf{X}\right] = \boldsymbol{\Omega}$, where $\mathbf{X}$ is a $NT \times NT$ block-diagonal matrix with typical block $(\boldsymbol{\Delta}\mathbf{Q}, \boldsymbol{\Delta}\mathbf{p}_1, \boldsymbol{\Delta}\mathbf{p}_2, \boldsymbol{\Delta}\mathbf{p}_3, \boldsymbol{\Delta}\mathbf{p}_4)$ and $\boldsymbol{\Delta}\mathbf{p}_j = (\Delta p_{j1}, \ldots, \Delta p_{jT})$. Below, we specify $\boldsymbol{\Omega}$ in order to account for (within-equation) autocorrelation and contemporaneous correlation between equations. Consistently with Parks (1967), Greene (2003) and Wooldridge (2010), define the $N \times N$ matrix of contemporaneous correlations as $\boldsymbol{\Sigma} = \{\sigma_{ij}\}$ and indicate with $\mathbf{P}_j$ the $T \times T$ matrix

$$\mathbf{P}_j = \begin{pmatrix} (1-\rho_j\rho_j)^{-1/2} & 0 & 0 & \ldots & 0 \\ \rho_j(1-\rho_j\rho_j)^{-1/2} & 1 & 0 & \ldots & 0 \\ \rho_j^2(1-\rho_j\rho_j)^{-1/2} & \rho_j & 1 & \ldots & 0 \\ \vdots & \vdots & & \ddots & \vdots \\ \rho_j^{T-1}(1-\rho_j\rho_j)^{-1/2} & \rho_j^{T-2} & \rho_j^{T-3} & \ldots & 1 \end{pmatrix}$$

where ρ_j is the autoregressive coefficient of the typical equation $\varepsilon_{jt} = \rho_j \varepsilon_{jt-1} + u_{jt}$ with $|\rho_j| < 1$. A system-variance-covariance matrix embodying autocorrelation and between-eqation contemporaneous correlation can be then specified as $\mathbf{P}\left(\boldsymbol{\Sigma} \otimes \mathbf{I_T}\right)\mathbf{P}'$, where $\mathbf{I_T}$ is a $T \times T$ identity matrix and $\mathbf{P}$ is a $NT \times NT$ block-diagonal matrix with typical block $\mathbf{P}_j$ for all $j \in \{1, \ldots, N\}$. Using first-stage system-OLS residuals of (3.6) we estimate each component inside $\boldsymbol{\Omega}$. In particular, let $\hat{\boldsymbol{\varepsilon}} := \mathbf{y} - \mathbf{X}\hat{\boldsymbol{\Pi}}_{OLS}$, where $\mathbf{y} = (\bar{h}_{11}\Delta q_{11}, \ldots, \bar{h}_{NT}\Delta q_{NT})$, $\hat{\boldsymbol{\Pi}} = (\theta_1, \ldots, \theta_N, \hat{\boldsymbol{\pi}}_1, \ldots, \hat{\boldsymbol{\pi}}_N)$ and $\hat{\boldsymbol{\pi}}_j = (\hat{\pi}_{j1}, \ldots, \hat{\pi}_{jN})$; then $\hat{\rho}_j$ are obtained from the regression of $\hat{\varepsilon}_{jt}$ on $\hat{\varepsilon}_{jt-1}$ for all $j \in \{1, \ldots, N\}$. Similarly, each component of the $\boldsymbol{\Sigma}$ matrix is computed as $\hat{\sigma}_{ij} := T^{-1}\sum_{i=1}^{N}\sum_{j=1}^{N}\hat{u}_{it}\hat{u}_{jt}$ for all $i, j \in \{1, \ldots, N\}$ with $\hat{u}_{jt} = \hat{\varepsilon}_{it} - \hat{\rho}\hat{\varepsilon}_{it-1}$. The estimated variance-covariance matrix $\hat{\boldsymbol{\Omega}}$ is used to estimate model (3.6) by FGLS and compute $\hat{\hat{\boldsymbol{\varepsilon}}} = \mathbf{y} - \mathbf{X}\hat{\boldsymbol{\Pi}}_{FGLS}$, $\hat{\hat{\rho}}$, $\hat{\hat{\sigma}}_{ij}$ and, finally, $\hat{\hat{\boldsymbol{\Omega}}}$. The process is repeated until $\hat{\boldsymbol{\Pi}}_{FGLS}$ converges.

Appendix D

We introduce the general SVAR methodology starting with the classical matrix representation of a dynamic simultaneous equation model [8]

$$\boldsymbol{\Gamma}\mathbf{y}_t = \mathbf{A}(L)\mathbf{y}_t + \boldsymbol{\varepsilon}_t \tag{D.1}$$

where $\mathbf{y}_t$ is a $K \times 1$ vector of time series, $\boldsymbol{\Gamma}$ represents a $K \times K$ invertible matrix of coefficients such that

$$\boldsymbol{\Gamma} \equiv \begin{pmatrix} \gamma_{11} & \gamma_{12} & \cdots & \gamma_{1K} \\ \gamma_{21} & \gamma_{22} & \cdots & \gamma_{2K} \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_{K1} & \gamma_{K2} & \cdots & \gamma_{KK} \end{pmatrix}$$

and $\mathbf{A}(L)$ denotes a matrix of polynomials in the lag operator L

$$\mathbf{A}(L) \equiv \begin{pmatrix} A(L)_{11} & A(L)_{12} & \dots & A(L)_{1K} \\ A(L)_{12} & A(L)_{22} & \dots & A(L)_{2K} \\ \vdots & \vdots & \ddots & \vdots \\ A(L)_{1K} & A(L)_{2K} & \dots & A(L)_{KK} \end{pmatrix}$$

Last, $\boldsymbol{\varepsilon}_t$ indicates a $K \times 1$ random vector of structural innovation defined as $\boldsymbol{\varepsilon}_t \sim (\mathbf{0}, \boldsymbol{\Sigma}_\varepsilon)$, where

$$\boldsymbol{\Sigma}_\varepsilon = \begin{pmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1K} \\ \sigma_{21} & \sigma_{22} & \cdots & \sigma_{2K} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{1K} & \sigma_{2K} & \cdots & \sigma_{KK} \end{pmatrix}.$$

and each σ_{ii} denotes the variance of the i^{th} innovation and σ_{ij} is the respective covariance. We can now expand model (D.1) to have a more clear representation of

---

[8] If we extracted the k^{th} equation from (D.1) we would obtain the following expression

$$\sum_{i=1}^{K} \gamma_{i1} y_{it} = \sum_{i=1}^{K} A(L)_{i1} y_{it} + \varepsilon_{1t}$$

the contemporaneous and/or pre-determined relationship between the variables included in $\mathbf{y}_t$

$$\begin{pmatrix} \gamma_{11} & \gamma_{12} & \dots & \gamma_{1K} \\ \gamma_{21} & \gamma_{22} & \dots & \gamma_{2K} \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_{K1} & \gamma_{K2} & \dots & \gamma_{KK} \end{pmatrix} \begin{pmatrix} y_{1t} \\ y_{2t} \\ \vdots \\ y_{Kt} \end{pmatrix} = \begin{pmatrix} A(L)_{11} & A(L)_{12} & \dots & A(L)_{1K} \\ A(L)_{12} & A(L)_{22} & \dots & A(L)_{2K} \\ \vdots & \vdots & \ddots & \vdots \\ A(L)_{1K} & A(L)_{2K} & \dots & A(L)_{KK} \end{pmatrix} \begin{pmatrix} y_{1t} \\ y_{2t} \\ \vdots \\ y_{Kt} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \vdots \\ \varepsilon_{Kt} \end{pmatrix}$$

