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Determinants of West African international agricultural trade

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Abstract. Agricultural production is clearly an important component of West African international trade. Purpose here is to identify determinants of West African international trade flows. For this, the expanded Structural Gravity model was used. The overall pattern of international agricultural transactions in this region is dominated by extra-regional transactions and there are differences between intra- and extra-regional determinants. In global transactions, flows are higher among the Economic Community of West African States (ECOWAS) member countries and the West African Economic and Monetary Union (WAEMU) does not significantly affect those flows. On the other hand, ECOWAS does not have significant impact on intra-regional agricultural trade and flows are greater among WAEMU member countries.

Keywords: West Africa, international trade, agricultural, intra and extra-regional determinants.
JEL codes: F14.

1. INTRODUCTION

Commercial transactions resulting from productive activities in West Africa, both internal and external, are concentrated in the agricultural sector. Speeding up integration and improving the trading capacity of countries are some of the main goals of regional policies. The agricultural sector is recognized as a potential driver of the economy and regional investments provide incentives for its development.

Improving agricultural trade in West Africa is a crucial step for promoting the integration of local farmers into the global trade system. The region's comparative advantages for agribusiness provide conditions that can be exploited to build a productive system that can actually improve the living conditions of its population and reduce its external dependence. The fast progress seen in communications services has shortened the distances between countries, facilitating and creating opportunities for more intense economic transactions. Traditional barriers are inefficient and unsustainable both to protect and to stimulate economic development and ensure a high level of international competitiveness. The possibility of exploiting natural competitive advantages - land, sunshine and water - appears as a window available to West Africa. All the major world nations in the past have played a major role in world trade and the importance of international trade in improving living conditions is, for some authors, an unquestionable fact (Appleyard, Field Jr, 2014).

Although the region consists of predominantly agricultural countries, the heterogeneities that make them complementary create intra-regional trade possibilities that can boost development. Added to this are regional investments in regional integration transportation infrastructure. Trade, especially regional trade, plays a major role in promoting economies of scale in production, whose potential is high in West Africa, given the unique traits of the region's countries (WB, 2015). According to FAO (2015) data for 2013, West African agricultural exports and imports accounted for 1.82% and 2.79% of Gross Domestic Product (GDP) in that year, respectively, indicating low integration and trade deficits.

The low level of agricultural exports reflects the low production levels of the countries and concentration of commercial agricultural production in raw material, as dictated by the region's current trade patterns. Given these conditions, identifying determinants of agricultural trade flows is fundamental for decisions aimed at improving their performance. And the objective of this investigation is to identify determinants of international agricultural trade flows in West Africa.

2. WEST AFRICAN INTERNATIONAL AGRICULTURAL TRADE AND EMPIRICAL APPLICATION OF THE GRAVITY MODEL

Between the 1990s and the 2000s, trade among developing countries grew significantly and transactions in the manufacturing sector quintupled. Considering only agricultural products, it more than doubled (Dethier, Effenberger, 2012). The primordial objective of West Africa's two main regional organizations – the Economic Community of West African States (ECOWAS) and the West African Economic and Monetary Union (WAEMU) – is to intensify trade between countries in the region as part of their regional integration policies. The growth of trade among countries in the region is enhanced by the actions of regional organizations (Torres, Van Seters, 2016).

Actions for this purpose are focused on developing regional transportation infrastructures and on unifying regional control systems. Regional organizations, in particular WAEMU, have a strategic plan for developing the transportation infrastructure, which consists of cross-country linkages and internal links within countries to regional infrastructures (JICA, 2012). ECOWAS regional integration efforts include building a common community market, characterized by the free movement of people and goods between member states, and a common monetary zone (ECOWAS, 1999), as well as developing the transportation, communication, and energy infrastructure (ECOWAS, 2007).

Several studies on West African trade are concerned with tariff and non-tariff barriers between countries and the implementation of regional trade agreements (Engel, Jouanjean, 2013; Torres, Van Seters, 2016). These issues have been addressed by agreements at the level of regional organizations and their implementation is under way through regional supervision posts. Commercial tariffs among ECOWAS member states have been done away with for agricultural products produced within the region and the remaining barriers are weak to generate large impacts on trade (Cissokho, Haughton, Makpayo, Seck, 2012).

The political strategies designed to intensify regional trade transactions between the countries of the region's two main organizations - ECOWAS and WAEMU - are focused on the agricultural sector (Engel, Jouanjean, 2013; Torres, Van Seters, 2016). The heterogeneity of agricultural production within West Africa shows potential for efficient trade among countries in the region (Cissokho, Haughton, Makpayo, Seck, 2012). But intra-regional trade is small and undocumented, dominated by informality and concentrated in agricultural products (Torres, Van Seters, 2016). Despite all the efforts already undertaken, limiting factors such as high trading costs are still evident.

Transportation infrastructure constraints are the main causes of the high intraregional trade costs recorded in West Africa, although major investments in infrastructure were made in recent years (Torres, Van Seters, 2016). Regional investments in transportation infrastructure are leading to major transformations in the regional trade dynamics (ECOWAS, 2007; JICA, 2012; Torres, Van Seters, 2016). The global dynamics of international trade, however, reveals a reduced chance of gain for developing countries whose trade is focused on commodities (Appleyard, Field Jr, 2014).

The most recent model of international trade is the Gravity Model, which focuses on the determinants of trade flows. Unlike previous models, it does not explain the benefits and losses resulting from international trade, but the reasons that determine trade flows between countries. It focuses on the interactions between resistance and attraction to trade (Appleyard, Field Jr, 2014).

The gravitational econometric model has been widely used for investigating the determinants of trade flows in empirical studies and has generated consistent results. It has been used to investigate the determinants of international trade patterns, which are in turn determined by income, distance, and other variables that affect trade flows (McCallum, 1995). In their empirical applications, other important variables that determine trade are included (Cissokho, Haughton, Makpayo, Seck, 2012; Head, Mayer, 2013; Magerman, Studnicka, Hove, 2015), such as regional trade policies. This model is mainly used to evaluate the impacts of trade policies (Head, Mayer, 2013), such as the effects of economic and monetary unions (Anderson, Van Wincoop, 2003).

The traditional Gravity Model considers only bilateral components in investigations of trade flows, but commercial relations between two countries are also affected by third parties. According to Anderson (2010), adjustments in the traditional model yield better results when other factors that affect trade are included, and bilateral constraints do not seem to fully explain trade flows. The multiple trade alternatives that exist simultaneously affect a bilateral trade relationship. This effect of other commercial alternatives on bilateral transactions is considered in the Structural Gravity Model (Anderson, Van Wincoop, 2003; Anderson, 2010), whose main characteristic is the multilateral resistance term (Head, Mayer, 2013). Debates on international economy generally depend on multilateral trade information, whose absence in gravitational models has been criticized as to its validity as a guiding instrument (Krugman, 1995). The inclusion of a multilateral resistance component in international trade allows for a solution to this problem of omission of a relevant variable to be investigated (Anderson, Van Wincoop, 2003).

Representing the multilateral resistance component of international trade in the empirical applications of the Structural Gravity Model is another specification problem. Using a constant term in time as a representation of multilateral resistance, as in Cissokho, Haughton, Makpayo and Seck (2012), the theoretical consistency and ease of application of which are highlighted by Head and Mayer (2013), does not seem plausible. This is so because bilateral relations change over time and, as a result, multilateral resistance must change. However, using specifications in investing international trade patterns with real inconsistency seems reasonable until a more rigorous approximation appears (Krugman, 1995).

Besides the problems involved in specifying the term of multilateral resistance in empirical applications, representing trade flows in investigations of its determinants raises questions about its explanatory adequacy. The gravitational model can be considered from a demand or supply point of view, both of which work for purposes of deduction or even to yield empirical results (Anderson, 2010). But trade flows are composed of imports and exports, and investigations of their determinants must involve both.

The reasons for exports may be totally different from those that drive imports. The volumes of the two can vary between countries due, among other reasons, to losses in trade and problems related to records. Unidirectional specification in the Gravity Model is consistent with the investigation of unidirectional determinants, as specified in a study on African exports (Czubala, Shepherd, Wilson, 2009). This fact requires a relevant theoretical foundation and deserves attention when specifying international trade flows using the Gravity Model. Incorporation of theoretical foundations into the Gravity Model has resulted in a better estimation and interpretation of the spatial interactions it represents (Anderson, 2010). A specification that encompasses the two directions of trade flows, as in McCallum (1995), is adequate to explain the determinants of trade between countries from parametric estimates.

In estimating the parameters of the Gravity Model, the results in terms of signals do not change with the method used, although the magnitudes of the effects vary (Magerman, Studnicka, Hove, 2015). This model assumes that the spatial distribution of goods and/or factors is determined by gravitational forces, which are in turn conditioned by the size of economic activities in each locality (Anderson, 2010). Empirical results confirm the assumptions of the model. Several studies have confirmed the economic assumptions about the relationship between distance, language, and shared borders with trade flows (Magerman, Studnicka, Hove, 2015). As pointed out by Anderson and Van Wincoop (2003) and Anderson (2010), factors other than those traditionally included in the models affect trade flows.

In the case of extra-regional trade in West Africa, flows seem to be driven by the raw material needs of its partners. The region's main trade partners are highly industrialized countries, to which it sells raw materials and from which it buys industrialized products (Torres, Van Seters, 2016). This is a fact common to developing countries and one that is characteristic of world trade. Global trade is dominated by industrialized countries and intra-regional transactions are more intense, African countries are nevertheless among the least performing in terms of intra-regional trade (Appleyard and Field Jr, 2014), despite their great agricultural potential and increasing demand for food products.

An increasing share of food supply in West Africa is imported, despite its great agricultural potential (WB, 2015). According to Torres and Van Seters (2016), the region exports a small number of raw materials concentrated in extractive natural resources and imports industrialized products, including an increasing volume of food products. Its trade balance in food products has deteriorated over the last decade as a result of its population growth and increased purchasing power. Exports from low-income countries are concentrated in the agricultural sector (Dethier, Effenberger, 2012), which constitutes the main productive sector in West Africa.

3. METHODOLOGY

The data used in this investigation were obtained from the statistical department of the United Nations Food and Agriculture Organization (FAO), the World Bank (WB), the World Trade Organization (WTO), the Center for Prospective Studies and International Information (*Centre d'*Études Prospectives et d'*Informations Internationales* - CEPII), the Economic Community of West African States (ECOWAS), and the West African Economic and Monetary Union (WAEMU). The period of analysis is 1990 through 2013. For the estimation, unbalanced panel data composed of sixteen West African countries were used.

The model adopted in this research was the Structural Gravity Model developed by Anderson and Van Wincoop (2003), which is very much followed in this area's literature (Head, Mayer, 2013). It was developed from a cost function of Constant Substitution Elasticity (CES) and specified for a given economic sector - in this case agriculture (Anderson, 2010). This model is given by:

$$X_{ij} = \frac{Y_i Y_j}{Y^w}\left(\frac{t_{ij}}{P_i P_j}\right)^{1-\sigma} \tag{1}$$

where X_{ij} are the agricultural exports of i-th country to j-th country, Y_i and Y_j represent international agricultural supply and demand – exports and imports – for i-th and j-th countries, respectively, Y^w are the world's agricultural exports, P_i and P_j are the consumer price indices of i-th and j-th countries, respectively, p_{ij} is the price paid by importer j to exporter i for a product, p_i is the producer price in the exporting country, the term $t_{ij} = \frac{p_{ij}}{p_i}$ is the trade cost factor between the two countries and represents bilateral barriers, and σ is the parameter of substitution elasticity.

The terms P_i and P_j represent multilateral barriers and $\frac{t_{ij}}{P_i P_j}$ is the relative resistance to trade between two countries (Anderson, Van Wincoop, 2003). It involves multilateral and bilateral resistance representing all trade costs.

After considering a stochastic form of equation (1), with an exponential error term and a parameter representing other determinants of trade flows not specified in the model, the equation was expressed in terms of a natural logarithm:

$$lnX_{ij} = \beta + \beta_4 lneyy + (1-\sigma) lntp + \mathcal{E} \tag{2}$$

where: $lneyy = ln\frac{Y_i Y_j}{Y^w}$ and $lntp = ln\left(\frac{t_{ij}}{P_i P_j}\right)$. In this logarithmic specification, the consideration of null (zero) records for trade flows requires mathematical transformations of data for their computation, given the logarithmic indeterminacy of that value. Estimations of trade flows using the Gravity Model in its standard specification generate biased results by not allowing the inclusion of null records (zeros) in the investigation (Helpman, Melitz, Rubinstein, 2008). Fortunately, records of this type do not compose the database used in this investigation.

Possible effects of sharing a common border, *fron*, an official language, *ling*, a common economic community, *ceco*, a common monetary community, *cmo*, and an inverse distance between countries, *disv,* specified in equation (2), are given by:

$$lnX_{ij} = \beta + \beta_1 fron + \beta_2 ling + \beta_3 disv + \beta_4 ceco + \beta_5 cmo + \beta_6 lneyy + (1-\sigma) lntp + \beta_i Dum_i \tag{3}$$

where: *fron*, *ling*, *ceco* e *cmo* are equal to one (1) if exporting and importing countries share these variables and zero otherwise, *disv* is the inverse distance in kilometers between those countries, Dum_i is equal to one for *i-th* country and zero otherwise and ε_{it} is the normally distributed random error term with zero mean and constant variance $\mathcal{E} \sim N\left(0, \sigma_{\mathcal{E}}^2\right)$.

Model (3) is used in this investigation of the determinants of global and intra-regional agricultural trade and model (4) is used for extra-regional agricultural trade in West Africa.

$$lnX_{ij} = \beta + \beta_2 ling + \beta_3 disv + \beta_6 lneyy + (1-\sigma) lntp + \beta_i Dum_i + \mathcal{E} \tag{4}$$

In the model for extra-regional trade with the border term, the economic and monetary communities were omitted because the countries involved do not share them with their five main trading exporting and importing partners.

For estimating the parameters of the determinants of trade flows that consider exports and imports, the dependent variable lnX_{ij}, refers to agricultural exports to $t_{ij} = \frac{p_{ij}}{p_i}$ and lnX_{ij} refers to agricultural imports to $t_{ji} = \frac{p_{ji}}{p_j}$ – when West Africa is the importing party and Y^w refers to global agricultural imports.