The SVAR analysis begins by specifying the reduced from of equation (D.1); since $\mathbf{\Gamma}$ is invertible, model (D.1) can be re-written as

$$\mathbf{y}_t = \mathbf{\Gamma}^{-1}\mathbf{A}(L)\mathbf{y}_t + \mathbf{\Gamma}^{-1}\boldsymbol{\varepsilon}_t$$

or

$$\mathbf{y}_t = \mathbf{A}^*(L)\mathbf{y}_t + \boldsymbol{e}_t \tag{D.2}$$

which represents the VAR reduced form of the original SVAR specification. The variance-covariance matrix of the reduced-form innovation vector $\mathbf{e}_t$ is expressed as $\mathbf{\Sigma}_e = \mathbf{\Gamma}^{-1}\mathbf{\Sigma}_\varepsilon\mathbf{\Gamma}^{-1'}$. Model (D.2) can be estimated in a straightforward way in order to obtain reduced form parameters. Next, a useful Moving Average (MA) re-parametrization of equation (D.1) is obtained using the Wold's decomposition theorem: the endogenous variables in $\mathbf{y}_t$ are expressed as function of current and past reduced form innovations

$$\mathbf{y}_t = \mathbf{\Phi}(L)\mathbf{e}_t \tag{D.3}$$

where $\mathbf{\Phi}(L) \equiv (\mathbf{I}_K - \mathbf{A}^*(L)^{-1})$. For example, take $\mathbf{y}_t = (y_{1t}, y_{2t})'$ and $\mathbf{e}_t = (e_{1t}, e_{2t})'$, then equation (D.3) can be represented in full matrix notation as

$$\begin{pmatrix} y_{1t} \\ y_{2t} \end{pmatrix} = \begin{pmatrix} \Phi(0)_{11} & \Phi(0)_{12} \\ \Phi(0)_{21} & \Phi(0)_{22} \end{pmatrix} \begin{pmatrix} e_{1t} \\ e_{2t} \end{pmatrix} + \begin{pmatrix} \Phi(1)_{11} & \Phi(1)_{12} \\ \Phi(1)_{21} & \Phi(1)_{22} \end{pmatrix} \begin{pmatrix} e_{1t-1} \\ e_{2t-1} \end{pmatrix} + \\ + \begin{pmatrix} \Phi(2)_{11} & \Phi(2)_{12} \\ \Phi(2)_{21} & \Phi(2)_{22} \end{pmatrix} \begin{pmatrix} e_{1t-2} \\ e_{2t-2} \end{pmatrix} + \dots$$

and each term $\Phi(h)_{ik}$, with $i, k \in \{1, \dots, K\}$, can be interpreted as the partial derivative $\partial y_{t+h}/\partial e_{i,t}$ or, in other words, the response of output i at time $t + h$ to a unit innovation in the reducer form disturbance term e_i occurred in period t, holding all other innovations constant. Based on specification (D.3), we can construct **impulse response functions** (IRF) which represent the aggregate plot of $\Phi(h)_{ik}$ against t (i.e. the response of output in time to a unit change in the reduced form innovation term).

Although model (D.2) can be always estimated, at this stage IRFs have no economic interpretation because they provide responses to shocks in reduced for innovations. In order to come up with economically meaningful IRFs, one shall re-arrange equation (D.3) by pre-multiplying $\boldsymbol{e}_t$ with a $K \times K$ identity matrix:

$$\mathbf{y}_t = \boldsymbol{\Phi}(L)\mathbf{I}_K\boldsymbol{e}_t = \boldsymbol{\Phi}(L)\boldsymbol{\Gamma}^{-1}\boldsymbol{\Gamma}\boldsymbol{e}_t = \boldsymbol{\Phi}^*(L)\boldsymbol{\varepsilon}_t \tag{D.4}$$

where $\boldsymbol{\Phi}^*(L) \equiv \boldsymbol{\Phi}(L)\boldsymbol{\Gamma}^{-1}$ and $\boldsymbol{\varepsilon}_t = \boldsymbol{\Gamma}\mathbf{e}_t$. It follows that the interpretation of the coefficients inside $\boldsymbol{\Gamma}$ is different in SVAR models: whereas in the classical dynamic simultaneous equation setup $\boldsymbol{\Gamma}$ models the contemporaneous relationships between endogenous variables, in a SVAR framework it models the contemporaneous relationships between reduced form innovations.

However, structural coefficients in $\boldsymbol{\Gamma}$ need to be known in order to compute $\boldsymbol{\Phi}^*(L)$; as it happens in dynamic simultaneous equation systems, this poses an identification problem.

Identification

Whereas the identification of structural parameters in the traditional dynamic simultaneous equation framework is mainly achieved through non-sample information (i.e. theoretical exclusion restrictions in $\boldsymbol{\Gamma}$), SVAR models are identified by imposing restrictions both on the structural variance-covariance matrix $\boldsymbol{\Sigma}_\varepsilon$ and inverse of the coefficient matrix $\boldsymbol{\Gamma}$. The restrictions imposed to $\boldsymbol{\Sigma}_\varepsilon$ are standard, while those in $\boldsymbol{\Gamma}^{-1}$ are based on non-sample information and diminish the contemporaneous relationship among shocks.

The first type of restrictions are known as *orthogonality restrictions*: the identification strategy of SVAR begins with the assumption of uncorrelation among structural innovations. Formally, this translates into the following expression:

$$\mathbf{\Sigma}_{\varepsilon} = \begin{pmatrix} \sigma_{11} & 0 & \dots & 0 \\ 0 & \sigma_{22} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \sigma_{KK} \end{pmatrix}$$

Since reduced form innovation terms are linked to the structural ones through $\mathbf{\Gamma}\mathbf{\Sigma}_e\mathbf{\Gamma}' = \mathbf{\Sigma}_{\varepsilon}$, the orthogonality restriction on $\mathbf{\Sigma}_{\varepsilon}$ provide non-linear restrictions on the coefficient matrix $\mathbf{\Gamma}$. The intuition behind orthogonality is effectively provided by Bernanke (1986) who describes structural innovations as exogenous signals impacting the system and causing shocks. As these shocks do not have common causes, they can be treated as if they were uncorrelated[9]. In the classical dynamic simultaneous equation setup, structural innovations play a conceptually different role: they represent error terms thus lack of any economic interpretation. For this reason $\mathbf{\Sigma}_{\varepsilon}$ is typically left unrestricted when identification is aimed at estimating static/dynamic multipliers.

The second stage in the SVAR identification strategy is *normalization* since IRFs are usually aimed as showing responses of $\mathbf{y}_t$ to one standard deviation shock in the structural innovations, $\sigma_{\varepsilon,ii}$ are set equal to one. Therefore, the structural innovations' variance-covariance matrix becomes a K-dimensional identity matrix which poses further restrictions on $\mathbf{\Gamma}$. When $\mathbf{\Sigma}_{\varepsilon} = \mathbf{I}_K$ then $\mathbf{\Sigma}_e = \mathbf{\Gamma}^{-1}\mathbf{\Sigma}_{\varepsilon}\mathbf{\Gamma}^{-1'} = \mathbf{\Gamma}^{-1}\mathbf{\Gamma}^{-1'}$; we can think of $\mathbf{\Sigma}_e = \mathbf{\Gamma}^{-1}\mathbf{\Gamma}^{-1'}$ as a system of nonlinear equations in the unknown parameters of $\mathbf{\Gamma}^{-1}$. Since $\mathbf{\Sigma}_e$ has $K(K+1)/2$ elements estimated along with reduced form parameters in model (D.2) and $\mathbf{\Gamma}^{-1}$ has K^2 elements, we need $K^2 - K(K+1)/2 = K(K-1)/2$ additional restrictions on $\mathbf{\Gamma}^{-1}$ to achieve identification.