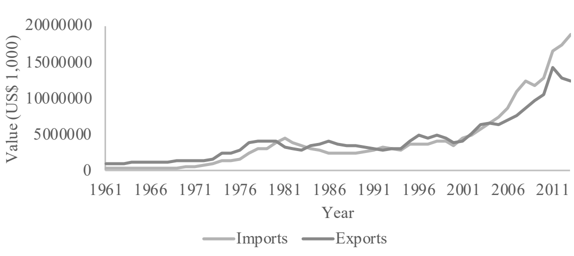
International agricultural transactions involving live animals (heads) were excluded from the investigation due to their incompatibility for determining average prices. It is worth noting that they account for a small volume of international agricultural trade in the region's countries according to FAO bilateral records, but they are relevant to the living conditions of the local population. Trade in live animals is an important component of international trade patterns among West African countries, especially among those without a direct connection to the ocean (Hanink and Owusu, 1998).

4. RESULTS AND DISCUSSION

Agricultural transactions constitute the main productive component of the export basket of West African countries. Regional participation in international trade is focused on exports of raw materials and imports of final consumer goods. In the 2000s, regional agricultural exports and imports grew, but no change was recorded in the composition of transactions in terms of processing degree (ECOWAS[b], 2015). Transactions consist mainly of exports of raw materials and imports of industrialized products (Torres, Van Seters, 2016). Although the agricultural sector is the main driver of production and occupation in West African countries, agricultural imports are on the rise. This development reflects an imbalance and/or divergence in the basket of products between local supply and demand. Both the import and export rate of agricultural products gained momentum from the year 2000 (Fig. 1).

Identifying and understanding the determinants of West Africa's international agricultural transactions is key for the regional planning of agricultural development. In this investigation, the Structural Gravity Model was expanded with the inclusion of dummies for shared borders, official language, and regional economic and monetary communities, as well as for geographical distances between importing and exporting countries. The results of the estimates for West Africa are presented in Tables 1 (global transactions), 2 (internal flows), and 3 (foreign trade).

Fig. 1. Evolution of the nominal value of West African agricultural imports and exports from 1961 through 2013.



Source: FAO, 2015.

With the exception of the common currency, *cmo*, all the other variables considered in the Structural Gravity Model in this specific investigation significantly affect global agricultural trade flows in West Africa at a statistical significance of 1% (Tab. 1). Transactions grow as supply and demand from the region's countries and their partners, *lneyy*, increase.

Increased regional agricultural production has a positive effect on international trade flows, especially on the sector's exports. This shows the reduced pressure on internal depreciation of producer prices resulting from productive expansion in West African countries. In the region, intra-regional trade has a limited offer due to the low production levels recorded in the primary (agricultural) and secondary (manufacturing) sectors (Hanink, Owusu, 1998). As Allen and Heinrigs (2016) point out, food prices in the region are high relative to other regions with similar incomes. This relationship ensures the benefit of international transactions to agricultural producers in the region, whose limiting factor is the level of production of the countries.

While supply and demand boost international agricultural trade flows, restrictions have significant impacts on the process. Transportation costs are the most important bilateral component of resistance to trade in the region's countries. Several studies have shown that exporting firms in Africa are those with the highest productive efficiency and capable of overcoming the limitations of high transportation costs (Van Biesebroeck, 2005). These costs are mostly incurred from the production gate to the flow ports, given the precariousness of the transportation infrastructure in rural areas of countries, particularly in West Africa. This is evident in the development strategies of regional organizations, such as in the strategic plans of WAEMU (JICA, 2012) and ECOWAS (ECOWAS, 2007) for developing transportation infrastructure.

As grounded by the Gravity Model, economic, social, and geographical approaches increase transactions between countries. Sharing a common border expands the agricultural trade of West African countries significantly in statistical terms. Agricultural trade in ECOWAS' countries is positively affected by product level, a common language, and a common border, and is negatively affected by geographical distance (Cissokho, Haughton, Makpayo, Seck, 2012).

The smaller the geographical distance, the greater the overall agricultural trade flows among West African countries, as shown by the result for reverse distance in the model, *disv*. In the research on the determinants of international trade, including West Africa, the negative relations of geographical distance and the positive effects of sharing a common language and border were confirmed (Baier, Bergstrand, 2007; Carrère, 2004; Nitsch, 2004).

Sharing the same official language, *ling*, significantly increases agricultural trade flows among West African countries. The relations between distance (negative) and sharing a common border and language (positive) and trade flows have been confirmed in research carried out by Helpman, Melitz and Rubinstein (2008) and consolidated in the literature. This contribution can be improved by implementing three official languages in the region, namely, Portuguese, English and French, as mandatory curricular subjects up to the last year of high school.

In addition to having intrinsic interactions, the definitions of which are given, West African countries are regional economic blocs. In the overall international agricultural trade, regional flows are statistically significant and more intense among ECOWAS member countries, *ceco*. That organization has been playing a decisive role in raising the level of trade in agricultural products through its investments in infrastructure (Cissokho, Haughton, Makpayo, Seck, 2012).

The coefficient of *ceco* reveals that international agricultural trade among ECOWAS member countries rises when transactions with all their trade partners are considered. This may be evidence of the shield resulting from the formation of this economic block in relation to outside partners. However, it may be the result of trade intensification among countries brought about by approaches promoted by the organization, without prejudice to the relations with extra-regional partners, which do not constitute a shield. Lower trade frictions induce transactions among non-trading countries and increases flows among partners already engaged in bilateral trade (Helpman, Melitz, Rubinstein, 2008).

There do not seem to exist barriers set up by ECOWAS for non-member countries, given that their common external rates are recent, launched in January 2015, and are not included in the period considered in this investigation. Their highest common external rate, 35%, which is lower than the upper limit of the bands consolidated in the World Trade Organization (WTO) by most countries, provides further evidence that support the degree of economic openness of countries in the region. This rate is mainly applied to agricultural products. With the exception of Cape Verde, Côte d'Ivoire, Liberia and Senegal, all other ECOWAS member countries adopt higher bands than the highest regional rate applied to agricultural products. It should be noted that the actual rates are usually lower than the upper limit consolidated by countries in the WTO (Appendix Tab. A.1). With the exception of Liberia, the level of economic openness of

Tab. 1. Result of the estimation of determinants of both intra- and extra-regional international agricultural trade of West Africa.

lnxij	Coefficient	Standard error	z	p-value
lneyy	0.8114	0.0145	55.87	0.000
lntp	-0.0854	0.0198	-4.30	0.000
fron	0.8219	0.1107	7.42	0.000
disv	283.5323	30.0766	9.43	0.000
ling	1.5452	0.0723	21.37	0.000
ceco	0.9754	0.0977	9.98	0.000
cmo	-0.1798	0.1152	-1.56	0.118
Benin (constant)	-0.8114	0.2157	-3.76	0.000
Burkina Faso	-0.1824	0.1202	-1.52	0.129
Cape Verde	0.3288	0.1291	2.55	0.011
Côte d'Ioire	0.0722	0.1038	0.70	0.487
Gambia	-0.2882	0.1284	-2.25	0.025
Ghana	-0.1042	0.1090	-0.96	0.339
Guinea	-0.7626	0.2864	-2.66	0.008
Guinea-Bissau#	-	(omitted)		
Liberia#	-	(omitted)		
Mali	-0,1876	0,1400	-1,34	0,180
Mauritania	-0,1511	0,1497	-1,01	0,313
Niger	-0,1128	0,1155	-0,98	0,329
Nigeria	-0,3716	0,1680	-2,21	0,027
Senegal	0,0817	0,1002	0,81	0,415
Sierra Leone##	-	(omitted)		
Togo	-0.2416	0.1081	-2.23	0.025
sigma_u	0	0.0239		
sigma_e	2.1574	0.0169		
rho	-	(omitted)		

Number of observations = 8,133
Log likelihood = -17,793.832 LR chi2(19) = 3,698.60
Prob > chi2 = 0.000
LR test of sigma_u=0: chibar2 (01) = 0.00
Prob >= chibar2 = 1.000

Omitted because their information on agricultural business transactions are not listed in the FAO Detailed Trade Matrix database as Reporting Countries. They only appear as partners of those that reported (Partner Countries).
Omitted because producer price information is missing on the bases consulted to determine t_{ij}.

countries is confirmed (Appendix Fig. A.1.). The end of two decades (1990-2000) of civil conflict in Liberia (LISGIS, 2009) was followed by large trade inflows into the country, which lost space for resuming local production and saw a reduction in economic openness. But unlike individual agreements, the actual implementation of regional common external rates does not allow for downward flexibility in tariffs, only for upward shifts. ECOWAS member countries have a 3% margin for changing their common external tariffs to adjust them to the rates individually agreed upon in the category of more favorable nations in the WTO if these are higher than the regional external rates adopted by the organization (DGIZ, 2014).

Greater protection for the agricultural sector appears to be standard in trade policies, even in central countries or in those experiencing a fast development process and with a high productive performance in the sector. Other protective mechanisms adopted for the sector, such as quality regulations, do not appear to be constraints for the West African agricultural market. Institutional shortcomings make it impossible to use these measures in the region, in particular for agricultural products. A limited coverage of specific agricultural products in WTO commitments corroborates a virtual absence of such restrictions (Appendix Tab. A.1.). Progress has been made in harmonizing regional and domestic policies in West Africa, but the region still faces restrictions to actually build a strong and dynamic common market mainly due to institutional shortcomings (ECOWAS[b], 2015).

West Africa has another large economic bloc, WAEMU, a monetary union made up of 50% of the region's countries that does not significantly affect their global agricultural international transactions, *cmo*. However, it is a major determinant of the region's internal trade flows, as will be discussed later. Monetary union raises trade flows between countries in the community by reducing transaction costs using a common currency and eliminating risks associated with exchange rate volatility (Carrère, 2004; Masson, Pattillo, 2004). But the result confirms that the global international transactions of WAEMU countries are not different from those of other ECOWAS member countries. One justification for this result lies in the composition of the international agricultural trade baskets of countries in the region and their directions. The largest share of these transactions is made up of outgoing raw materials and incoming finished products from countries with an advanced level of agricultural development outside West Africa, as pointed out by Torres and Van Seters (2016). This is a condition that dictates the behavioral pattern of global trade flows in the region and which may change as countries advance in terms of agricultural development. Increased agricultural processing and transformation and improved infrastructure are likely to redirect flows and/or reset the intensity of agricultural transactions. And the commercial advantages afforded by the monetary union will likely lead to a more intense agricultural trade among its member countries.

Regional blocs were formed in West Africa with the main purpose of intensifying relations between their member countries based on the liberalization of borders and trade. Developing the agricultural market is a priority in the region's discussions (Me-Nsope, 2014; Me-Nsope, Staatz, 2015). The behavior of internal and external international agricultural trade flows in the region must be differentiated. The strategies for the two dimensions will not be the same, although they are convergent in terms of improving the quality of life of local populations. This is evident in the trade policies adopted by ECOWAS and WAEMU, which seek to eliminate internal taxes and unify external ones. Regional treaties are more efficient in raising the level of intra-regional trade, especially in West Africa (Carrère, 2004).

In intra-regional international agricultural trade, factors of resistance (*lntp*), monetary unions (*cmo*), and particularities between countries increase trade flows between them. ECOWAS (*ceco*) does not affect internal transactions, as opposed to aggregate behavior. The effects of the other variables regarding directions and statistical significance did not change, despite their different magnitudes (Tab. 2).

Increased agricultural demand and supply enhance trade flows among West African countries, *lneyy*, and reveal that policies designed to expand production have a positive effect on internal transactions. The edaphoclimatic heterogeneities that make them complementary in agricultural production mitigate the depressive effect of increased production on prices. And increased regional agricultural imports reveal that local production needs can be met through market adjustments between local supply and demand. Although edaphoclimatic conditions reveal a potential for productive complementarity in West Africa, intra-regional trade is more intense in competitive rather than complementary products (Hanink, Owusu, 1998).

The low level of commercial agricultural production directed to the regional market is the main restriction preventing trade among countries from becoming more intense. Investment in transportation infrastructures and standardization of regulations yield benefits tied to private engagement in agricultural development. Harmonization of standards increases trade among countries, especially African exports (Czubala, Shepherd, Wilson, 2009). Regional convergence between supply and demand will speed up transactions between countries in the sector, for which purpose agricultural industrialization is fundamental to correct divergences.

In West Africa's internal agricultural transactions, the greater the multilateral constraints, the lower the flows, and the greater the bilateral ones, the larger the transactions between the region's countries, *lntp*. The result reveals contradictory directions between bilateral and multilateral resistance to trade. One of the justifications for the behavior of bilateral resistance lies in the concentration of transactions in border areas between countries, meaning that the high prices paid by importers do not reflect trading costs (except profits), but rather higher profit margins. Restrictions on international transactions have no significant influence on trade in border areas between West African countries (ECOWAS[b], 2015). The positive coefficient for *lntp* provides evidence that intra-regional agricultural trade is dominated by the movement of traders from one country to another rather than by transactions between exporters and importers from different countries. The share of production in the countries that meets regional demands moves between neighbors according to its best remuneration. This result corroborates the effects of sharing a common border and of geographical distance.

The positive contribution of shorter distances to trade flows provides evidence of the contribution of infrastructure investment, a challenge reserved for countries, given that regional infrastructures do not cover rural areas to a large extent. Several studies on international trade in sub-Saharan Africa have shown a negative relationship between trade and distances between countries (Buys, Deichmann, Wheeler, 2010). Regional investment packages, whose effectiveness requires simultaneous actions at regional level and complementarity among them at the level of the countries involved, is one of the strategies to ensure the expected benefits.

The role of unofficial languages in ensuring closer relations between West African countries, particularly in border areas, should be highlighted. Although official languages contribute positively to trade flows, the role played by unofficial languages is even more important in internal international transactions in the region due to the low schooling levels prevailing there. The peculiarities of local languages among the region's countries are one of the factors limiting trade flows (ECOWAS[b], 2015). Actions to improve their contribution through political interventions are restricted to promoting stability and sound coexistence among communities in border areas. As opposed to official languages, traditional languages are not components of formal education and their learning results from acquaintanceship.

ECOWAS does not have a statistically significant impact, *ceco*, on internal international agricultural trade flows in West Africa. Buys, Deichmann and Wheeler (2010) found the same result in their investigation of trade flows in Sub-Saharan Africa. Contrary to studies by Cernat (2001) and Cissokho, Haughton, Makpayo and Seck (2012), who pointed out that trade increased between countries as a result of effects caused by ECOWAS, but these might reflect effects brought about by WAEMU – the monetary union – that were not controlled for in their investigations. Trade patterns in West Africa are not different from those that prevailed prior to the establishment of ECOWAS and the community has not been promoting trade between its member states effectively (Hanink, Owusu, 1998). The effects of its trade policies have not yet been felt in intra-regional transactions, in part because of the ongoing structuring efforts to promote liberalization effectively. The absence of these conditions is cause of the inefficiencies of trade blocs in Africa, as highlighted by Yang and Gupta (2008).

The impacts of intra-regional trade agreements in West Africa have not been actually felt so far because the required conditions to ensure their effectiveness are under construction, such as community checkpoints, regional standardization of products, and use of regional passports. Thus, the conditions that prevailed before those agreements were entered into force still affect commercial transactions in the region. Constraints related to the effective implementation of trade treaties raise questions as to their actual capacity to promote trade (Cernat, 2001). This fact constitutes one of the explanations for the insignificance of ECOWAS as a determinant of intraregional agricultural trade in the period under analysis.

Unlike other economic measures, the impacts of trade measures on transactional flows depend on their effective implementation, especially in West Africa. Due to the political fragility of African countries, the positive effects of anticipating trade agreements are unlikely to be verified (Cernat, 2001).

Bilateral costs are factors of resistance to international transactions, partly due to the exchange rate, which is eliminated by a monetary union when the countries involved in the transactions are both member states (Carrère, 2004; Masson, Pattillo, 2004). The WAEMU is the only African economic bloc that has been consistently boosting trade among its member countries (Yang, Gupta, 2008). The West African monetary union, *cmo*, has been significantly expanding trade flows among its member countries. The impacts of the WAEMU are not limited to reducing exchange rate costs, as the organization also invests in infrastructure, provides credit, and promotes macroeconomic stability. It may be difficult to distinguish the effects of a monetary union from those of other regional integration policies on international transactions, since they are usually overlapping effects, as is the case of those brought about by WAEMU (Masson, Pattillo, 2004). The monetary union in this community has boosted the impacts of intra-regional trade policies (CARRÈRE, 2004).

This result provides empirical evidence of the capacity of the monetary union in West Africa to speed up economic integration in the region. Accession of the other countries of the region to the WAEMU should be encouraged to ensure that the socioeconomic benefits it affords are expanded at the regional level. Establishing a monetary union that includes all West African countries is an intention of ECOWAS since it was set up, but political constraints in some of the region's countries and the higher priority given to other economic strategies have been delaying this process (Masson, Pattillo, 2004).

Increased intra-regional transactions will stimulate production oriented to this market and the economic exploitation of the unique aspects of West African countries. Specific individual effects may vary between those involved in a given commercial transaction and make a difference in defining trade flows (Helpman, Melitz, Rubinstein, 2008). Global analysis of West African agricultural trade suggests that countries are not taking advantage of the economic opportunities afforded by their complementarities in their edaphoclimatic heterogeneities. However, the results suggest an increase in the intra-regional transactions of specific countries, confirming that they are exploiting their peculiarities. The high trade potential among countries in the region is evident and capable of leveraging returns to scale (WB, 2015). This contradiction reveals the difference between the pattern of intra-regional trade, in which transactions of subsistence crop surpluses prevail, and the pattern of extra-regional trade, which is focused on the large- scale commercial production of raw materials.

Table 3 shows the estimation results of extra-regional determinants of West African agricultural trade. They reveal how the predominance of these transactions define the behavioral pattern observed in the global analysis and confirm that commercial agriculture is focused on producing raw material to be exported to markets outside the region. This composition of the commercial basket reflects the effects of trade liberalization on the region's development, which according to Shaik (2017) has a negative effect on the agricultural productivity of Sub-Saharan Africa. Most trade models according to which the greater the openness of economies, the greater the welfare of society ignore adjustment costs (Kerr, 2016). It has been emphasized in discussions that the African production framework has not changed and that its traditional share in international trade remains the same – that of a provider of raw materials – with little evidence that structural foundations capable of generating development have been actually laid (Nyarko, 2012).

Geographical distance does not have statistically significant impacts on these extra-regional flows. The needs between the partners involved, expressed in terms

Tab. 2. Result of the estimation of determinants of intra-regional international agricultural trade in West Africa.

lnxij	Coefficient	Standard error	z	p-value
lneyy	0.7257	0.0307	23.65	0.000
lntp	0.0749	0.0339	2.21	0.027
fron	0.7854	0.1194	6.58	0.000
disv	316.3479	33.6849	9.39	0.000
ling	0.2909	0.1459	1.99	0.046
ceco	-0.1304	0.3458	-0.38	0.706
cmo	0.7530	0.1593	4.73	0.000
Benin (constant)	0.9574	0.5187	1.85	0.065
Burkina Faso	1.2791	0.2488	5.14	0.000
Cape Verde	1.8267	0.3874	4.72	0.000
Côte d'Ivoire	1.3623	0.2241	6.08	0.000
Gambia	1.1771	0.2834	4.15	0.000
Ghana	1.0664	0.2401	4.44	0.000
Guinea	1.8476	0.6530	2.83	0.005
Guinea-Bissau	-	(omitted)		
Liberia	-	(omitted)		
Mali	1.4483	0.2655	5.45	0.000
Mauritania	0.2772	0.5176	0.54	0.592
Niger	2.4347	0.2498	9.75	0.000
Nigeria	0.1956	0.4689	0.42	0.677
Senegal	1.5538	0.2119	7.33	0.000
Sierra Leone	-	(omitted)		
Togo	1.2464	0.2125	5.87	0.000
sigma_u	0	0.0454		
sigma_e	2.1306	0.0321		
rho	-	(omitted)		

Number of observations = 2,207
Log likelihood = -4,801.0085 LR chi2(19) = 925.95
Prob > chi2 = 0.000
LR test of sigma_u=0: chibar2(01) = 0.00
Prob >= chibar2 = 1.000

Tab. 3. Result of the estimation of determinants of extra-regional international agricultural trade in West Africa.

lnx_{ij}	Coefficient	Standard error	z	p-value
lneyy	0.8436	0.0172	49.03	0.000
lntp	-0.1267	0.0243	-5.22	0.000
ling	1.9689	0.0840	23.45	0.000
disv	561.0062	533.867	1.05	0.293
Benin (constant)	-1.2142	0.2821	-4.3	0.000
Burkina Faso	-0.5860	0.1371	-4.28	0.000
Cape Verde	-0.0079	0.1351	-0.06	0.953
Côte d'Ivoire	-0.1743	0.1159	-1.5	0.133
Gambia	-0.6811	0.1418	-4.8	0.000
Ghana	-0.3925	0.1204	-3.26	0.001
Guinea	-1.3437	0.3115	-4.31	0.000
Guinea-Bissau	-	(omitted)		
Liberia	-	(omitted)		
Mali	-0.5954	0.1678	-3.55	0.000
Mauritania	-0.4446	0.1613	-2.76	0.006
Niger	-0.8427	0.1294	-6.51	0.000
Nigeria	-0.7182	0.1787	-4.02	0.000
Senegal	-0.3626	0.1136	-3.19	0.001
Sierra Leone	-	(omitted)		
Togo	-0.635	0.1251	-5.08	0.000
sigma_u	0	0.0274		
sigma_e	2.1125	0.0194		
rho	-	(omitted)		

Number of observations = 5,926
Log likelihood = -12,840.604 LR chi2(16) = 3,023.37
Prob > chi2 = 0.000
LR test of sigma_u=0: chibar2(01) = 0.00
Prob >= chibar2 = 1.000

of supply and demand, make such distance irrelevant in defining those flows. As pointed out by Torres and Van Seters (2016), the transactions of West African countries are focused on countries that demand their raw materials and offer products that meet their final consumption needs. Consistent with the pattern of trade in the region's countries, this fact provides evidence of the potential for expanding transactions with nearby countries, especially other African countries. Raising the level of processing of agricultural products in the region is crucial for taking advantage of this opportunity.

5. CONCLUSION

The patterns of intra and extra-regional international agricultural trade in West Africa are different in their determinants. Commercial production is directed toward extra-regional transactions and focused on raw material exports. Agricultural imports are in turn dominated by products destined to final consumption, given the low degree of agroindustrialization of the region's countries. This divergence between regional agricultural supply and demand limits the intra-regional intensity of international trade in the sector.

Although logistic costs impact West Africa's extra-regional agricultural transactions negatively, geographical distance does not significantly affect these flows. Needs expressed in terms of supply and demand forces overlap logistical constraints in such transactions. However, the intensity of trade within the region is greater between geographically closer countries. And in both intra- and extra-regional flows, sharing a common official language increases international agricultural transactions.

In West Africa's global agricultural transactions, flows are higher among ECOWAS member countries and the monetary union has not affected them significantly. The greater intensity of transactions between ECOWAS member countries is not due to any economic closure promoted by the bloc, but rather to the fact that they constitute a natural cluster based on their geographical distribution and cultural bonds. ECOWAS has not affected the degree of economic openness of its member countries, as its external rates are recent and generally lower than those agreed upon by them at the World Trade Organization (WTO). To a large extent, its trade policy has not been effective due to institutional and infrastructural constraints.

As for the non-significance of the West African Economic and Monetary Union (WAEMU) effect, it is justified by the regional divergence between agricultural supply and demand and by the concentration of commercial production of West African countries in products destined for extra-regional trade. And because the extra-regional pattern is dominant in the aggregate, the effects brought about by the monetary union have not been reflected in the region's global agricultural flows.

In intra-regional international agricultural transactions, ECOWAS has not significantly affected trade flows between countries. On the other hand, these flows are higher among WAEMU member countries. The institutional and infrastructural limitations that have been preventing the effective implementation of the ECOWAS trade policy are the causes of its ineffectiveness in boosting trade in West Africa. In contrast, the monetary union has intensified trade between member countries partly because of its immediate effects, particularly the elimination of exchange rate costs.

For the international agricultural transactions of West African countries to be redirected and intensified, agro-industrial development must be promoted in the region to increase domestic consumption of raw materials and local supply of products with a high degree of processing. The formation of physical capital in this process must be reserved to the private sector, while the public sector should create a favorable macroeconomic environment and provide incentives and credit adjusted to the local context in terms of finance.

Finally, in addition to the empirical application of the Structural Gravity Model to the specific context of West Africa's agricultural sector, bidirectional specifications of flows and components of bilateral resistance are scientific contributions of this investigation. The unidirectional flow specification implicitly excludes information, particularly on costs, from importing countries between the border and final consumers. And the bidirectional one incorporates such information by considering the exports of both parties, including for the most remote parts of the countries between the gate and the border. Although information on imports is not exactly lost, this is the best approximation possible for this investigation.

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APPENDIX

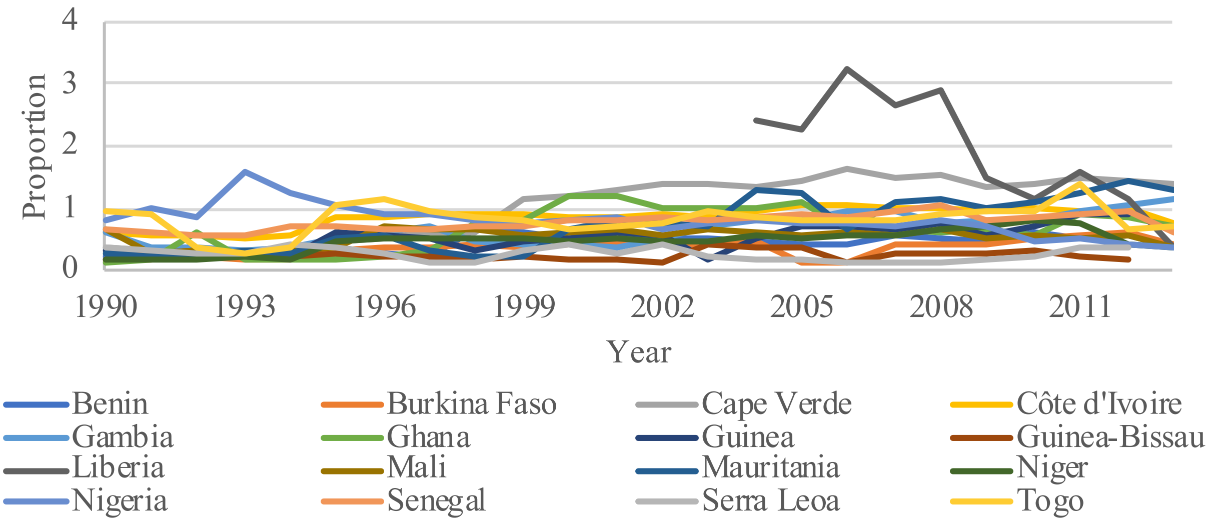
Tab. A.1. Average external tariffs (ad valorem) of West African countries, ECOWAS, WAEMU, South Africa, Brazil, China, United States of America, and the European Union.

Individuo	Simple average of upper limit (final bound)[1]			Simple average applied to the most favored nations (MFN applied)[2]			Trade weighted average[3]			Binding coverage[4]	
	Tot	Ag	NAg	Tot	Ag	NAg	Tot	Ag	NAg	Tot	NAg
Benin	28.3	61.8	11.3	12.2	15.8	11.5	11.1	12.6	9.9	39.1	29.9
Burkina Faso	42.1	98.1	13.8	12.2	15.8	11.5	9.8	15.0	9.0	39.1	30.0
Cape Verde	15.8	19.3	15.2	10.0	12.2	9.7	10.7	15.5	8.9	100	100
Côte d'Ivoire	11.1	14.9	8.5	12.2	15.8	11.6	7.2	11.2	6.6	33.3	23.3
Gambia	102.8	104.6	60.5							13.7	0.7
Ghana	92.5	97.1	39.7							14.3	1.3
Guinea	20.1	39.7	10.1							38.7	29.5
Guinea-Bissau	48.7	40.1	50.0	11.9	14.6	11.5				97.7	97.4
Liberia	26.7	23.8	27.2	10.2	10.6	10.1				100	100
Mali	28.5	59.2	13.4	12.2	15.8	11.5				39.9	30.9
Mauritania	19.8	38.1	10.6	12.0	11.1	12.2	8.1	6.6	8.3	39.3	30.1
Niger	44.7	85.7	38.2	12.2	15.8	11.5	11.3	14.8	10.1	96.7	96.2
Nigeria	118.3	150.0	49.2	12.1	15.8	11.4	10.7	10.3	10.7	19.1	7.0
Senegal	30.0	29.8	30.0	12.2	15.8	11.5	9.4	12.9	8.4	100	100
Sierra Leone	47.4	40.4	48.5							100	100
Togo	80.0	80.0	80.0	12.2	15.8	11.5	11.1	16.3	10.4	13.9	0.9
South Africa	19.0	40.4	15.7	7.6	8.5	7.5	5.7	10.5	5.3	96.1	95.5
Brazil	31.4	35.4	30.8	13.5	10.0	14.1	9.9	12.5	9.8	100	100
China	10.0	15.7	9.2	9.9	15.6	9.0	4.5	9.2	4.2	100	100
USA	3.5	4.8	3.3	3.5	5.2	3.2	2.2	3.8	2.1	100	100
European Union	4.8	10.9	3.9	5.1	10.7	4.2	2.7	8.5	2.3	100	100

Tariff classification category	ECOWAS[5]	WAEMU
Basic social products	0.0	0.0
to be continued		
conclusion		
Basic products, raw materials and capital goods	5.0	5.0
Semifinished goods and inputs (intermediaries)	10.0	10.0
Final goods	20.0	20.0
specific goods for economic development	35.0	-

[1] Tariff band assumed in the World Trade Organization (WTO).
[2] Most Favored Nations (MFN) tariffs are the standard tariffs charged for imports from WTO member nations, do not include preferential tariffs and the lowest tariffs set within import quotas.
[3] Effective tariffs applied, weighted by the traded volumes of the products, 2014.
[4] Percentage of products or tariff lines (products defined at a highly detailed level for the fixing of import taxes) in the country's legally assumed WTO commitments.
[5] The definition of product categories in ECOWAS and WAEMU common external tariffs is based on the needs of the products for the countries, the use purpose and the contribution to development.
Tot = Total, Ag = Agricultural e NAg = Non Agricultural.
Sources: WTO, 2016, DGIZ, 2014 and ECOWAS 2010.