Given the idea that reduced form innovations are linear functions of contemporaneous structural form innovations though $\mathbf{e}_t = \mathbf{\Gamma}^{-1}\boldsymbol{\varepsilon}_t$, one can choose to set the remaining $K(K-1)/2$ restrictions to relate $\boldsymbol{\varepsilon}_t$ and $\mathbf{e}_t$ in a convenient and theoretically grounded way. In other words, when exclusion restrictions on the structural parameters are imposed,

---

[9] Naturally, this assumption is far from being without critiques, see Gottschalk (2001) for a synthetic discussion.

one should figure out which structural shocks could affect the variable of interest at time t. For example, in the 2×2 case one needs $2(2-1)/2 = 1$ exclusion restriction on $\mathbf{\Gamma}^{-1}$ to achieve identification; if the structural parameter $\gamma_{12} \in \mathbf{\Gamma}^{-1}$ is set equal to zero, then we implicitly assume that y_1 does not react to a standard deviation innovation in y_2 at time t. This is easily verified by writing model (D.4) in full matrix notation:

$$\begin{pmatrix} y_{1t} \\ y_{2t} \end{pmatrix} = \begin{pmatrix} \Phi(0)_{11} & \Phi(0)_{12} \\ \Phi(0)_{21} & \Phi(0)_{22} \end{pmatrix} \begin{pmatrix} \gamma_{11} & 0 \\ \gamma_{21} & \gamma_{22} \end{pmatrix} \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix} + \begin{pmatrix} \Phi(1)_{11} & \Phi(1)_{12} \\ \Phi(1)_{21} & \Phi(1)_{22} \end{pmatrix} \begin{pmatrix} \gamma_{11} & 0 \\ \gamma_{21} & \gamma_{22} \end{pmatrix}$$
$$\begin{pmatrix} \varepsilon_{1t-1} \\ \varepsilon_{2t-1} \end{pmatrix} \begin{pmatrix} \Phi(2)_{11} & \Phi(2)_{12} \\ \Phi(2)_{21} & \Phi(2)_{22} \end{pmatrix} \begin{pmatrix} \gamma_{11} & 0 \\ \gamma_{21} & \gamma_{22} \end{pmatrix} \begin{pmatrix} \varepsilon_{1t-2} \\ \varepsilon_{2t-2} \end{pmatrix} + \ldots$$

which is equivalent to

$$\begin{aligned} y_{1t} &= \left(\Phi(0)_{11}\gamma_{11} + \Phi(0)_{12}\gamma_{21}\right)\varepsilon_{1t} + \Phi(0)_{12}\gamma_{22}\varepsilon_{2t} + \left(\Phi(1)_{11}\gamma_{11} + \Phi(1)_{12}\gamma_{21}\right)\varepsilon_{1t-1} \\ &\quad + \Phi(1)_{12}\gamma_{22}\varepsilon_{2t-1} + \left(\Phi(2)_{11}\gamma_{11} + \Phi(2)_{12}\gamma_{21}\right)\varepsilon_{1t-2} + \Phi(2)_{12}\gamma_{22}\varepsilon_{2t-2} + \ldots \\ &= \left(\Phi(0)^*_{11} + \Phi(0)^*_{12}\right)\varepsilon_{1t} + \Phi(0)^*_{12}\varepsilon_{2t} + \left(\Phi(1)^*_{11} + \Phi(1)^*_{12}\right)\varepsilon_{1t-1} + \Phi(1)^*_{12}\varepsilon_{2t-1} \\ &\quad + \left(\Phi(2)^*_{11} + \Phi(2)^*_{12}\right)\varepsilon_{1t-2} + \Phi(2)^*_{12}\varepsilon_{2t-2} + \ldots \\ y_{2t} &= \left(\Phi(0)_{21}\gamma_{11} + \Phi(0)_{22}\gamma_{21}\right)\varepsilon_{1t} + \Phi(0)_{12}\gamma_{22}\varepsilon_{2t} + \left(\Phi(1)_{21}\gamma_{11} + \Phi(1)_{22}\gamma_{21}\right)\varepsilon_{1t-1} \\ &\quad + \Phi(1)_{22}\gamma_{22}\varepsilon_{2t-1} + \left(\Phi(2)_{21}\gamma_{11} + \Phi(2)_{22}\gamma_{21}\right)\varepsilon_{1t-2} + \Phi(2)_{22}\gamma_{22}\varepsilon_{2t-2} + \ldots \\ &= \left(\Phi(0)^*_{21} + \Phi(0)^*_{22}\right)\varepsilon_{1t} + \Phi(0)^*_{22}\varepsilon_{2t} + \left(\Phi(1)^*_{21} + \Phi(1)^*_{22}\right)\varepsilon_{1t-1} + \Phi(1)^*_{22}\varepsilon_{2t-1} \\ &\quad + \left(\Phi(2)^*_{21} + \Phi(2)^*_{22}\right)\varepsilon_{1t-2} + \Phi(2)^*_{22}\varepsilon_{2t-2} + \ldots \end{aligned}$$

Note that

$$\mathbf{\Gamma} = \begin{pmatrix} 1 & 0 \\ \gamma^*_{21} & 1 \end{pmatrix} \qquad \text{and} \qquad \mathbf{\Gamma}^{-1} = \begin{pmatrix} \gamma_{11} & 0 \\ \gamma_{21} & \gamma_{22} \end{pmatrix}$$

are practically identical although the elements on the main diagonal differ because of a alternative normalization strategies. In fact, there exist other approaches to system identification; one consists of leaving the diagonal elements of $\mathbf{\Sigma}_\varepsilon$ unrestricted (i.e. $\mathbf{\Sigma}_\varepsilon \neq \mathbf{I}_K$) and set the diagonal elements of $\mathbf{\Gamma}$ to unity in $\boldsymbol{\varepsilon}_t = \mathbf{\Gamma}\mathbf{e}_t$. A very useful result in this context is that when $\mathbf{\Gamma}$ is lower triangular, $\mathbf{\Gamma}^{-1}$ is lower triangular as well; however, since the variance of the structural errors is no longer one, the estimated $\mathbf{\Gamma}^{-1}$ (recall that we can only estimate $\mathbf{\Gamma}^{-1}$ through $\mathbf{\Sigma}_e = \mathbf{\Gamma}^{-1}\mathbf{\Gamma}^{-1\prime}$) must be re-scaled by one (residual) standard deviation to make sure that the structural IRFs represent responses to one-standard deviation shocks in $\boldsymbol{\varepsilon}_t$.

To sum up, exclusion restrictions on $\mathbf{\Gamma}$ or $\mathbf{\Gamma}^{-1}$ are imposed in order to trace out the dynamic responses of the model to structural innovations. Gottschalk (2001) refers to this way of interpreting restrictions as "shock view" of SVAR models: given equation (D.1) and $\mathbf{\Sigma}_\varepsilon = \mathbf{I}_K$, the author shows that subtracting $E\left[\mathbf{y}_t | \mathfrak{I}_{t-1}\right]$ to both sides of model (D.1), where $\mathfrak{I}_{t-1}$ is the information available at time $t-1$, yields to the relationship $\boldsymbol{\varepsilon}_t = \mathbf{\Gamma}\mathbf{e}_t$. In this case, the SVAR presented in equation (D.1) only models the unexpected changes in $\mathbf{y}_t$.

SVAR modelling under non-stationarity and cointegration

Assume that the vector $\mathbf{y}_t$ consists of K non-cointegrated $I(1)$ processes. In this case $\Delta\mathbf{y}_t = (\Delta y_{1t}, \ldots, \Delta y_{Kt})$ is $I(0)$ and equation (D.1) has the form

$$\mathbf{\Gamma}\Delta\mathbf{y}_t = \mathbf{A}(L)\mathbf{y}_t + \boldsymbol{\varepsilon_t} \tag{D.5}$$

with $\boldsymbol{\varepsilon_t} \sim WN\left(\mathbf{0}, \mathbf{I}_K\right)$. Similarly, when $\mathbf{y}_t$ is a mixture of j non-cointegrated $I(1)$ processes and $K-j$ $I(0)$ series, $\Delta\mathbf{y}_t$ contains both variables in first differences and variables in levels, namely: $\Delta\mathbf{y}_t = (\Delta y_{1t}, \ldots, \Delta y_{K-jt}, y_{K-j+1t}, \ldots, y_{Kt})$ (see Blanchard and Quah (1988)). It follows that the reduced form of (D.5) becomes

$$\begin{aligned}\Delta\mathbf{y}_t &= \mathbf{\Gamma}^{-1}\mathbf{A}(L)\Delta\mathbf{y}_t + \mathbf{\Gamma}^{-1}\boldsymbol{\varepsilon_t} \\ &= \mathbf{A}^*(L)\Delta\mathbf{y}_t + \mathbf{e}_t\end{aligned}$$

Therefore, identification and structural IRFs estimation are tackled as in ordinary SVAR modelling.

Suppose now that the vector $\mathbf{y}_t$ consists of K cointegrated $I(1)$ processes such that $\mathbf{y}_t \sim CI\left(1, b\right)$ and the linear combination $\mathbf{z}_t = \boldsymbol{\beta}\mathbf{y}_t$ is $I(1-b)$ (in most cases $\mathbf{y}_t \sim CI(1,1)$). Following Engle and Granger (1987) if $\mathbf{y}_t \sim CI\left(1, b\right)$, then there must exist a *vector error correction model* (VECM) representation of the dynamic system governing the joint behaviour of each $y_{it} \in \mathbf{y}_t$; the VECM has the following form:

$$\Delta \mathbf{y}_t = \boldsymbol{\alpha}\boldsymbol{\beta}' \mathbf{y}_{t-1} + \boldsymbol{\Theta}_1 \Delta \mathbf{y}_{t-1} + \boldsymbol{\Theta}_2 \Delta \mathbf{y}_{t-2} + \ldots + \boldsymbol{\Theta}_{p-1} \Delta \mathbf{y}_{t-p+1} + \mathbf{e}_t \tag{D.6}$$

Even through equation (D.6) does not include any assumption from theory, it can be however interpreted as the reduced form of a structural VEC model (SVEC). A general specification of a SVEC without deterministic trends and exogenous variables can be represented by the following expression:

$$\boldsymbol{\Gamma} \Delta \mathbf{y}_t = \boldsymbol{\Pi}^* \mathbf{y}_{t-1} + \boldsymbol{\Theta}_1^* \Delta \mathbf{y}_{t-1} + \boldsymbol{\Theta}_2^* \Delta \mathbf{y}_{t-2} + \ldots + \boldsymbol{\Theta}_{p-1}^* \Delta \mathbf{y}_{t-p+1} + \boldsymbol{\varepsilon}_t \tag{D.7}$$

where $\boldsymbol{\Pi}^* = \boldsymbol{\Gamma}\boldsymbol{\alpha}\boldsymbol{\beta}'$, $\boldsymbol{\Theta}_t^* = \boldsymbol{\Gamma}\boldsymbol{\Theta}_t$ and $\boldsymbol{\varepsilon}_t = \boldsymbol{\Gamma}\mathbf{e}_t$. It follows that the interpretation of the parameters in $\boldsymbol{\Gamma}$ does not change when non-stationarity is included in SVAR models; therefore, in order to identify structural from parameters, non-sample restrictions shall again be imposed to $\boldsymbol{\Gamma}$. Obviously, parameters' matrices in the reduced form equation (D.6) are defined as $\boldsymbol{\alpha}\boldsymbol{\beta}' = \boldsymbol{\Gamma}^{-1}\boldsymbol{\Pi}^*$, $\boldsymbol{\Theta}_t = \boldsymbol{\Gamma}^{-1}\boldsymbol{\Theta}_t^*$. The vector process in (D.7) has also an MA representation named after Beveridge and Nelson (1981)

$$\mathbf{y}_t = \boldsymbol{\Xi} \sum_{i=1}^{T} \mathbf{e}_i + \sum_{j=0}^{\infty} \boldsymbol{\Xi}^* \mathbf{e}_{t-j} + \mathbf{y}_0^* \tag{D.8}$$

where $\boldsymbol{\Xi} \sum_{i=1}^{T} \mathbf{e}_i$ is an $I(1)$ process reflecting the long-run effects of the reduced form innovation on $\mathbf{y}_t$ (common trend term), while $\sum_{j=0}^{\infty} \boldsymbol{\Xi}^* \mathbf{e}_{t-j}$ is an $I(0)$ process representing the short-run effects (transitory effects) of reduced form innovations because they fade out as $j \to \infty$. Note that $\boldsymbol{\Xi}^*$ need to be absolutely summable for the infinite sum to be defined ($\sum_{j=0}^{\infty} \boldsymbol{\Xi}^* \mathbf{e}_{t-j} \to 0$ as $j \to \infty$). The matrix $\boldsymbol{\Xi}$ has rank $K - r$, where r is the amount of transitory effects and $K - r$ is the number of common trends; r is typically determined through the popular testing procedures proposed by Johansen (1995).

Identification of SVEC models is slightly different from what is typically applied in a SVAR framework (Lütkepohl, 2006); however, the focus is once again on the relationship between reduced form and structural innovations $\boldsymbol{\varepsilon}_t = \boldsymbol{\Gamma}\mathbf{e}_t$ or

$$\boldsymbol{\Gamma}^{-1} \boldsymbol{\varepsilon}_t = \mathbf{e}_t. \tag{D.9}$$

Plugging (D.9) into (D.8) leads to the structural counterpart of the Beveridge and Nelson (1981) representation

$$\mathbf{y}_t = \mathbf{\Lambda} \sum_{i=1}^{T} \boldsymbol{\varepsilon}_i + \sum_{j=0}^{\infty} \mathbf{\Lambda}^* \boldsymbol{\varepsilon}_{t-j} + \mathbf{y}_0^* \tag{D.10}$$

where $\mathbf{\Lambda} = \mathbf{\Xi}\mathbf{\Gamma}^{-1}$ and $\mathbf{\Lambda}^* = \mathbf{\Xi}^*\mathbf{\Gamma}^{-1}$ [10]. Therefore, the long-run effects of structural innovations are given by $\mathbf{\Lambda}$. The number of transitory effects (r) translates into r columns of $\mathbf{\Lambda}$ being set to zero; this implies that r structural innovation do not play any contemporaneous effect on $\mathbf{y}_t$ in the long run (i.e. r structural innovations only have transitory effects), while $r(K-r)$ must have long-run (permanent) effects. Overall, just-identification still requires $K(K-1)/2$ parameter restrictions. It is reasoned from the Beveridge and Nelson (1981) representation that if $r(K-r)$ shocks exert permanent effects and only r are transitory, then $r(K-r)$ restrictions can be imposed according to the cointegration structure of the model. Therefore, $[K(K-1)/2] - [r(K-r)] = C$ further parameters shall be properly excluded to identify structural parameters and estimate structural IRFs. In fact, $r(r-1)/2$ restrictions out of C must be placed on $\mathbf{\Gamma}^{-1}$ to disentangle transitory innovation shocks, while the remaining $r(K-r)\left[r(K-r)-1\right]/2$ serve to identify permanent shocks and shall be introduced in $\mathbf{\Lambda}$ (King et al., 1987; Gonzalo and Ng, 2001; Lütkepohl, 2006).

Variance decomposition

Consider the Wold representation of an identified SVAR model

$$\mathbf{y}_t = \mathbf{\Phi}^*(L)\boldsymbol{\varepsilon}_t$$

The variance of the i^{th} entry of the random vector $\mathbf{y}_t$ is given by the following expression

$$\begin{aligned} \text{var}(y_{it}) &= \sum_{k=1}^{K} \sum_{h=0}^{\infty} \Phi_{ik}^*(h)^2 \text{var}(\varepsilon_{kt}) \\ &= \sum_{k=1}^{K} \sum_{h=0}^{\infty} \Phi_{ik}^*(h)^2 \end{aligned}$$

---

[10] note that specification (D.10) is analogous to (D.4) with the exception of $\mathbf{\Lambda}\sum_{i=1}^{T} \boldsymbol{\varepsilon}_i$; whereas in (D.4) we only care about shot-run contemporaneous relationships, when we have $\mathbf{y}_t \sim C(1, b)$ we also need the account for a long-run component.

because $\mathrm{var}(\varepsilon_{kt}) = 1$. Obviously, $\sum_{h=0}^{\infty} \Phi_{ik}^{*}(h)^2$ represents the variance of y_{it} generated by the k^{th} shock; therefore, the share of variance of y_{it} attributable to the k^{th} shock is given by the ratio

$$\frac{\sum_{h=0}^{\infty} \Phi_{ik}^{*}(h)^2}{\sum_{k=1}^{K} \sum_{h=0}^{\infty} \Phi_{ik}^{*}(h)^2} \tag{D.11}$$