Fig. A.1. Evolution of the economic openness [(X + M) / Y] of West African countries, real rates at 2013 prices, from 1990 through 2013.



Sources: WTO and WB, 2015.

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Crescita economica e riduzione dei GHG_S: un problema globale

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Abstract. The environmental sustainability is probably one of the most controversial topics of national policy agendas. The needs to combine economic growth and well-being, have forced governments to introduce tools for reducing CO_2 emission and avoiding climate change. This paper aims to assess the effectiveness of these measures in the 1990-2014 period for a sample of 188 countries; and to analyze the determinants of CO_2 in the 2000-2014 period for a sample of 175 countries. The results suggest that *i*) richest countries have a GDP elasticity of CO_2 greater than that of poorest countries; and *ii*) GDP, energy consumption, urbanization, agricultural development, tourism and depletion of natural resources are directly correlated to CO_2, while forest area, alternative energy, trade openness and FDI inflows are inversely related to CO_2.

Keywords: CO_2, crescita ecosostenibile, consumi energetici, urbanizzazione, fonti energetiche alternative.
JEL codes: B22, N50, Q56, Q57.

1. INTRODUZIONE

Il tema della sostenibilità ambientale costituisce probabilmente uno degli argomenti più controversi e discussi all'interno delle agende di politica economica non solo dei paesi sviluppati ma anche di quelli di recente industrializzazione. Negli ultimi trenta anni la necessità di coniugare crescita economica ed equilibrio naturale, di preservare la biodiversità, e le sempre maggiori preoccupazioni sui mutamenti climatici prodotti dalle emissioni industriali di gas serra, hanno spinto la comunità internazionale a promuovere progetti e agende condivise sui temi dello sviluppo ecosostenibile.

Difatti, il surriscaldamento globale generato dall'intensificazione delle attività produttive e dal progressivo esaurimento del capitale naturale, ha mobilitato le coscienze e gli strati più profondi della società civile, sollevando l'esigenza di una revisione radicale delle direttrici lungo le quali si stanno sviluppando i rapporti uomo-ambiente e sviluppo economico.

Nel corso degli ultimi anni si sono, dunque, susseguiti numerosi incontri tesi alla promozione di accordi di carattere sia volontario che vincolante, e aventi come obiettivo primario l'individuazione e l'adozione delle strategie più efficaci nella riduzione delle emissioni di gas serra. Fra i più noti, ritroviamo le Conferenze sull'Ambiente e lo Sviluppo delle Nazioni Unite tenutesi a Rio de Janeiro nel 1992 e nel 2012 (Rio +20) e gli Accordi di Parigi (2015).

Allo stato attuale, le numerose iniziative di sensibilizzazione e responsabilizzazione portate avanti dalla maggioranza dei paesi industrializzati non hanno dato i risultati sperati. Basti pensare che secondo il recente rapporto internazionale dell'Agenzia Nazionale Oceanica e Atmosferica (NOAA), *State of the Climate*, nel 2017 la concentrazione di CO_2 nell'atmosfera ha raggiunto il record storico di 405 parti per milione (Blenden *et al.*, 2018), circa il 14,4% in più del 1990 (elaborazioni su dati NOAA)[1]. Allo stesso tempo, dal 1990 al 2017 le temperature globali delle terre emerse e dei mari sono aumentate mediamente di circa 0,38°C (elaborazioni su dati Met Office Hadley Centre)[2].

L'obiettivo del lavoro in oggetto sarà duplice: *i*) da un lato proveremo a verificare se la cogenza degli accordi internazionali abbia avuto un effetto significativo sull'andamento delle emissioni dei paesi avanzati; e *ii*) dall'altro cercheremo di individuare le principali determinanti delle emissioni di CO_2 per un campione di 175 paesi, al fine di identificare gli strumenti di politica ambientale più efficaci nella lotta all'inquinamento.

2. I PRINCIPALI ACCORDI INTERNAZIONALI SUL CLIMA

Prima di addentrarci nelle questioni tecno-economiche, è utile descrivere sinteticamente i principali accordi internazionali sul clima stipulati negli ultimi decenni. La cronistoria delle convenzioni sull'ambiente ha inizio con la Conferenza sull'Ambiente e lo Sviluppo delle Nazioni Unite tenutasi a Rio de Janeiro nel 1992[3], alla quale hanno preso parte 172 paesi e 108 capi di stato. L'incontro, ribattezzato Summit della Terra, ha condotto alla firma comune di numerosi e importanti documenti di impegno formale, fra cui la Convenzione sui cambiamenti climatici, l'Agenda 21, la Convenzione sulla biodiversità, l'Accordo sugli stock ittici e la Dichiarazione sulle foreste. La Convenzione quadro sui cambiamenti climatici delle Nazioni Unite (UNFCCC), divenuta vincolante nel 1997 con l'adozione del Protocollo di Kyoto (e attuativa nel 2005), costituisce la pietra d'angolo dell'intero progetto, in quanto con essa viene stabilita la necessità e l'urgenza di ridurre progressivamente le emissioni di gas serra, con particolare riguardo per i paesi industrializzati e le economie in transizione[4].

Nello specifico, il Protocollo di Kyoto, con i suoi 26 articoli, ha obbligato per la prima volta le parti contraenti al rispetto di limiti giuridicamente vincolanti di emissioni di gas serra[5], prevedendo anche il miglioramento dell'efficienza energetica, la correzione delle imperfezioni dei mercati e lo sviluppo concordato di forme di energia sostenibili e di agricoltura biologica (United Nations, 1998).

Queste preliminari disposizioni sono state successivamente riconfermate e integrate nel corso di diversi summit internazionali e richiamate dall'ONU tra i *Sustainable Development Goals*. In particolare, il Clima e le relative politiche hanno caratterizzato due summit incentrati sugli obiettivi di riduzione delle emissioni di gas serra e in particolare di monossido di carbonio: *i*) l'incontro del 2008 fra l'Unione Europea e 37 paesi industrializzati sulla prima fase di impegno degli accordi[6] (Idem); e *ii*) l'adozione dell'Emendamento di Doha[7] nel 2012 sulla seconda fase di impegno degli accordi (United Nations, 2012).

Al fine di assicurare il rispetto di tali accordi in seno all'UE-28, la Commissione Europea – su approvazione del Parlamento europeo – ha varato la dir. 2009/28/CE, il c.d. Pacchetto per il clima e l'energia 2020. Un disposto normativo avente tre obiettivi fondamentali entro il 2020: *i*) la riduzione delle emissioni di gas serra di almeno il 20% rispetto al 1990; *ii*) la riduzione del 20% dell'e-

[1] Le serie storiche sono reperibili alla URL: http://www.esrl.noaa.gov/gmd/ccgg/trends/.

[2] Le serie storiche sono reperibili alla URL: https://www.metoffice.gov.uk/hadobs/hadcrut4/index.html. Per maggiori dettagli sulla metodologia, invece, si rimanda a Morice *et al.* (2012).

[3] È necessario precisare che l'incontro è stato preceduto da diverse tappe preparatorie, il cui asse portante è rappresentato dalla prima Conferenza delle Nazioni Unite sulla protezione dell'ambiente di Stoccolma, che nel 1972 ha riunito 113 paesi e condotto all'adozione della prima Dichiarazione dei diritti e delle responsabilità ambientali dell'uomo.

[4] I paesi effettivamente vincolati sono solo 39 su 180, come riportato nell'elenco *Annex I* dell'accordo.

[5] L'accordo ha previsto limiti restrittivi per i gas serra con il maggior potere climalterante: anidride carbonica, esafluoro di zolfo, idrofluorocarburi, metano, ossido di azoto e perfluorocarburi. L'esafluoro, gli idrofluorocarburi e i perfluorocarburi vengono anche chiamati F-gas o gas fluorurati. Per garantire il raggiungimento degli obiettivi dichiarati, l'accordo ha previsto l'utilizzo di tre strumenti: *i*) l'*emission trading*, ovvero la possibilità per i paesi più virtuosi di vendere "permessi" di inquinamento ai paesi meno accorti; *ii*) la *joint implementation*, che si riferisce all'opportunità di accordi fra le parti contraenti sulla redistribuzione degli obiettivi, a patto che l'obbligo complessivo venga rispettato; e *iii*) i *clean development mechanisms*, con i quali i paesi giuridicamente vincolati, aiutando i paesi relativamente più poveri a contrarre l'inquinamento da CO_2, possono ottenere speciali certificati di riduzione delle emissioni (CERs) da sottrarre ai valori effettivamente registrati sul territorio nazionale (United Nations, 1998).

[6] Col quale i firmatari del Protocollo di Kyoto si sono impegnati a ridurre le emissioni di CO_2 del 5% rispetto al 1990 entro il 2012.

[7] Col quale i firmatari del Protocollo di Kyoto si sono impegnati a ridurre le emissioni di CO_2 del 18% rispetto al 1990 entro il 2020. Nel corso di questo incontro, le parti hanno inoltre aggiunto alla lista dei gas serra il trifluoruro di azoto.

nergia consumata proveniente da fonti fossili, attraverso il miglioramento dell'efficienza energetica; e *iii*) l'approvvigionamento del 20% del fabbisogno energetico totale con fonti rinnovabili.

L'ultimo significativo incontro in ordine temporale è infine costituito dagli Accordi di Parigi sui Cambiamenti climatici del 2015, con cui 195 paesi si sono giuridicamente impegnati a rispettare un rigido piano d'azione composto da 29 articoli. Lo scopo è quello contenere il surriscaldamento globale al di sotto dei 2 gradi centigradi, attraverso la riduzione delle emissioni di CO_2 di almeno il 40% dal 1990 entro il 2030 (United Nations, 2015).

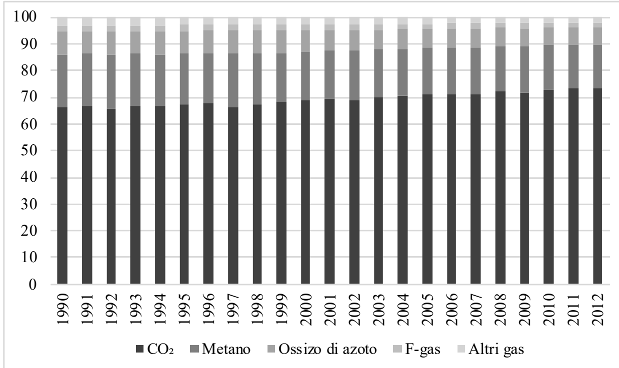
3. UNA RASSEGNA DELLA LETTERATURA SULLE DETERMINANTI DELLA CO_2

La CO_2 può essere considerata a pieno titolo come il gas serra quantitativamente più presente nell'atmosfera, nonché il più pericoloso, nel breve periodo, per il delicato equilibrio climatico del pianeta[8]. Difatti, nel periodo 1990-2012 la CO_2 ha contribuito in media per il 69,21% alle emissioni totali di gas serra, seguita nell'ordine dal metano (18,28%), dall'ossido di azoto (7,82%) e dai gas fluorurati con il 4,69%. E come mostra la Figura 1 il suo apporto è progressivamente aumentato lungo tutta la finestra temporale considerata, passando dal 66,19% del 1990 al 73,24% del 2012, con uno scostamento netto del +7,05%.

Così, negli ultimi tre decenni – complice la maggiore attenzione della comunità internazionale per le tematiche ambientali – si è sviluppata una copiosa letteratura sull'argomento, che ha provato a indagare le determinanti delle divergenze fra i paesi industrializzati e in via di sviluppo nelle emissioni di CO_2 (Shafik, 1994; Schmalensee *et al.*, 1998; Ravallion *et al.*, 2000; Friedl, Getzner, 2003; Ang, 2007 e 2009; Weber *et al.*, 2008; Choi *et al.*, 2010; Iwata *et al.*, 2012; Solarin, 2014; Dogan, Seker, 2016a; Balogh, Jámbor, 2017).

Schmalensee *et al.* (1998), avvalendosi di un campione variabile di paesi per il periodo 1950-1990, trovano una relazione a campana fra l'andamento del reddito pro-capite a parità di potere d'acquisto (ppa) e il consumo di energia pro-capite, e le emissioni pro-capite di CO_2, avallando l'esistenza della c.d. curva di Kuznets ambientale (d'ora in avanti EKG).

Fig. 1. Andamento comparato delle emissioni di gas serra a livello mondiale nel periodo 1990-2012.



Fonte: elaborazioni dell'autore su dati World Bank.

La EKG stabilisce una relazione parabolica fra la crescita del reddito pro-capite e l'inquinamento ambientale di un paese. In altri termini, inizialmente l'aumento del reddito nei paesi relativamente più arretrati è associato a un incremento consistente delle emissioni inquinanti, che tuttavia, raggiunto un certo picco di benessere economico cominciano gradualmente a ridursi[9] (Kuznets, 1955; Grossman, Krueger, 1991; Dogan, Seker, 2016b).

Un'evidenza confermata, almeno nel segno della sua relazione, da Ang (2009), che analizzando i dati sui consumi energetici e sulle emissioni inquinanti in Cina nel periodo 1953-2006, stima che le principali determinanti della CO_2 sono il consumo pro-capite di energia, il pil pro-capite e il grado di apertura commerciale.

Lo studio di Sharma (2011), invece, concentra la sua attenzione su un numero maggiore di variabili indipendenti, studiate attraverso un modello panel dinamico per un campione di 69 economie mondiali nel periodo 1985-2005. Nello specifico, egli rileva che il pil pro-capite e il consumo di energia primaria pro-capite sono positivamente e significativamente correlati alla dinamica delle emissioni di CO_2; mentre, il tasso di urbanizzazione, il grado di apertura commerciale e il consumo pro-capite di energia sembrano essere associati a una riduzione delle emissioni di CO_2.

Balogh e Jámbor (2017) considerano il ruolo giocato da variabili meno convenzionali ma altresì fondamenta-

[8] In termini relativi il gas più pericoloso è il metano, che – nonostante consenta di ridurre le emissioni di CO_2 e particolato – detiene un potere climalterante da 21 a 28 volte maggiore lungo un orizzonte di 100 anni, e 84 volte superiore su un periodo di 20 anni (Mohajan, 2011; IPCC, 2014).

[9] È necessario, tuttavia, sottolineare che non tutti gli studi convergono su questa ipotesi. Secondo un'analisi realizzata da Andersson e Karpestam (2013) la relazione di associazione fra crescita economica ed emissioni di gas serra non troverebbe adeguato fondamento scientifico. Mentre Tiwari (2011), Lim *et al.* (2014) e Gosh *et al.* (2014) dimostrano l'esistenza di una relazione addirittura negativa fra crescita del pil ed emissioni di CO_2, rispettivamente per l'India, le Filippine e il Bangladesh.

li nello spiegare l'andamento dei livelli di inquinamento. Essi testano le loro ipotesi attraverso una serie di modelli panel GMM (generalized method of moments) su un campione di 168 paesi per il periodo 1990-2013, trovando che l'uso di fonti energetiche rinnovabili, l'energia nucleare, lo sviluppo del settore agricolo e del settore finanziario riducono le emissioni di CO_2, mentre l'aumento dei turisti internazionali pro-capite, il grado di apertura commerciale, la produttività del settore agricolo e l'utilizzo di energia prodotta dal carbone favoriscono un'accelerazione delle emissioni di CO_2.

Fra queste variabili è utile menzionare il grado di apertura commerciale, lo sviluppo del settore agricolo e il turismo internazionale. Per quanto concerne l'agricoltura, secondo Grace *et al.* (2014) essa contribuisce fra il 7-14% alle emissioni globali di CO_2, ovvero fra i 2,5 e i 5 miliardi di tonnellate di CO_2 equivalente solo nel 2014. In particolare, l'aumento delle terre coltivate accrescerebbe i processi di deforestazione, provocando una diminuzione della naturale proprietà dei boschi di sottrarre CO_2 all'atmosfera (Baccini *et al.*, 2012). Con riferimento al commercio internazionale, invece, alcuni studi dimostrano che la maggiore facilità di accesso alle nuove conoscenze tecnologiche in materia di tutela ambientale, indotta dal potenziamento degli scambi commerciali, può consentire di ridurre significativamente le emissioni complessive di CO_2 (Akin, 2014).

Infine, in merito al turismo, Lee e Brahmasrene (2013), avvalendosi di modelli panel con effetti fissi e di tecniche di cointegrazione per i paesi dell'Unione Europea nel periodo 1988-2009, dimostrano che esisterebbe una relazione negativa di lungo periodo fra il numero dei turisti internazionali e le emissioni di CO_2[10]. A cui si aggiunge anche il rapporto di correlazione inversa fra gli investimenti diretti esteri (IDE) in entrata e i livelli di inquinamento.

4. ANALISI GEOGRAFICA E REDDITUALE DELLE EMISSIONI DI CO_2

Come puntualizzato nella parte introduttiva dell'elaborato, l'obiettivo primario (ma non esclusivo) degli accordi internazionali stipulati dai paesi industrializzati è stato quello di ridurre progressivamente le emissioni di gas serra e contestualmente di promuovere uno sviluppo economico ecosostenibile e biocompatibile. Tuttavia, nonostante l'adesione volontaria di una parte considerevole della comunità internazionale, l'attuazione dei relativi disposti normativi ha incontrato non pochi problemi, che possiamo sintetizzare nei seguenti due punti: *i*) le delocalizzazioni e/o esternalizzazioni produttive e *ii*) il *free riding*.

In primo luogo, i paesi industrializzati possono aggirare i limiti imposti dai trattati internazionali delocalizzando e/o esternalizzando nei paesi relativamente più poveri fasi particolarmente inquinanti dei propri processi produttivi, sfruttandone la legislazione ambientale più permissiva e gli standard lavorativi molto bassi (Yunus, 2008; Rodrik, 2011). Una circostanza che da un lato determina un incremento dell'impronta ecologica[11] dei paesi arretrati e in via di sviluppo e dall'altro distorce significativamente il sistema di imputazione delle responsabilità delle emissioni (Piccari, 2018)[12].

In seconda istanza, i paesi contraenti possono decidere unilateralmente di non adempiere alle obbligazioni stipulate e di scaricare sugli altri governi l'intero onere della riparazione del danno ambientale, godendo esclusivamente dei benefici dello sfruttamento del bene pubblico, assumendo *de facto* un atteggiamento da *free rider* (Gosseries, 2004; Meyer, Roser, 2011; Huggel *et al.*, 2016). Un classico problema di *tragedy of the commons* generato dalle specificità dei beni pubblici, caratterizzati dalla non escludibilità nel consumo e dalla non rivalità nel godimento. In un tale contesto, l'incentivo a sfruttare i comportamenti virtuosi dei paesi più responsabili e attenti alla salvaguardia dell'ecosistema, attraverso l'assunzione di atteggiamenti opportunistici, è quindi particolarmente elevato (Castellucci, 2017; Tirole, 2017). Difatti, secondo Hardin (1968, p. 1244, ns. traduzione) «la rovina è la destinazione verso cui tutti gli uomini si precipitano, ognuno perseguendo il proprio miglior interesse in una società che crede nella libertà dei beni comuni. La libertà nei beni comuni porta tutti alla rovina».

Proviamo a verificare tali eventualità, cominciando con l'analisi dell'andamento medio delle emissioni pro-capite di CO_2 in tonnellate nel periodo 1990-2014[13],

[10] Diversamente, Shakouri *et al.* (2017), utilizzando un modello panel GMM per 12 paesi dell'area asiatica e pacifica nel periodo 1995-2013, trovano una relazione positiva e significativa fra gli arrivi di turisti internazionali e le emissioni di CO_2.

[11] Si tratta di un indice che prova a stimare la superficie di terra e di mare necessaria a un paese per rigenerare le risorse consumate e assorbire i rifiuti prodotti. E l'impronta di carbonio incide circa per il 50% dell'indicatore complessivo. Esso, dunque, consente di fornire una misura di sintesi dell'impatto delle attività umane sull'ecosistema (Wackernagel e Rees, 1998).

[12] Non bisogna, tuttavia, dimenticare che talvolta sono gli stessi paesi in via di sviluppo ad adottare strumenti di politica ambientale particolarmente blandi al fine di attirare gli IDE dei paesi più ricchi. Ciò accade soprattutto nei settori ad alta intensità di inquinamento, dove la regolamentazione ambientale può assumere carattere pienamente endogeno (Dean *et al.*, 2009).

[13] Limitatamente ai dati resi disponibile dalla World Bank Open Data.

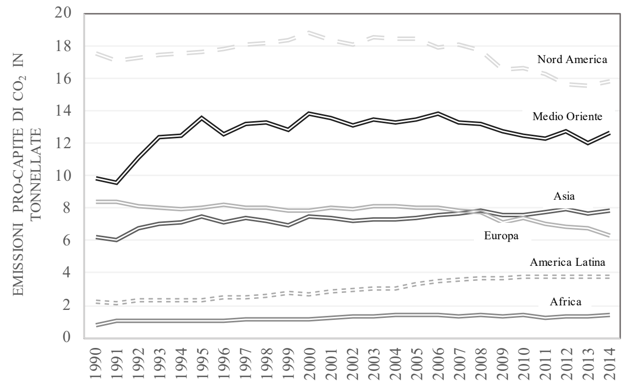
per cinque grandi aree geografiche del mondo[14]: Africa, America Latina, Asia, Europa, Medio Oriente e Nord America.

Dalla Figura 2 notiamo come nel periodo indagato nessuna delle regioni selezionate abbia fatto registrare una contrazione significativa delle emissioni di CO_2 che possa essere ricondotta in qualche modo all'adozione delle prescrizioni e al rispetto dei vincoli imposti dai trattati internazionali. Nel dettaglio, rileviamo che nei paesi africani, latino americani e asiatici, coerentemente con l'ipotesi della EKG, le emissioni pro-capite sono aumentate rapidamente, con variazioni medie del 73,7%, 72,07% e del 26,81%, rispettivamente; nel Medio Oriente, sono rimaste sostanzialmente stabili, manifestando un andamento medio sinusoidale, se si eccettua l'accelerazione fra il 1991 e il 1993; mentre, l'unica riduzione si è verificata nel Nord America e in Europa, con uno scostamento medio del -9,63% e del -24,32%, rispettivamente. Un *output* dovuto principalmente al crollo del reddito e della produzione industriale ivi registrate a seguito della recessione economica del biennio 2007/2008. Non è un caso che nel periodo immediatamente antecedente la crisi, le emissioni abbiano registrato invece un andamento sempre costante, che consente di escludere l'eventualità che la dinamica inquinante dei paesi interessati possa essere spiegata con la geometria della EKG.

Se analizziamo i valori medi assoluti, rileviamo che nel periodo indagato i livelli maggiori di inquinamento da CO_2 hanno riguardato i paesi del Nord America e del Medio Oriente, con emissioni pari a 17,49 e 12,67 tonnellate pro-capite annuali, rispettivamente; mentre quelli minori hanno interessato l'area africana e dell'America Latina, con emissioni pro-capite equivalenti a 1,23 e 3,01 tonnellate annuali, rispettivamente. Interessante è anche la dinamica dei paesi Europei, i quali vengono sopravanzati da quelli asiatici nel 2008. Entrambi si collocano in una posizione intermedia fra i due blocchi suindicati, con valori medi pari a 7,76 tonnellate per l'Europa e a 7,31 tonnellate per l'Asia.

Ma non solo, se calcoliamo l'elasticità delle emissioni di CO_2 al pil pro-capite nel periodo 1990-2014[15] per un campione di 188 paesi, rileviamo che, *ceteris paribus*, i paesi con reddito medio superiore ai 10.000 dollari (ppa) registrano valori superiori a quelli con reddito medio inferiore ai 10.000 dollari (ppa). Nello specifico, nei primi un aumento dell'1% del reddito pro-capite è

Fig. 2. Andamento comparato delle emissioni pro-capite di CO_2 nel mondo nel periodo 1990-2014.



Fonte: elaborazioni dell'autore su dati World Bank.

associato a un incremento dell'1,02% delle emissioni pro-capite di CO_2; mentre, nei secondi a un incremento dell'1% del reddito pro-capite corrisponde un aumento dello 0,82% delle emissioni di CO_2. I coefficienti di correlazione mostrano una discreta concordanza fra le due variabili, che varia fra lo 0,48 dei paesi con reddito superiore e lo 0,56 dei paesi con reddito inferiore. Quindi, i paesi relativamente più ricchi fanno segnare in media un'elasticità più elevata dello 0,2% rispetto a quelli relativamente più poveri. Ovvero, nel periodo 1990-2014 hanno contribuito in misura proporzionalmente maggiore all'emissione di gas climalteranti in rapporto alla dinamica relativa del reddito.

Da una prima e sommaria analisi possiamo, dunque, affermare che i paesi industrializzati da un lato hanno ottemperato in modo solo parziale e incidentale alle prescrizioni contenute negli accordi internazionali in materia di riduzione delle emissioni, accrescendo anche il loro apporto relativo al processo di degradazione ambientale, e dall'altro sembrano aver viepiù gravato i paesi arretrati e in via di sviluppo delle esternalità negative connesse all'inquinamento[16].

5. METODOLOGIA E RISULTATI DELLE STIME EMPIRICHE

Nella parte centrale dell'elaborato stimiamo, attraverso un modello OLS (ordinary least square) multi-

[14] Al fine di evitare distorsioni nelle serie storiche, dal computo sono stati esclusi i valori dei microstati.

[15] Per le emissioni di CO_2 abbiamo considerato lo scostamento percentuale fra le medie del triennio 1990-1992 e 2012-2014. Per quanto concerne il reddito pro-capite, abbiamo invece considerato la variazione percentuale fra il 2014 e il 1990.

[16] Non ci si riferisce al surriscaldamento globale che colpisce indiscriminatamente tutti i paesi, ma agli effetti negativi che le attività industriali possono generare nel breve-medio periodo sul benessere sociale, come l'inquinamento idrico, acustico e atmosferico.

Tab. 1. Calcolo dell'elasticità delle emissioni di CO_2 pro-capite al reddito pro-capite in dollari internazionali (ppa), nel periodo 1990-2014.

Classificazione dei Paesi	Paesi considerati	Elasticità emissioni di CO_2 al reddito	Coefficiente di correlazione
Reddito pro-capite > 10.000 $	67	1,0194	+0,48
Reddito pro-capite < 10.000 $	121	0,8227	+0,56
Tutti i Paesi	188	0,9372	+0,57

Fonte: elaborazioni dell'autore su dati World Bank.

variato, i principali *driver* delle emissioni di CO_2[17] nel periodo 2000-2014, per un campione di 175 paesi[18]. Il periodo individuato sconta la mancanza di osservazioni complete per tutte le variabili oggetto dello studio e riflette la necessità di analizzare i cambiamenti strutturali e ambientali intervenuti nell'ultimo quindicennio.

Come nel paragrafo precedente, al fine di mitigare gli effetti distorsivi prodotti dalle procedure di rilevazione delle emissioni di CO_2, abbiamo scelto di considerare lo scostamento fra le medie del triennio 2000-2002 e 2012-2014[19].