Consider now the forecast error at time t

$$\mathbf{y}_t - E\left[\mathbf{y}_t | \Im_{t-1}\right]$$

This expression indicates the change in each variable inside $\mathbf{y}_t$ that could not have been forecast between $t-1$ and t; this inaccuracy is due to the realization of the structural shocks in the system presented in equation (D.1). More generally, we can compute the forecast error over many different horizons, h; therefore, the previous definition can be re-written as

$$\mathbf{y}_{t+h} - E\left[\mathbf{y}_{t+h} | \Im_{t+h-1}\right]$$

Since the mean forecast error is equal to zero, for $h = 1$ and $\mathbf{y}_y = (y_{1t}, y_{2t})$ we have that

$$y_{1t+1} - E\left[y_{1t+1} | \Im_t\right] = \Phi_{11}^{*}(0)\varepsilon_{1t+1} + \Phi_{11}^{*}(1)\varepsilon_{1t} + \Phi_{12}^{*}(0)\varepsilon_{2t+1} + \Phi_{12}^{*}(1)\varepsilon_{2t}$$

and its variance is simply

$$\mathrm{var}\left(y_{1t+1} - E\left[y_{1t+1} | \Im_t\right]\right) = \Phi_{11}^{*}(0)^2 + \Phi_{11}^{*}(1)^2 + \Phi_{12}^{*}(0)^2 + \Phi_{12}^{*}(1)^2$$

For an arbitrary h, we can define the forecast error variance for the i^{th} component of the $(K \times 1)$ random vector $\mathbf{y}_t$ recursively as

$$\begin{aligned}
&\Omega_i(0) = \Phi_{i1}^{*}(0)^2 + \ldots + \Phi_{iK}^{*}(0) \\
&\Omega_i(1) = \Phi_{i1}^{*}(1)^2 + \ldots + \Phi_{iK}^{*}(1) + \Omega_i(0) \\
&\vdots \\
&\Omega_i(h) = \Phi_{i1}^{*}(h)^2 + \ldots + \Phi_{iK}^{*}(h) + \Omega_i(h-1) \\
&\vdots \\
&\Omega_i(H) = \Phi_{i1}^{*}(H)^2 + \ldots + \Phi_{iK}^{*}(H)^2 + \Omega_i(H-1) = \sum_{k=1}^{K} \sum_{h=0}^{H} \Phi_{ik}^{*}(h)^2
\end{aligned}$$

with $i, k \in \{1, \ldots, K\}$. Therefore, in order to quantify the importance of each shock in explaining the variation in each variable in the system, we can use the same expression as in equation (D.11) namely:

$$\omega_{ik}(H) = \frac{\sum_{h=0}^{H} \Phi_{ik}^{*}(h)^2}{\Omega_i(H)}$$

BIBLIOGRAPHY

Akerlof, G. A. (1970). The market for "lemons": quality uncertainty and the market mechanism. *The quarterly journal of economics*, 488–500.

Armington, P. S. (1969). A theory of demand for products distinguished by place of production (une théorie de la demande de produits différenciés d'après leur origine)(una teoría de la demanda de productos distinguiéndolos según el lugar de producción). *Staff Papers-International Monetary Fund*, 159–178.

Bellaloui, N. and A. Mengistu (2008). Seed composition is influenced by irrigation regimes and cultivar differences in soybean. *Irrigation Science 26*(3), 261–268.

Bernanke, B. S. (1986). Alternative explanations of the money-income correlation. In *Carnegie-Rochester conference series on public policy*, Volume 25, pp. 49–99. Elsevier.

Bertheau, Y. (2009). GM and non-GM supply chains: their CO-EXistence and TRAceability. Technical report, European Commission.

Bertheau, Y. and J. Davison (2011). *Soybean in the European Union, status and perspective.* INTECH Open Access Publisher.

Berwald, D., C. A. Carter, and G. P. Gruère (2006). Rejecting new technology: the case of genetically modified wheat. *American Journal of Agricultural Economics 88*(2), 432–447.

Beveridge, S. and C. R. Nelson (1981). A new approach to decomposition of economic time series into permanent and transitory components with particular attention to measurement of the business cycle. *Journal of Monetary economics 7*(2), 151–174.

Blackorby, C., D. Primont, and R. R. Russell (1978). *Duality, separability, and functional structure: Theory and economic applications.* North-Holland New York.

Blanchard, O. J. and D. Quah (1988). The dynamic effects of aggregate demand and supply disturbances. Technical report, National Bureau of Economic Research.

Boccaletti, S., G. Leoni, A. Varacca, and C. Soregaroli (2012). Coexistence implications within the EU and international supply chain. Technical report, European Commission. PRICE Project: project n FP7-KBBE-2011-5.

Boonsaeng, T., S. M. Fletcher, et al. (2008). The effect of the us foreign market development program on import demand for shelled peanuts in the european union. In *Annual Meeting, Orlando, Florida.*

Bouxin, A. (2013). Feed & food statistical yearbook 2013. FEFAC. Available at: `http://www.fefac.eu/files/57916.pdf`.

Bullock, D. S. and E. I. Nitsi (2001). Roundup ready soybean technology and farm production costs measuring the incentive to adopt genetically modified seeds. *American Behavioral Scientist 44*(8), 1283–1301.

Burgess, D. F. (1974a). A cost minimization approach to import demand equations. *The Review of Economics and Statistics*, 225–234.

Burgess, D. F. (1974b). Production theory and the derived demand for imports. *Journal of International Economics 4*(2), 103–117.

Campiche, J. L., H. L. Bryant, J. W. Richardson, and J. L. Outlaw (2007). Examining the evolving correspondence between petroleum prices and agricultural commodity prices. In *The American Agricultural Economics Association Annual Meeting, Portland, OR.*

Carlier, L., I. Rotar, and R. Vidican (2010). The EU policy regulates and controls the farming practices. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Agriculture 67*(1).

Carpenter, J. and L. Gianessi (1999). Herbicide tolerant soybeans: Why growers are adopting roundup ready varieties. *AgBioForum*.

Carter, C. A. and A. Smith (2007). Estimating the market effect of a food scare: the case of genetically modified starlink corn. *The Review of Economics and Statistics 89*(3), 522–533.

Carter, C. A., F. Zhong, and J. Zhu (2009). China's role in the 2007–2008 global food price boom and bust. *EuroChoices 8*(2), 17–23.

Cavaillès, É. (2009). *La relance des légumineuses dans le cadre d'un plan protéine: quels bénéfices environnementaux?* Commissariat général au développement durable, Service de l'économie, de l'évaluation et de l'intégration du développement durable.

CERA (2013). GM Crop Database. Center for Environmental Risk Assessment. Available online at: `http://cera-gmc.org/index.php?action=gm_crop_database`.

CFTC (2015). Historical Compressed Commitments of Traders - U.S. Commodities Futures Trading Commission. Available online at: `http://www.cftc.gov/MarketReports/CommitmentsofTraders/HistoricalCompressed/index.htm`.

Chambers, R. G. (1988). *Applied production analysis: a dual approach.* Cambridge University Press.

Christiano, L., M. Eichenbaum, and C. Evans (1996). The effects of monetary policy shocks: Evidence from the flow of funds. *The Review of Economics and Statistics 78*, 16–34.

Christou, A. P., R. L. Kilmer, J. A. Sterns, and S. T. Feleke (2005). Derived demand for disaggregated cheese products imported into Japan. *Agribusiness 21*(1), 1–16.

Clark, X., D. Dollar, and A. Micco (2004). Port efficiency, maritime transport costs, and bilateral trade. *Journal of development economics 75*(2), 417–450.

Clements, K. W. and G. Gao (2015). The rotterdam demand model half a century on. *Economic Modelling 49*, 91–103.

Cornelius, P., M. E. Porter, and K. Schwab (2003). *The Global Competitiveness Report 2002-2003*. Oxford University Press, USA.

Cure, J., R. Patterson, C. Raper, and W. Jackson (1982). Assimilate distribution in soybeans as affected by photoperiod during seed development. *Crop Science 22*(6), 1245–1250.

da Silva Lopes, A. C. (2006). Deterministic seasonality in Dickey–Fuller tests: should we care? *Empirical Economics 31*(1), 165–182.

David, R. J. and S.-K. Han (2004). A systematic assessment of the empirical support for transaction cost economics. *Strategic Management Journal 25*(1), 39–58.