Nello specifico, la variazione delle emissioni di CO_2 in tonnellate pro-capite nel periodo 2000-2014, che costituiscono la variabile dipendente del modello, saranno funzione delle seguenti dieci variabili esplicative[20]:

- la variazione del pil pro-capite in dollari internazionali (ppa) nel periodo 2000-2014 (World Bank database);
- la variazione del consumo pro-capite di energia primaria[21] espresso in kg di petrolio equivalente nel periodo 2000-2014 (IEA database);
- la variazione del tasso di urbanizzazione, i.e. della percentuale della popolazione urbana sul totale, nel periodo 2000-2012 (United Nations, 2018);
- la variazione della superficie forestale sul totale in kmq nel periodo 2000-2014 (FAOSTAT-Forestry database);
- la variazione percentuale della superficie destinata a uso agricolo[22] sul totale nel periodo 2000-2014 (FAOSTAT database);
- la variazione dell'approvvigionamento energetico, espresso come percentuale del consumo totale di energia, assicurato dall'energia nucleare e in generale dalle energie alternative[23] nel periodo 2000-2014 (IEA database);
- la variazione del grado di apertura commerciale di un paese[24] nel periodo 2000-2014 (World Bank database);
- la variazione del numero pro-capite di turisti internazionali in arrivo[25] nel periodo 2000-2014 (UNWTO database; World Bank database);
- la variazione del tasso di esaurimento delle risorse naturali[26] in percentuale del pil nel periodo 2000-2014 (World Bank database);
- e la media degli IDE in entrata in percentuale del pil nazionale nel periodo 2000-2014 (IMF database; World Bank database).

Al fine di evitare distorsioni nel modello e renderne comparabili le stime, tutte le variabili indipendenti sono state implementate come numeri indici a base fissa (2000=100). L'unica eccezione ha interessato gli IDE in entrata che, data l'elevata volatilità registrata nel periodo considerato, abbiamo preferito introdurre come media

[17] I dati sulla CO_2 sono calcolati dal centro di analisi delle informazioni sull'anidride carbonica del Dipartimento di Energia degli Stati Uniti (CDIAC) sulla base dei dati sui consumi di combustibili fossili (contenuti nel dataset sull'energia mondiale della Divisione di Statistica delle Nazioni Unite) e sulla produzione mondiale di cemento (contenuti nelle Indagini Geologiche del Dipartimento dell'Interno degli Stati Uniti).

[18] La differenza rispetto al campione precedente è determinata dalla mancanza di osservazioni sufficienti per alcune delle variabili implementate e dall'eliminazione dei paesi africani in guerra.

[19] Secondo il CDIAC, i calcoli sul livello di inquinamento da CO_2 hanno probabilmente un limite di errore non superiore al 10%. Tuttavia, il grado di accuratezza delle stime nazionali può essere significativamente inferiore. Quindi, le possibilità di errori sistematici legati a osservazioni individuali non possono essere sottovalutate.

[20] I dati originali delle elaborazioni sono stati estrapolati dalla World Bank Open Data, disponibile alla URL: https://data.worldbank.org/. Quando non diversamente specificato, essi si intendono raccolti ed elaborati direttamente dalla World Bank. Alcune statistiche descrittive sono riportate in appendice (Tab. A.1.).

[21] Si intende l'uso di energia primaria prima della trasformazione in altri combustili a uso finale (come elettricità e prodotti petroliferi raffinati). Esso include l'energia da combustibili rinnovabili e rifiuti, biomasse solide e prodotti animali, gas e liquidi provenienti dalle biomasse e rifiuti municipali e industriali.

[22] Si fa riferimento alla superficie di terra arabile, a pascolo permanente e coltivata in modo permanente.

[23] Si intendono le fonti energetiche che non producono CO_2, come l'energia solare, eolica, idroelettrica, geotermica, l'energia ricavata dalle biomasse e il biodiesel.

[24] Si intende la somma delle esportazioni e delle importazioni di beni e servizi in percentuale del pil.

[25] Si intendono gli arrivi di turisti che hanno una residenza diversa dal paese di destinazione, e standardizzati sulla popolazione di quest'ultimo. I dati si riferiscono al numero degli arrivi e non a quello dei turisti, cosicché se una stessa persona viaggia più volte in un dato luogo, sarà registrata più volte.

[26] Si fa riferimento alla somma dell'esaurimento netto delle foreste, dell'energia e dei minerali. L'esaurimento netto delle foreste è calcolato come l'eccesso di raccolto di legname rispetto alla crescita naturale; l'esaurimento netto dell'energia è calcolato come il rapporto fra il valore dello stock di risorse energetiche (di carbone, petrolio e gas naturale) e la durata residua delle risorse (fissata a 25 anni); infine, l'esaurimento netto dei minerali è calcolato come il rapporto fra il valore dello stock di risorse minerarie (come oro, argento, rame etc.) e la durata residua della riserva (fissata a 25 anni).

dell'intera serie storica[27].

A causa dei problemi di eteroschedasticità degli errori rilevati con il test di Whyte (1980), per il calcolo degli stimatori OLS ci siamo avvalsi degli errori standard robusti rispetto alla violazione dell'ipotesi di omoschedasticità, ottenuti secondo la procedura di Huber (1967) e Whyte (1980). Mentre, la violazione dell'ipotesi di distribuzione normale degli errori, rilevata col test di Shapiro-Wilk (1965), è stata corretta mediante la trasformazione logaritmica della variabile dipendente.

La statistica *F* di Fischer-Snedecor restituisce un valore pari a 17,92, nettamente superiore rispetto a quello tabulato (2,05); quindi, il modello OLS stimato risulta statisticamente verificato a un livello di significatività dell'1%.

Come mostrato dalla Tabella 2, tutte le variabili indipendenti implementate nel modello risultano statisticamente verificate, anche se con intensità e livelli di significatività diversi. A riguardo, l'indice di determinazione ci informa che i regressori consentono di spiegare congiuntamente circa il 60% della variabilità delle emissioni di CO_2 nel periodo 2000-2014.

Nello specifico, il pil pro-capite, il consumo di energia primaria pro-capite, il tasso di urbanizzazione, la superficie agricola, l'esaurimento delle risorse naturali e il numero di turisti internazionali pro-capite sono positivamente correlati alla variazione delle emissioni di CO_2; mentre, la superficie forestale, la produzione di energia nucleare e di energie alternative, il grado di apertura commerciale e gli IDE in entrata sono inversamente correlati alla dinamica delle emissioni di CO_2. I regressori che sembrano contribuire maggiormente all'aumento delle emissioni inquinanti sono in ordine decrescente[28]: la superficie agricola, il consumo di energia pro-capite, il tasso di urbanizzazione e il pil pro-capite. Fra questi, i consumi di energia primaria pro-capite assumono un ruolo centrale; difatti, come mostrato dalla matrice di correlazione in appendice (Tab. A.2.), il coefficiente di correlazione con le emissioni inquinanti è molto alto e prossimo allo 0,9[29]. Mentre, le variabili che consentono di ridurre in modo più significativo le emissioni di CO_2 sono la superficie forestale e l'energia nucleare e alternativa.

In entrambi i casi, tali valori non solo sono caratterizzati dai coefficienti mediamente più elevati, ma nella maggior parte dei casi risultano anche verificati a un livello di significatività dell'1%.

L'unica eccezione è rappresentata dal tasso di urbanizzazione, che assieme agli IDE in entrata e al numero di turisti internazionali pro-capite risulta significativo solo un livello del 10%. Tuttavia, l'elevato numero di paesi considerati e la congruenza dei regressori con la letteratura di riferimento, ci inducono a ritenere complessivamente affidabile l'*output* ottenuto.

Tab. 2. Risultati delle stime OLS sulle emissioni di CO_2 in 175 paesi, nel periodo 2000-2014.

Variabili	Modello OLS (Errore Standard)
Costante	3,9211***
	(0,2271)
Δ Pil pro-capite	0,0022***
	(0,0005)
Δ Consumo di energia primaria	0,0026***
	(0,0005)
Δ Urbanizzazione	0,0023*
	(0,0014)
Δ Superficie forestale	-0,0042***
	(0,0012)
Δ Superficie agricola	0,0042***
	(0,0012)
Δ Energia nucleare e alternativa	-0,0010***
	(0,0003)
Δ Apertura commerciale	-0,0001**
	(0,0000)
Δ Esaurimento risorse naturali	0,0000***
	(0,0000)
Δ Turisti internazionali pro-capite	0,0000*
	(0,0000)
Media IDE in entrata	-0,0013*
	(0,0008)
R^2 corretto	0,5971
Shapiro-Wilk (p-value)	0,5218
Whyte (p-value)	0,0031
Numero di osservazioni	175

Fonte: elaborazioni dell'autore su dati World Bank. Note: ***p-value < 0,01; **p-value < 0,05; *p-value < 0,10. Errori standard fra parentesi, basati sul procedimento di Huber (1967) e Whyte (1980).

6. DISCUSSIONE DEI RISULTATI E POSSIBILI TRAIETTORIE DI SVILUPPO FUTURE

In primo luogo, i segni delle variabili indipendenti utilizzate nel modello sembrano decisamente coerenti con la letteratura recente sulle determinanti delle emissioni di CO_2 (Sharma, 2011; Akin, 2014; Grace *et al.*,

[27] Il relativo coefficiente di regressione non deve essere dunque interpretato come scostamento dalla *baseline* (1990) ma come variazione sul pil totale.

[28] Assumiamo per semplicità che il rapporto di causazione sia unidirezionale.

[29] Si tratta di un risultato atteso, in quanto i consumi di energia procapite possono essere utilmente utilizzati, almeno statisticamente, come *proxy* delle principali variabili di sviluppo socioeconomico (Csereklyei *et al.*, 2016; Wang *et al.*, 2016).

2014; Pazienza, 2015; Balogh, Jámbor, 2017; Shakouri *et al.*, 2017). In particolare, i risultati sembrano confermare che lo sfruttamento intensivo delle risorse naturali di un territorio, una maggiore urbanizzazione, una forte attrattività turistica, e in generale un maggiore livello di ricchezza economica possono incidere negativamente e pesantemente sui livelli generali di inquinamento da CO_2. Sul fronte opposto, rileviamo che, nonostante sia impossibile individuare una panacea al progressivo degrado ambientale, un contributo rilevante può derivare dall'imboschimento e dalla forestazione, dall'utilizzo di fonti energetiche alternative[30] e da una maggiore apertura commerciale e finanziaria verso l'estero, che consenta di importare protocolli e ritrovati tecnologici più efficienti e dunque suscettibili di abbattere le emissioni dei sistemi produttivi industriali.

Fra quest'ultimi possiamo ricordare: *i*) l'introduzione di fonti energetiche alternative e rinnovabili come il bioetanolo e le biomasse (Lippke *et al.*, 2012; Zhang *et al.*, 2015) e *ii*) lo sviluppo di processi di agricoltura simbiotica, i.e. l'utilizzo di microbiologia positiva (batteri, funghi[31] e lieviti) che consenta di neutralizzare i c.d. stress abiotici a cui sono sottoposti le piante, come gli sbalzi termici, le elevate temperature, la siccità, l'elevata salinità del terreno e delle acque irrigue, le carenze nutritive e la presenza di metalli pesanti nel terreno (Vernieri *et al.*, 2006; Obata, Fernie, 2012; Zhu, 2016).

Tali innovazioni, pur consentendo una riduzione delle emissioni inquinanti e un miglioramento significativo della produttività[32], possono generare impatti anche molto significativi sui sistemi socioeconomici e politici dei paesi arretrati, come la perdita di conoscenza contestualizzata e "millenaria" o l'introduzione di barriere all'ingresso nel mercato della terra. Si dovrà, dunque, tener conto anche di questi fattori, al fine di non creare distorsioni nell'equilibrio già precario dei sistemi produttivi dei paesi più poveri.

Tali risultanze sollevano dunque la necessità, soprattutto per i paesi avanzati e le economie emergenti, di affrontare sistematicamente e seriamente il problema della sostenibilità ambientale della crescita economica. I.e., di favorire lo sviluppo della c.d. bioeconomia, nelle sue tre accezioni: la *bio-technology*, la *bio-resource* e la *bio-ecology*. Nello specifico: *i*) la *bio-technology* si riferisce all'importanza della ricerca e dell'implementazione della biotecnologia nei diversi settori economici; *ii*) la *bio-resource* si concentra sulla sperimentazione e lo sviluppo di materie prime biologiche, nonché sulla creazione di nuove catene del valore in una logica di Economia Circolare; e infine *iii*) la *bio-ecology* sottolinea i processi ecosostenibili che consentono un uso più efficiente dell'energia, promuove la biodiversità ed evidenzia l'importanza di preservare il suolo (Bugge *et al.*, 2016).

Una scelta che potrebbe avere un senso anche solo sotto un profilo di mera profittabilità economica. Difatti, il settore della bioeconomia negli ultimi anni ha dimostrato buone potenzialità di crescita e di espansione. Es., solo nel periodo 2010-2015, il suo fatturato nell'UE-28 è cresciuto circa del 10%. A livello assoluto, nel 2015 essa valeva quasi l'8% (2,28 miliardi di euro) dell'intero pil dell'UE-28, e impiegava 18,5 milioni di lavoratori, ovvero circa l'8,5% dell'intera forza lavoro impiegata nell'UE-28. E i settori maggiormente coinvolti riguardavano gli alimenti e le bevande[33], l'industria primaria (agricoltura e foreste), e i comparti della chimica e dei materiali plastici (Piotrowki *et al.*, 2016, 2018)[34].

Un ruolo ovviamente complementare è quello che potrebbero svolgere le fonti energetiche rinnovabili. Es., nell'UE-28 nel 2015 il 16,56% dei consumi complessivi di energia elettrica erano coperti dalle energie rinnovabili[35]. Tale incidenza è cresciuta notevolmente dal 1990, quando la quota di energia assicurata dalle fonti rinnovabili si assestava solo al 6,12%; un business che nel 2015 ha assorbito circa 1,14 milioni di lavoratori e ha prodotto un fatturato pari a 153 miliardi di euro nella sola UE-28 (EurObserv'ER, 2016; World Bank database)[36].

Dati che sottolineano le grandi potenzialità dei set-

[30] Questo è punto dirimente se si pensa che i primi 25 paesi al mondo per produzione di gas e petrolio nel periodo 2000-2014 (elaborazioni su dati U. S. Energy Information Administration) hanno registrato una media pro-capite di emissioni di CO_2 pari a 11,38 e 12,26 tonnellate, di gran lunga superiore rispetto al resto del mondo, che non ha superato in media le 3,7 e le 3,65 tonnellate di CO_2, rispettivamente (elaborazioni su dati World Bank).

[31] Si tratta delle così dette micorrize, che – a causa della loro versatilità e straordinarie proprietà – negli ultimi anni hanno registrato una certa popolarità (Smith e Read, 2010; Di Martino *et al.*, 2018).

[32] Nel caso degli stress abiotici, essi possono determinare la perdita di circa il 70% della produttività totale delle colture più importanti (Boyer, 1982).

[33] Da solo, il comparto alimentare e delle bevande nel 2015 valeva 1,14 miliardi di euro, ovvero il 50% del fatturato complessivo generato dalla bioeconomia nell'UE-28; e assorbiva circa 10 milioni di lavoratori.

[34] Ma non solo, alcuni dei settori *bio-based* mostrano una produttività estremamente elevata. È il caso dei settori della produzione di elettricità e di biocombustibili liquidi, che nel 2014 hanno fatto registrare rispettivamente 820.000 e 530.000 euro di fatturato per persona impiegata. Al terzo posto troviamo a pari merito i settori della produzione dei prodotti chimici, farmaceutici, plastici e della gomma, che hanno fatto segnare circa 320.000 euro di fatturato per persona impiegata (Ronzon *et al.*, 2017).

[35] Bisogna comunque sottolineare che a livello mondiale l'apporto complessivo delle risorse rinnovabili ai consumi energetici finali ha fatto segnare un trend piuttosto statico, passando dal 17,1% del 1990 al 18% del 2015.

[36] Inoltre, diversi studi confermano l'esistenza di forte correlazione positiva fra consumi energetici da fonti rinnovabili e crescita del pil, sia in Europa che nel resto del mondo (Apergis e Payne, 2012; Ntanos *et al.*, 2018).

tori dello sviluppo sostenibile, capaci allo stesso tempo di assorbire quote rilevanti della forza lavoro e di creare indotto per segmenti primari del sistema economico.

7. CONCLUSIONI

Il presente lavoro ha cercato di perseguire due obiettivi fra loro complementari: *i*) in prima istanza, di indagare l'effettiva efficacia e cogenza dei principali accordi internazionali sulle emissioni di gas serra per i paesi sviluppati; e *ii*) in secondo luogo, di individuare, attraverso l'analisi delle determinanti della CO_2, gli strumenti di politica economica e ambientale più opportuni nella lotta al surriscaldamento globale.

In merito al primo obiettivo, i risultati suggeriscono che nel periodo 1990-2014 i paesi con reddito maggiore, non solo hanno contribuito in modo solo marginale e incidentale alla riduzione della CO_2, ma hanno fatto registrare un'elasticità al reddito delle emissioni superiore rispetto a quella dei paesi con reddito inferiore. In altre parole, hanno concorso in modo proporzionalmente maggiore all'inquinamento, in rapporto alla crescita economica sperimentata.

Con riguardo al secondo obiettivo, le stime evidenziano che i fattori direttamente collegati alla crescita economica, come il reddito, il consumo di energia, l'urbanizzazione, l'espansione delle aree coltivate, il turismo e lo sfruttamento delle risorse naturali, presentano un rapporto di correlazione positiva con la dinamica delle emissioni di CO_2. Mentre, l'utilizzo di fonti energetiche alternative, gli interventi di forestazione e imboschimento, e l'apertura ai mercati esteri sono negativamente correlati alle emissioni di CO_2.

Ovviamente, la sostenibilità ambientale ed economica non possono prescindere dalla sostenibilità sociale, che deve essere assicurata nelle sue quattro dimensioni principali: *i*) la sicurezza, intesa come la necessità di adottare tutti gli strumenti possibili per la riduzione dei pericoli nel lungo periodo; *ii*) la giustizia, intesa come diritto trasversale all'identità, all'equità di trattamento e alle pari opportunità; *iii*) l'eco-*prosumption*, i.e. la produzione di valore aggiunto secondo modelli rispettosi dell'ambiente e socialmente responsabili; e *iv*) le *urban forms*, i.e. la dimensione fisica desiderata dei modelli di sviluppo urbano (Eizenberg, Jabareen, 2017). Difatti, secondo Samimi *et al.* (2011) e Arfanuzzaman (2016) l'indice di sviluppo umano (HDI)[37] – che è una buona misura di sintesi del grado di sviluppo sociale di un paese – ha un impatto positivo e significativo sulle performance ambientali, sia nei paesi industrializzati che in via di sviluppo.

In definitiva, nonostante i notevoli sforzi in ambito comunitario e globale, ancora molto deve essere fatto affinché i processi di degradazione ambientale e di perdita della biodiversità possano essere rallentati. Gli strumenti fin qui implementati non hanno consentito di ridurre significativamente le immissioni di gas serra nell'atmosfera, condizione necessaria per evitare gli impatti negativi sul benessere dell'umanità nel lungo periodo.

Molto dipenderà, come abbiamo sottolineato nei precedenti passaggi, da come il processo di decarbonizzazione dell'economia potrà sfruttare le potenzialità di sviluppo future della bioeconomia e dalle sue applicazioni nei diversi settori produttivi. Solo rendendo economicamente conveniente l'adozione di innovazioni tecnologiche, specialmente in campo industriale ed energetico, si riuscirà, forse, a pervenire alla responsabilizzazione e alla cooperazione di tutti i soggetti coinvolti.

[37] Si tratta di un indice compreso fra 0 e 1, costruito sulla base di tre pilastri: *i*) speranza di vita; *ii*) grado di istruzione della popolazione; e *iii*) potere d'acquisto del reddito medio (UNDP, 2016).

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APPENDICE

Tabella A.1. Alcune statistiche descrittive sulle variabili del modello OLS.

Variabili	N	Media	Mediana	Deviazione standard	Coeff. di variazione
Emissioni	175	128,75	117,13	66,65	0,52
Pil pro-capite	175	149,38	133,72	51,74	0,25
Consumo energia	175	122,08	109,39	70,51	0,58
Urbanizzazione	175	111,10	106,43	15,34	0,14
Superficie fores.	175	100,33	100,00	15,56	0,16
Superficie agricola	175	100,30	100,00	14,02	0,14
Nucleare e altre f.	175	249,27	100,00	1047,4	4,20
Apertura comm.	175	135,75	112,97	268,53	1,98
Esaurimento ris.	175	330,88	115,27	938,11	2,84
Turisti internaz.	175	326,47	201,22	389,56	1,19
IDE in entrata	175	5,52	3,56	9,69	1,76

Fonte: elaborazioni dell'autore su dati World Bank.

Tab. A.2. Coefficienti di correlazione fra le variabili del modello OLS, calcolati usando le osservazioni 1-175; valore critico al 5% (per due code) = 0,1484.

Pil pro-capite	Consumo energia	Urbaniz.	Superficie Agricola	Superficie forestale	Nucleare e altre fonti	
1,0000	0,1927	0,2368	0,0709	0,0275	0,0827	Pil pro-cap.
	1,0000	0,1578	0,0204	0,0694	-0,1095	Energia
		1,0000	0,0658	-0,2324	-0,0719	Urbaniz.
			1,0000	-0,0904	-0,0576	S. Agricola
				1,0000	-0,0488	S. Forestale
					1,0000	Nucleare

Apertura Commerc.	Esaurim. risorse	Turisti internaz.	IDE in entrata	Emissioni di CO_2	
0,3086	0,0532	0,3456	0,0179	0,3351	Pil pro-cap.
-0,0032	-0,0061	0,0602	-0,0578	0,8611	Energia
0,0702	-0,0574	0,1274	-0,0871	0,2576	Urbaniz.
0,0924	0,0148	0,0930	-0,0034	0,1628	S. Agricola
-0,0723	0,1572	-0,0250	0,0432	-0,1008	S. Forestale
0,0715	0,1559	-0,0152	-0,1465	-0,1685	Nucleare
1,0000	-0,0004	0,0612	-0,0147	0,0190	A. commer.
	1,0000	0,0169	0,0194	0,0270	E. Risorse
		1,0000	-0,0503	0,1902	Turisti Int.
			1,0000	-0,0476	IDE in ent.
				1,0000	Emissioni

Fonte: elaborazioni dell'autore su dati World Bank.

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Technical efficiency and farm size: an analysis based on the Brazilian agriculture and livestock census[1]

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Abstract. This paper analyzes the relationship between technical efficiency and farm size, considering different classes of area and efficiency levels in Brazil. Stochastic Frontier Production was used to obtain the technical efficiency and the Quantile Regression was used to identify their determinants. Microdata from the 2006 Brazilian Agriculture Census were used. It was found a positive and non-linear relationship between farm size and efficiency in all area classes. However, the more efficient the producers, the weaker the relationship, which indicates that such producers were less dependent on the land factor. In addition, irrigation, technical assistance and cooperatives membership were the factors which contributed most to increasing efficiency, especially for the less efficient producers.

Keywords: Farm size, agriculture and livestock, stochastic frontier, technical efficiency, quantile regression.
JEL codes: Q10, Q15, C21

1. INTRODUCTION

Most studies on the productivity of the agriculture and livestock sector have pointed to an inverse relationship between farm size and productivity (Mazumdar, 1965; Berry, Cline, 1979; Sen, 1966), which could lead to a policy of land reordering so as to increase the productive performance of the entire sector. However, recent results have been contradictory, especially when the omission of relevant variables related to the characteristics of the producer, involving the human, physical and social capital of the farms, is taken into account. In addition, most of the studies use partial productivity measures, which are considered insufficient for analysing the importance of farm size and its influence on productive performance.

Since the beginning of studies in the field of agricultural economics, the relationship between farm size and productivity has been of great interest

[1] The authors thank the Brazilian Institute of Geography and Statistics (IBGE) for allowing access to the 2006 Agriculture and Livestock Census microdata.

(Bagi, 1982). However, this debate has not yet yielded a definitive solution, given the divergent results found in both the national literature and that of different countries. This issue is still relevant as it has direct implications for the role of agrarian reform policies if conditions are to be created to reduce inequality and generate economic growth in rural areas.

In the first studies, it was generally accepted that there was an inverse relationship between these variables, or in other words, the productivity of a farm decreases as its size increases (Mazumdar, 1965; Berry, Cline, 1979; Sen, 1966). However, especially from the 90's onwards, researches rejecting this hypothesis began to appear more frequently (Newell *et al.*, 1997; Rios, Shively, 2005). For Teryomenko (2008), the emergence of more advanced methodologies and superior quality data contributed to this deeper analysis of the theme, and also allowed for the inclusion of specific control variables which can directly affect the relationship between productivity and size.

One of the pioneering studies which identified the inverse relationship between productivity and size was undertaken by Mazumdar (1965) when analyzing two districts in the state of Uttar Pradesh, India. His justification for the inverse relationship is based on the fact that small farms use family labor more intensively. According to Mazumdar (1965), this is due to their economic incentive, as the motivation to put more effort into the work is greater for family members than for hired workers. In addition, hired labor requires more supervision, which could raise costs. Studies by Sen (1966), Benjamin (2002) and others have also analysed this approach.

Another explanation for this inverse relationship is proposed by Deolalikar (1981), who broadened the debate on the subject by incorporating the significance of technical progress. He argues that this inverse relationship is only observed where agriculture uses traditional farming techniques, that is, the hypothesis that small farmers are more productive is only valid when agriculture uses a low technological level.

Feder's (1985) study rejects the hypothesis that a labor market failure has greatest responsibility for the inverse relationship between productivity and size. For him, as family labor is a fixed resource on each farm, if there are no failures in capital or land markets and if each farm operates to maximize profits, then market forces would lead to an optimal solution. This solution implies that, if the market worked perfectly, each family would use the resources that were necessary to maintain ideal production, which would be proportional to the size of the family. Thus, the labor/land relationship would be the same across farms, and productivity would not be affected by farm size. However, this scenario changes when credit market failures are assumed because the amount of capital available to each family would depend on the amount of collateral (property land) it could offer.

Dyer (1997) and Havnevik and Skarstein (1997) argue that small farms present greater productivity of the land in the short term only, as in the long term, this would tend to fall. According to them, the reason for the fall in productivity is the more intensive use of land in the effort to maintain labor productivity at the same level. Thus, as more people worked on the farm and considering that small farms would have fewer resources to invest in preserving the fertility of the soil, then the productivity of the soil would decrease in the long term, thereby reducing the productivity of the land.

As argued by Helfand and Levine (2004), the type of measure used to represent productivity could also produce distinct results for the relationship with farm size. In this same sense, a study by Moreira *et al.* (2007) set out to investigate the inverse relation for Brazilian agriculture and livestock farms, using two measures for productivity: a partial measure, based on the productivity of the land, and the other based on total factor productivity (TFP). The results identified an inverse relationship between productivity of the land and farm size for the five Brazilian macro regions. However, when total factor productivity was analysed, only the Northern, Northeastern and Southeastern regions presented an inverse relationship between size and productivity of agriculture and livestock farms.

Helfand *et al.* (2015) investigated the relationship between farm size and TFP growth based on information from the 1985, 1995-96, and 2006 Agriculture and Livestock Censuses. They used aggregated data at municipal level and considered five classes of area: 0-5 ha, 5-20 ha, 20-100 ha, 100-500 ha and more than 500 ha. Based on a Stochastic Frontier Production approach, they identified a decline in the technical efficiency of the representative farms analysed in all groups, which contributed to lower TFP growth between 1985 and 2006. They also saw that the medium-sized farms belonging to the 20-100 and 100-500 ha groups presented the lowest rate of TFP growth in practically all Brazilian regions.

Thus, the results found in the literature show that the relationship between productivity and farm size is still a controversial issue. In addition, more recent literature presents the use of more complete measures to represent productive performance, such as the technical efficiency of the farm, which reduce the possibility of bias in favor of small farms and other measurement errors, which could occur when using partial productivity measures[2].

Against such a background, this study set out to determine the relationship between technical efficiency and farm size, by controlling productive heterogeneity in relation to the different classes of area and efficiency levels in rural Brazil in 2006. In addition, the study also allowed for the identification of the main determinants of the productive performance of farms when different efficiency ranges were considered.

When identifying the main determinants of the productive performance of farms, such as total area, total financing, access to cooperatives, irrigation technology and others, the consideration of different levels of technical efficiency makes a significant contribution to the existing literature. This analysis is relevant because, if a low performance farm is to increase its yield, a greater investment in factors other than those which would guarantee the maintenance of efficiency of farms with greater productivity may be necessary. Thus, agricultural policies could be more efficient in reducing inequality between small and large producers if they also considered the efficiency of the farms and not just the type of producer.

It is also believed that the relationship between performance and farm size could be altered according to the level of efficiency of the producer, thereby showing the farm's greater or lesser dependence on the land. It should be noted that research with a focus on Brazil is generally based on aggregate data at state or municipal level, or by choosing representative farms for different area groups in a municipality[3]. This research used microdata from the 2006 Agriculture and Livestock Census, as they allow for broad characterizations, and the minimization of possible bias caused by the aggregation of data at municipal or state levels[4].

This study is divided into 3 sections, along with the Introduction. Section 2 presents the methodology and source of the data used to reach the proposed objective. Section 3 presents and discusses the results of the research, while Section 4 presents the conclusions of the study.

[2] According to Lima *et al.* (2017), it is understood by technical efficiency how an optimal combination of inputs is employed in the productive process in order to obtain the maximum product. This means that this efficiency deals with the relationship between the inputs and the total final product, so it can be considered a more complete measure for productivity. For the estimation of the technical efficiency scores the Stochastic Production Frontier approach was used, as presented in section 2.1.