Davis, G. C. and K. L. Jensen (1994). Two-stage utility maximization and import demand systems revisited: Limitations and an alternative. *Journal of Agricultural and resource Economics*, 409–424.

Davison, J. (2010). Gm plants: Science, politics and ec regulations. *Plant Science 178*(2), 94–98.

de Faria, R. N. and C. Wieck (2014). Measuring the extent of GMO asynchronous approval using regulatory dissimilalrity indices: the case of maize and soybean. *EAAE Congress*.

de Faria, R. N. and C. Wieck (2015). Empirical evidence on the trade impact of asynchronous regulatory approval of new gmo events. *Food Policy 53*, 22–32.

De Visser, C. L. M., R. Schreuder, and F. Stoddard (2014). The EUs dependency on soya bean import for the animal feed industry and potential for eu produced alternatives. *OCL 21*(4), D407.

Dickey, D. A. and W. A. Fuller (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American statistical association 74*(366a), 427–431.

Diewert, W. E. (1986). Export supply and import demand functions: a production theory approach.

EIA (2015). Monthly biodiesel production report. Available online at: `http://www.eia.gov/biofuels/biodiesel/production/archive/2011/2011_12/biodiesel.cfm`.

Enders, W. (2004). Applied time series econometrics. *Hoboken: John Wiley and Sons. ISBN X 52183919*.

Engle, R. F. and C. W. Granger (1987). Co-integration and error correction: representation, estimation, and testing. *Econometrica: journal of the Econometric Society*, 251–276.

European Commission (2010). Europeans and biotechnology in 2010. Winds of change? Available online at: `http://ec.europa.eu/public_opinion/archives/ebs/ebs_341_winds_en.pdf`.

European Commission (2014). European Union sets import duty above zero for maize, sorghum and rye. Available online at: `http://europa.eu/rapid/press-release_MEMO-14-488_en.htm`.

European Commission (2015a). Commission publishes compendium of results of EU-funded research on genetically modified crops. Available online at: `http://europa.eu/rapid/press-release_IP-10-1688_en.htm`.

European Commission, A. . R. D. (2015b). Balance sheets for cereals, oilseeds and rice. Technical report. Available online at: `http://ec.europa.eu/agriculture/cereals/balance-sheets/index_en.htm`.

Eurostat (2015). Eurostat, international trade detailed data. Available at: `http://ec.europa.eu/eurostat/data/database`.

FAO (2015). Faostat - Crops production. Available online at: `http://faostat3.fao.org/download/Q/QC/E`.

Fernandez-Cornejo, J., C. Klotz-Ingram, and S. Jans (2002). Farm-level effects of adopting herbicide-tolerant soybeans in the USA. *Journal of Agricultural and Applied Economics 34*(01), 149–163.

Fernandez-Cornejo, J., W. D. McBride, C. Klotz-Ingram, and S. Jans (2000). *Genetically engineered crops for pest management in US agriculture: farm-level effects*, Volume 786. US Department of Agriculture, Economic Research Service.

Finger, R., N. El Benni, T. Kaphengst, C. Evans, S. Herbert, B. Lehmann, S. Morse, and N. Stupak (2011). A meta analysis on farm-level costs and benefits of gm crops. *Sustainability 3*(5), 743–762.

Foreign Agricultural Service (2012a). Argentina, Agricultural Biotechnology Annual Report. Technical report, Global Agricultural Information Network (GAIN), USDA.

Foreign Agricultural Service (2012b). EU 27, Agricultural Biotechnology Annual Report. Technical report, Global Agricultural Information Network (GAIN), USDA. Report number: FR9105.

Foster, S. T. (2008). Towards an understanding of supply chain quality management. *Journal of Operations Management 26*(4), 461–467.

Geyskens, I., J.-B. E. Steenkamp, and N. Kumar (2006). Make, buy, or ally: a transaction cost theory meta-analysis. *Academy of management journal 49*(3), 519–543.

Ghysels, E., H. S. Lee, and J. Noh (1994). Testing for unit roots in seasonal time series: some theoretical extensions and a monte carlo investigation. *Journal of econometrics 62*(2), 415–442.

Gonzalo, J. and S. Ng (2001). A systematic framework for analyzing the dynamic effects of permanent and transitory shocks. *Journal of Economic Dynamics and Control 25*(10), 1527–1546.

Gottschalk, J. (2001). An introduction into the SVAR methodology: identification, interpretation and limitations of SVAR models. Technical report, Kieler Arbeitspapiere.

Greene, W. H. (2003). *Econometric analysis*. Pearson Education India.

Grieshop, C. M. and G. C. Fahey (2001). Comparison of quality characteristics of soybeans from Brazil, China, and the United States. *Journal of agricultural and food chemistry 49*(5), 2669–2673.

Harri, A., L. Nalley, D. Hudson, et al. (2009). The relationship between oil, exchange rates, and commodity prices. *Journal of Agricultural and Applied Economics 41*(2), 501–510.

Häusling, M. (2011). The eu protein deficit: what solution for a long-standing problem? (2010/2111(ini)). Technical report, European Parliament.

Hausman, C., M. Auffhammer, and P. Berck (2012). Farm acreage shocks and crop prices: an SVAR approach to understanding the impacts of biofuels. *Environmental and Resource Economics 53*(1), 117–136.

Henseler, M., I. Piot-Lepetit, E. Ferrari, A. Gonzalez Mellado, M. Banse, H. Grethe, C. Parisi, and S. Hlaine (2013). On the asynchronous approval of GM crops: Potential market impacts of a trade disruption of EU soy imports. *Food Policy* (41), 166–176.

Herring, R. J. (2008). Opposition to transgenic technologies: ideology, interests and collective action frames. *Nature Reviews Genetics 9*(6), 458–463.

Hollingworth, R. M., L. F. Bjeldanes, M. Bolger, I. Kimber, B. J. Meade, S. L. Taylor, and K. B. Wallace (2003). The safety of genetically modified foods produced through biotechnology.

Institut National de la Recherche Agronomique INRA (2009). Comparative review of coexistence and traceability systems in selected countries of Europe, North and South America. Technical report, European Commission.

Irwin, S. H. and D. R. Sanders (2011). Index funds, financialization, and commodity futures markets. *Applied Economic Perspectives and Policy*, ppq032.

Irwin, S. H., D. R. Sanders, and R. P. Merrin (2009). Devil or angel? the role of speculation in the recent commodity price boom (and bust). *Journal of Agricultural and Applied Economics 41*(02), 377–391.

ISAAA (2013). GM Approval Database. Available online at: `http://www.isaaa.org/gmapprovaldatabase/`.

James, C. (2010). *Global status of commercialized biotech/GM crops: 2010.* International Service for the Acquisition of Agri-biotech Applications (ISAAA) Ithaca, NY, USA.

James, C. (2012). *Global status of commercialized biotech/GM crops: 2012.* International Service for the Acquisition of Agri-biotech Applications (ISAAA) Ithaca, NY, USA.

Jap, S. D. (1999). Pie-expansion efforts: collaboration processes in buyer-supplier relationships. *Journal of marketing Research*, 461–475.

Johansen, S. (1995). Likelihood-based inference in cointegrated vector autoregressive models. *OUP Catalogue*.

Joshi, A. W. and R. L. Stump (1999). Transaction cost analysis: Integration of recent refinements and an empirical test. *Journal of Business-to-Business Marketing 5*(4), 37–71.

Kalaitzandonakes, N. (2011). The economic impacts of asynchronous authorizations and low level presence: An overview. *International Food and Agricultural Trade Policy Council. Washington, DC*.

Karr-Lilienthal, L. K., C. M. Grieshop, N. R. Merchen, D. C. Mahan, and G. C. Fahey (2004). Chemical composition and protein quality comparisons of soybeans and soybean meals from five leading soybean-producing countries. *Journal of agricultural and food chemistry 52*(20), 6193–6199.

Kastens, T. L. and G. W. Brester (1996). Model selection and forecasting ability of theory-constrained food demand systems. *American Journal of Agricultural Economics*, 301–312.

Key, S., J. K. Ma, and P. M. Drake (2008). Genetically modified plants and human health. *Journal of the Royal Society of Medicine 101*(6), 290–298.

Kilian, L. (2006). Not all oil price shocks are alike: disentangling demand and supply shocks in the crude oil market.

King, R. G., C. I. Plosser, J. H. Stock, and M. W. Watson (1987). Stochastic trends and economic fluctuations. Technical report, National Bureau of Economic Research.

Klein, S., G. L. Frazier, and V. J. Roth (1990). A transaction cost analysis model of channel integration in international markets. *Journal of Marketing research*, 196–208.

Klümper, W. and M. Qaim (2014). A meta-analysis of the impacts of genetically modified crops.

Kohli, U. (1991). *Technology, duality, and foreign trade: the GNP function approach to modeling imports and exports.* Harvester Wheatsheaf.

Kohli, U. R. (1978). A gross national product function and the derived demand for imports and supply of exports. *Canadian Journal of Economics*, 167–182.

Koopman, R. B. and K. Laney (2012). Brazil: Competitive factors in Brazil affecting U.S. and Brazilian agricultural sales in selected Third Country markets. Technical report, U.S. International Trade Commission. Available at: `http://www.usitc.gov/publications/332/pub4310.pdf`.

Krautgartner, R., M.-C. Henard, S. Lieberz, M. Boshnakova, and the group of FAS oilseeds specialists in the EU (2010). EU-27. oilseeds - increased domestic soybean and soybean meal. Technical report, USDA GAIN.

Ku, Y., S. L. Ingale, J. S. Kim, S. H. Lee, Y. H. Kim, and B. J. Chae (2013). Effects of origins of soybean meal on growth performance, nutrient digestibility and fecal microflora of growing pigs. *Journal of Animal Science and Technology 55*(4), 263–272.

Kuiper, H. A., G. A. Kleter, H. P. Noteborn, and E. J. Kok (2001). Assessment of the food safety issues related to genetically modified foods. *The plant journal 27*(6), 503–528.

Laitinen, K. and H. Theil (1978). Supply and demand of the multiproduct firm. *European Economic Review 11*(2), 107–154.

Lapan, H. E. and G. Moschini (2004). Innovation and trade with endogenous market failure: The case of genetically modified products. *American Journal of Agricultural Economics 86*(3), 634–648.

Lee, P. K., A. C. Yeung, and T. Edwin Cheng (2009). Supplier alliances and environmental uncertainty: an empirical study. *International Journal of Production Economics 120*(1), 190–204.

Li, Y. and J. C. Beghin (2014). Protectionism indices for non-tariff measures: An application to maximum residue levels. *Food Policy 45*, 57–68.

López, R. C. and N. Poole (1998). Quality assurance in the maritime port logistics chain: the case of Valencia, Spain. *Supply Chain Management: An International Journal 3*(1), 33–44.

Lopez-Carlos, A., M. E. Porter, and K. Schwab (2006). *The Global Competitiveness Report 2005-2006*. Oxford University Press.

Lopez-Carlos, A., M. E. Porter, K. Schwab, and X. Sala-i Martin (2007). *The Global Competitiveness Report 2006-2007*. Oxford University Press.

Lütkepohl, H. (2006). *Structural vector autoregressive analysis for cointegrated variables*. Springer.

Magnier, A., S. Konduru, and N. Kalaitzandonakes (2009). Market and welfare effects of trade disruptions from unapproved biotech crops. *Agricultural & Applied Economics Association, Milwaukee, WI, USA.*

Management Committee for the Common Organisation of Agricultural Markets (2012). EU oilseeds trade 2011/12. Technical report, European Commission. Available at: `http://ec.europa.eu/eurostat/data/database`.

Mas-Colell, A., M. D. Whinston, J. R. Green, et al. (1995). *Microeconomic theory*, Volume 1. Oxford university press New York.

McPhail, L. L. (2011). Assessing the impact of us ethanol on fossil fuel markets: A structural var approach. *Energy Economics 33*(6), 1177–1185.

McPhail, L. L. and B. A. Babcock (2012). Impact of us biofuel policy on us corn and gasoline price variability. *Energy 37*(1), 505–513.

McPhail, L. L., X. Du, and A. Muhammad (2012). Disentangling corn price volatility: The role of global demand, speculation, and energy. *Journal of agricultural and applied economics 44*(03), 401–410.

Ménard, C. (2004). The economics of hybrid organizations. *Journal of Institutional and Theoretical Economics (JITE)/Zeitschrift für die gesamte Staatswissenschaft*, 345–376.

Ménard, C. (2012). Hybrid modes of organization. alliances, joint ventures, networks, and other'strange'animals. *The Handbook of Organizational Economics*, 1066–1108.

Ménard, C. and E. Valceschini (2005). New institutions for governing the agri-food industry. *European Review of Agricultural Economics 32*(3), 421–440.

Moschini, G., H. Bulut, and L. Cembalo (2005). On the segregation of genetically modified, conventional and organic products in European agriculture: a multi-market equilibrium analysis. *Journal of Agricultural Economics 56*(3), 347–372.

Mounts, T., J. Snyder, R. Hinsch, A. Bongers, and A. Class (1990). Quality of soybeans in export. *Journal of the American Oil Chemists Society 67*(11), 743–746.

Muhammad, A. and R. L. Kilmer (2008). The impact of EU export subsidy reductions on US dairy exports. *Agribusiness 24*(4), 557–574.

Murphy, E., B. Norwood, and M. Wohlgenant (2004). Do economic restrictions improve forecasts? *Journal of Agricultural and Applied Economics 36*(03), 549–558.

Mutondo, J. E. and S. R. Henneberry (2007). A source-differentiated analysis of US meat demand. *Journal of Agricultural and Resource Economics*, 515–533.

Mutuc, M., S. Pan, D. Hudson, et al. (2010). Response of cotton to oil price shocks. In *The Southern Agricultural Economics Association Annual Meeting, Orlando, FL.*

Nakamura, M., S. Sakakibara, and R. Schroeder (1998). Adoption of just-in-time manufacturing methods at us-and Japanese-owned plants: some empirical evidence. *Engineering Management, IEEE Transactions on 45*(3), 230–240.

Ng, S. and P. Perron (2001). Lag length selection and the construction of unit root tests with good size and power. *Econometrica*, 1519–1554.

Northern Crops Institute, N. (2013). Overview of soybean and soybean meal quality.

Park, H. S. and C. R. Hurburgh Jr (2002). Improving the US position in world soybean meal trade.

Parks, R. W. (1967). Efficient estimation of a system of regression equations when disturbances are both serially and contemporaneously correlated. *Journal of the American Statistical Association 62*(318), 500–509.

Passuello, F., S. Boccaletti, and C. Soregaroli (2013). Managing "GM-Free" food supply chains in Italy: insights from a case study. In *17th International Conference on Economics of Bio-Economy Innovation and Policy for the Bioeconomy*, pp. 1–32. icabr.

Pelaez, V., D. Aquino, R. Hofmann, M. Melo, and P. D. Goldsmith (2010). Implementation of a Traceability and Certification System for non-genetically modified soybeans: The experience of Imcopa Co. in Brazil. *International Food and Agribusiness Management Review 13*(1), 27–44.

Philippidis, G. (2010). EU import restrictions on genetically modified feeds: impacts on Spanish, EU and global livestock sectors. *Spanish Journal of Agricultural Research 8*(1), 3–17.

Pollock, D. S. G., R. C. Green, and T. Nguyen (1999). *Handbook of time series analysis, signal processing, and dynamics.* Academic Press.

Porter, M. E., X. Sala-i Martin, and K. Schwab (2008). *The Global Competitiveness Report 2007-2008.* Oxford University Press.

Porter, M. E. and K. Schwab (2009). *The Global Competitiveness Report 2008-2009.* Oxford University Press.

Ranum, P., J. P. Peña-Rosas, and M. N. Garcia-Casal (2014). Global maize production, utilization, and consumption. *Annals of the New York Academy of Sciences 1312*(1), 105–112.

Reuters, T. (2015). Datastream professional.

Reviron, S. (2000). *La diversité des systèmes de marché, Proposition d'une représentation du cadre des négociations commerciales pour les marchés de biens; le cas des marchés agro-alimentaires.* Ph. D. thesis.

Réviron, S. and J.-M. Chappuis (2005). Effects of the Swiss retailers' strategy on the governance structure of the fresh food products supply chains. *Agribusiness 21*(2), 237–252.

Rose, I. (1988). Effects of moisture stress on the oil and protein components of soybean seeds. *Crop and Pasture Science 39*(2), 163–170.

Rubio-Ramirez, J. F., D. F. Waggoner, and T. Zha (2010). Structural vector autoregressions: Theory of identification and algorithms for inference. *The Review of Economic Studies 77*(2), 665–696.

Sachs, D. J., P. K. Cornelius, W. J. McArthur, M. E. Porter, and K. Schwab (2002). *The Global Competitiveness Report 2001-2002.* Oxford University Press, USA.

Sachs, D. J., A. M. Warner, W. J. McArthur, M. E. Levinson, Macha Porter, and K. Schwab (1999). *The Global Competitiveness Report 1999.* Oxford University Press, USA.

Sachs, D. J., A. M. Warner, W. J. McArthur, M. E. Porter, and K. Schwab (2000). *The Global Competitiveness Report 2000.* Oxford University Press, USA.

Said, S. E. and D. A. Dickey (1984). Testing for unit roots in autoregressive-moving average models of unknown order. *Biometrika 71*(3), 599–607.

Sala-i Martin, X., M. E. Porter, K. Schwab, and A. Lopez-Carlos (2004). *The Global Competitiveness Report 2003-2004.* Oxford University Press.

Sala-i Martin, X., M. E. Porter, K. Schwab, and A. Lopez-Carlos (2005). *The Global Competitiveness Report 2004-2005.* Oxford University Press.

Schmitz, T. G., A. Schmitz, and C. B. Moss (2005). The economic impact of starlink corn. *Agribusiness 21*(3), 391–407.

Schott, P. K. (2004). Across-product versus within-product specialization in international trade. *The Quarterly Journal of Economics*, 647–678.

Schwab, K. (2010). *The Global Competitiveness Report 2009-2010.* Oxford University Press.

Schwab, K. (2011). *The Global Competitiveness Report 2010-2011.* Oxford University Press.

Schwab, K. (2012). *The Global Competitiveness Report 2011-2012*. Oxford University Press.

Schwab, K. (2013). *The Global Competitiveness Report 2012-2013*. Oxford University Press.

Schwab, K., X. Sala-i Martin, and R. Greenhill (2011). The global competitiveness report 2011-2012. Citeseer.

Schwert, G. W. (1989). Tests for unit roots: A Monte Carlo investigation. *Journal of Business & Economic Statistics 7*(2), 5–17.

Seale Jr, J. L., L. Zhang, and M. R. Traboulsi (2013). Us import demand and supply response for fresh tomatoes, cantaloupes, onions, oranges, and spinach. *Journal of Agricultural and Applied Economics 45*(03), 435–452.

Séralini, G.-E., E. Clair, R. Mesnage, S. Gress, N. Defarge, M. Malatesta, D. Hennequin, and J. S. De Vendômois (2012). Retracted: Long term toxicity of a roundup herbicide and a roundup-tolerant genetically modified maize. *Food and chemical toxicology 50*(11), 4221–4231.

Shiferaw, B., B. M. Prasanna, J. Hellin, and M. Bänziger (2011). Crops that feed the world 6. past successes and future challenges to the role played by maize in global food security. *Food Security 3*(3), 307–327.

Snell, C., A. Bernheim, J.-B. Bergé, M. Kuntz, G. Pascal, A. Paris, and A. E. Ricroch (2012). Assessment of the health impact of gm plant diets in long-term and multigenerational animal feeding trials: a literature review. *Food and Chemical Toxicology 50*(3), 1134–1148.

Sobolevsky, A., G. Moschini, and H. Lapan (2005). Genetically modified crops and product differentiation: Trade and welfare effects in the soybean complex. *American Journal of Agricultural Economics 87*(3), 621–644.

Stegelin, F. et al. (2011). Comparing second generation ge crops to first generation ge crops. *Journal of Food Distribution Research 42*(1), 116.

Taleb, N. N., Y. Bar-Yam, R. Douady, J. Norman, and R. Read (2014). The precautionary principle: fragility and black swans from policy actions. *Extreme Risk InitiativeNYU School of Engineering Working Paper Series*.

Theil, H. (1977). The independent inputs of production. *Econometrica: Journal of the Econometric Society*, 1303–1327.

Theil, H. (1980). The system-wide approach to microeconomics.

Tillie, P., M. Vigani, K. Dillen, and E. R. Cerezo (2012). Markets for non genetically modified identity preserved crops and derived products. Technical report, Institute for Prospective and Technological Studies, Joint Research Centre.

Trostle, R. (2010). *Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices (rev.* DIANE Publishing.

Truett, L. J. and D. B. Truett (1998). The demand for imports in korea: a production analysis approach. *Journal of Development Economics 56*(1), 97–114.

UN Trade Statistics, S. D. (2015). Un comtrade database. Available online at: `http://comtrade.un.org/data/`.

USDA, NASS (2015). Adoption of genetically engineered crops in the US. Available online at: `http://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-us.aspx`.

Veeman, T. S. and R. Gray (2010). The shifting patterns of agricultural production and productivity in Canada. *The Shifting Patterns Of Agricultural Production And Productivity Worldwide*.

Vigani, M., V. Raimondi, and A. Olper (2012). International trade and endogenous standards: the case og GMO regulations. *World Trade Review 11*(3), 415–437.

Walker, G. and D. Weber (1984). A transaction cost approach to make-or-buy decisions. *Administrative science quarterly*, 373–391.

Wang, D. and W. G. Tomek (2007). Commodity prices and unit root tests. *American Journal of Agricultural Economics 89*(4), 873–889.

Washington, A. A. and R. L. Kilmer (2002a). The derived demand for imported cheese in Hong Kong. *The International Food and Agribusiness Management Review 5*(1), 75–86.

Washington, A. A. and R. L. Kilmer (2002b). The production theory approach to import demand analysis: A comparison of the Rotterdam model and the differential production approach. *Journal of Agricultural and Applied Economics 34*(3), 431–444.

Wei, H.-L., C. W. Wong, and K.-h. Lai (2012). Linking inter-organizational trust with logistics information integration and partner cooperation under environmental uncertainty. *International Journal of Production Economics 139*(2), 642–653.

Williamson, O. E. (1979). Transaction-cost economics: the governance of contractual relations. *Journal of law and economics*, 233–261.

Williamson, O. E. (1981). The economics of organization: The transaction cost approach. *American journal of sociology*, 548–577.

Williamson, O. E. (1987). Transaction cost economics: The comparative contracting perspective. *Journal of economic behavior & organization 8*(4), 617–625.

Williamson, O. E. (1991). Comparative economic organization: The analysis of discrete structural alternatives. *Administrative science quarterly*, 269–296.

Wilson, W. W. (1994). Demand for wheat classes by pacific rim countries. *Journal of Agricultural and Resource Economics*, 197–209.

Wolf, R., J. Cavins, R. Kleiman, and L. Black (1982). Effect of temperature on soybean seed constituents: oil, protein, moisture, fatty acids, amino acids and sugars. *Journal of the American Oil Chemists Society 59*(5), 230–232.

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data.* MIT press.

Working, H. (1960). Speculation on hedging markets. *Food Research Institute Studies* (02).

World Bank (2010). How to decrease freight logistics costs in Brazil. Available online at: `http://siteresources.worldbank.org/BRAZILINPOREXTN/Resources/3817166-1323121030855/FreightLogistics.pdf?resourceurlname=FreightLogistics.pdf`.

World Bank (2015). World Bank, official exchange rate. Available at: `http://data.worldbank.org/indicator/PA.NUS.FCRF`.

Yu, T.-H., D. A. Bessler, and S. Fuller (2006). Cointegration and causality analysis of world vegetable oil and crude oil prices. In *American Agricultural Economics Association Annual Meeting, Long Beach, CA, July*, pp. 23–26.