[3] Helfand and Levine (2004), Rada and Valdes (2012), and others.

[4] Microdata (data at farm level) of the 2006 Agriculture and Livestock Census were accessed in a reserved room at the IBGE headquarters in Rio de Janeiro, with prior approval for the research project.

2. METHODOLOGY

The strategy adopted to achieve the objectives proposed in the research was based on two procedures. The first was using the Stochastic Frontier Production[5] technique to obtain the efficiency levels of Brazilian agriculture and livestock farms for the country as a whole, and for each area class: minifundium, small, medium, and large[6]. In the second stage of the research, the Quantile Regression[7] technique was used to identify the explanatory power of the variables[8] understood as determinants of technical efficiency, considering different efficiency ranges. The two methods are presented below.

2.1. Stochastic Frontier Production

The main aim of the Stochastic Frontier model is to estimate a production function, where it is expected to obtain maximum production from a combination of factors at a given technological level. However, there is no guarantee that an efficient combination of factors which maximize production is used, as there could be technical inefficiencies in the use of these factors. This implies that the farm could be producing below the maximum production frontier. Thus, the amount by which the production of this farm falls short of the production frontier provides a logical measure of technical inefficiency.

According to Taylor and Shonkwiler (1986), the stochastic nature of the model is directly related to the possible existence of factors which cause deviations from the production frontier and could escape the farmer's control, such as climatic variations, pests and diseases. In contrast to deterministic frontier models, where random variations are incorporated into the measure of technical inefficiency, the specification of stochastic frontier models includes a random error component to explain such variations.

In this study, as data refer to the 2006 Agriculture and Livestock Census microdata, that is, data at farm level, the basic form of the stochastic frontier production function is given by:

$$Y_i = f\left(X_i;\beta\right) e^{\left(v_i - u_i\right)}, \text{ where } i = 1, 2, 3,..., n \tag{1}$$

where Y_i represents the production obtained by the i-th farm; X_i is the vector of the production factors used,

[5] For more detail see Coelli *et al.* (2005) and Hadley (2006).

[6] The criteria used to classify Brazilian agriculture and livestock farms in each area group are presented in Section 3.3.

[7] For more detail on the method, see Koenker and Basset (1978).

[8] The variables used are presented in Section 3.3.

β the vector of parameters to be estimated; and v_i and u_i are the error terms. The v_i random error component explains production measurement errors due to climatic variations, the presence of unobservable inputs in production, and errors in the observation and measurement of data. The u_i error component represents the restriction of the level of production to values equal to or lower than those of the frontier, therefore characterizing the technical inefficiency of the agriculture and livestock farm. The parameters are frequently estimated via Maximum Likelihood methods.

Given the above, the first step in the empirical application of the method is to define the functional form of the stochastic frontier, as pointed out by Coelli and Battese (1996). Different functional forms are used in the application of output analysis; however, according to Hanley and Spash (1993), the Cobb-Douglas function is preferable to other forms if there are three or more independent variables in the model, as they involve less loss of degrees of freedom. In this study, the number of independent variables is greater than three, hence the Cobb-Douglas function was used.

Chambers (1988) identified certain advantages in using the Cobb-Douglas: 1) simplicity in estimating the parameters because in logarithmic forms, the Cobb-Douglas function is linear in parameters; 2) regression coefficients provide the production elasticities which can be compared to each other; 3) because it is a homogeneous function, the sum of the regression coefficients determines the returns to scale; and, 4) when compared to the transcendental logarithmic functional form (translog), the Cobb-Douglas function has a small number of parameters for estimation as it is less susceptible to the common problems of multicollinearity in estimating the production function.

Thus, by incorporating dummy variables for states and total area groups, the logarithmic form of the stochastic frontier function can be represented by:

$$lnY_i = \sum_{i=1}^{n} ln\beta_i X_i + \sum_{h=1}^{26} E_h + \sum_{g=1}^{3} G_g + v_i - u_i \tag{2}$$

where Y_i is the total value of production of the i-th farm, in reals, in 2006; X_i is the vector of the factors of production considered[9]; E_h are dummies to represent the Brazilian states; G_g are dummies to represent the area groups; and β_i is a vector of the parameters to be estimated, which define the production technology. It should be noted that it was necessary to include dummies to capture the fixed characteristics of each area group or state, and to try to control possible spatial autocorrelation, so as to obtain an estimate of efficiency free from these effects[10].

The estimated model assumed that the v_i random error component has a normal distribution, independent and identically distributed (iid), truncated at zero, with variance $\sigma_v^2\left[v \sim iidN\left(0,\sigma_v\right)\right]$ and captures the stochastic effects beyond the control of the productive unit, such as measurement errors and climate, for example; and u_i is responsible for capturing the technical inefficiency of the i-th farm, that is, the part of the error which constitutes a downward deviation in relation to the production frontier, and are non-negative random variables. This unilateral (non-negative) term can follow half-normal, truncated normal, exponential or gamma distributions with mean $\mu > 0$ and variance σ_u^2 (Aigner *et al.*, 1977; Greene, 1980).

Initially, it was expected to find a positive relationship between the factors of production considered and the gross value of production, showing a directly proportional relationship between an increase in these factors and an increase in the value of agriculture and livestock production. However, the possibility of finding negative signs for these coefficients was not ruled out.

It should be noted that, because of the existing heterogeneity between farms, the standard errors were estimated using the bootstrap resampling method[11], considering 50 replications. In this way, the degree of reliability in the inferences made on the basis of the estimated statistical results is greater.

Given a vector of production factors, X_i, potential $\left(Y_i^*\right)$ is defined as the maximum production obtained in the absence of technical inefficiency throughout the productive process and is represented by:

$$Y_i^* = e^{\left(X_i\beta + v_i\right)} \tag{3}$$

Thus, the estimated technical efficiency of the i-th farm can then be defined as the ratio between its observed production and potential production, also known as frontier production, given the technology available, and is formulated as follows:

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{e^{\left(x_i\beta + v_i - u_i\right)}}{e^{\left(x_i\beta + v_i\right)}} = e^{-u_i} \tag{4}$$

[9] The variables used are presented in Section 3.3.

[10] It should be noted that area dummies are only included in the estimated frontier for Brazil as a whole, as the other frontiers are specific to each area group.

[11] For more details on the procedure, see Song *et al.* (2012).

where the technical efficiency score (TE_i) is a value between zero and ($0 \leq TE_i \leq 1$), where zero represents full inefficiency and 1, total efficiency. After estimating the stochastic frontier model, the technical efficiencies of the sample farms were estimated using conditional expectation, $E\left[\exp\left(-U_i | V_i - U_i\right)\right]$, as suggested by Battese and Coelli (1988)[12].

Aigner *et al.* (1977) suggested that the maximum likelihood estimates of the model parameters should be obtained in terms of parametrization, where $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\lambda = \frac{\sigma_u}{\sigma_v}$. A value greater than 1 for λ means that the variance of the technical inefficiency (u_i) is greater than the stochastic error term (v_i) and vice versa when λ is less than 1.

2.2. Determinants of technical efficiency in different ranges of efficiency

After estimating the technical efficiency scores via the stochastic frontier method, the second stage of the analysis involves identifying the main factors which influence the efficiency of the productive units. The quantile regression method is used to identify the main determinants of technical efficiency, when different efficiency ranges are taken into consideration. This method is feasible since the explanatory power of the independent variables over the dependent variable could be distinct at different points in the distribution of the sample analysed, depending on the dispersion and heterogeneity of the sample. Thus, using estimation techniques based on least squares may not be the most correct way to obtain the coefficients of a model. So, for the present study, the estimated equation is given by:

$$Q_\theta(LnTE_i | Z_i) = f\left(Z_i; \beta_\theta\right) \tag{5}$$

where $LnTE_i$ is the logarithm of technical efficiency of the i-th farm; Z_i is the vector of the determinant characteristics considered[13] and β_θ, the vector of parameters to be estimated in the θth quantile. Equation (5) was estimated in five quantiles (0.10, 0.25, 0.50, 0.75, 0.90), with the dependent variable being the efficiency in each range, or conditional quantile, of the error distribution of the stochastic function (Equation 4).

According to Buchinsky (1995), estimated parameters are interpreted by the marginal effect (*MEg*) of each explanatory variable in each specific conditional quantile, given by the partial derivative of each regressor of Equation 5:

$$ME_g = \frac{\partial Q_y\left(q | Z\right)}{\partial z_j} \tag{6}$$

In terms of the variables represented by dummies, the *MEg* should be interpreted as the response of the conditional q-th quantile of efficiency to the change of the j-th element of the vector Z of the independent variables from zero to 1. This means that, for the dummy variables, the marginal effect is obtained by the difference of the probabilities of Z being equal to 1 or equal to zero, as described in the equation below:

$$ME_g = P\left[Q_y = y \mid Z_j = 1\right] - P\left[Q_y = y \mid Z_j = 0\right] \tag{7}$$

The Wald test is applied to verify if the coefficients estimated in each quantile are, in fact, statistically different from each other. According to Hao and Naiman (2007), when variance and covariance are estimated, this test allows one to verify the equality hypothesis between pairs of coefficients in each quantile $\beta_i^{(p)}$ and $\beta_i^{(q)}$, corresponding to the same variance, but between quantiles p and q using the Wald statistic:

$$Wald(W) = \frac{\left(\beta_j^{(p)} - \beta_j^{(q)}\right)^2}{\beta_j^{(p)} - \beta_j^{(q)}} \tag{8}$$

The Wald statistic follows the χ^2 distribution with q degrees of freedom, considering q the number of hypotheses tested jointly or with F distribution, where $F = \frac{1}{q}W$, with q degrees of freedom in the numerator and d degrees of freedom in the denominator (Cameron, Trivedi, 2009).

Thus, by estimating the quantile regression (5), it is possible to identify the power of determination, if it exists, of the explanatory variables in groups of the sample differentiated by bands, or quantiles, of efficiency. Thus, the way each group responds to changes in these variables is verified, and not just the effect in relation to the sample mean. This analysis is interesting considering that the estimated efficiency could present great productive heterogeneity, given the peculiarities of each state and/or area class. In addition, it also allows one to investigate whether the relationship between productive performance and farm size changes at each level of efficiency.

It should also be noted that, as in the previous stage, the heterogeneity of the productive units was considered

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[12] See study by Battese and Coelli (1988), for more detail on the technical efficiency estimator used.

[13] The variables used are presented in Section 3.3.

in the estimation process. The standard errors were estimated via the bootstrap resampling method, in order to give greater reliability to the inferences made on the basis of the estimated statistical results.

2.3. Source and treatment of data

Information about the variables used in the present study is based on microdata from the 2006 Agriculture and Livestock Census, accessed directly from the headquarters of the Brazilian Institute of Geography and Statistics (IBGE). The microdata had to be selected and treated, so that the final base drawn up would be suited to the analyses undertaken. As the study set out to determine the relationship between technical efficiency and farm size (area), farms where areas were undeclared were excluded (255,019 observed). Farms located in urban areas were equally excluded (192,350 observed), as were those in special sectors such as slums, barracks, shelters, ports, indigenous villages, asylums, etc. (117,530 observed), thereby maintaining those exclusively of the sector.

Farms belonging to settlements were also excluded (139,496 observed), in order to avoid possible errors in measuring the variables. Although the enumerators were instructed to consider each settler's plot as a farm, in several cases the area of the whole settlement was considered a single farm, as the agricultural work was undertaken in a collective manner.

In addition, the sample included only those farms owned by an individual producer. Those classified as condominiums, consortiums or partnerships, cooperatives[14], corporations or limited liability companies, public utility institutes, whether government (federal, state, or municipal) or otherwise (190,838 observed) were not considered, because even if characteristics define a single person as being responsible for them, in practice, they have multiple owners. Likewise, farms where the type of producer was not identified (20,440 observed) were excluded.

After selections and transformations had been made, 915,673 observations were deleted (17.7% of the original sample), leaving a final sample composed of 4,259,963 agriculture and livestock farms. In order to obtain a more accurate estimate of the relationship between productivity and farm size, the microdata were organized into four classes according to farm size (minifundium, small, medium, and large), classified by IBGE in accordance with fiscal modules[15]. It should be noted that all aggregations, data generated and analyses were performed using the STATA® software.

As seen in previous subsections, the first step in obtaining the efficiency scores was the estimation of the production frontier function. For this, the 2006 gross production value (*prodval*), in reals, was defined as the product variable[16]. The factors of production were defined by the following variables: productive area (*prodarea)*, comprising the sum, in hectares, of the areas of cropland, livestock and agroforestry, representing a proxy for the land factor; total value, in reals, of the assets of the property (*valprop*), as a proxy for capital goods; sum of the number of family and contracted labor units (*laboru*)[17] as a proxy for the labor factor; (*totinput*), referring to the sum of expenses with soil amendments, fertilizers, pesticides, veterinary medicine, seeds and seedlings, salt/feed, fuel and energy, as a proxy for inputs; and the number of livestock units (*stocku*) (equivalent to the total number of animals on farms), as a proxy for livestock.

[14] The exclusion of cooperatives does not mean that their members were excluded as they were included as individual producers if they had agriculture and livestock farms.

[15] The Fiscal Module (FM) is an agrarian unit of measure expressed in hectares, fixed for each municipality, considering the type of exploration predominant in the municipality, income from the predominant exploration, other types of exploration in the municipality which, although not predominant, are significant depending on the income or area used; and the concept of family property. The measure represents the minimum area required for rural properties to be considered economically viable, ranging in size from 5 to 110 hectares, depending on the municipality. The fiscal module serves as a parameter for the classification of rural property in the municipality in terms of size, in accordance with Law 8,629, dated February 25, 1993, and rural properties can be classified as: a) minifundia, with a size of up to 1 fiscal module; B) small properties, with an area of between 1 and 4 fiscal modules; C) medium-sized properties, with a size greater than 4 and up to 15 fiscal modules; and D) large properties, with an area greater than 15 fiscal modules.

[16]The choice to use the total gross value of production in each farm was due to the limitation of the microdata of the Agricultural Census, regarding the information about the productive inputs. That is, although the Census presents detailed information about the production value of each commodity, it is not possible to identify the amount of some inputs (labor, capital and others inputs) used in each crop specifically. In this way, it was not possible to estimate production stochastic frontiers for each agricultural product.

[17] According to the methodology of the 2006 Agriculture and Livestock Census, a family labor unit was obtained by adding the number of people, men or women, with ties of kinship, of 14 years of age or older, including the person running the farm, to half of the number of people with ties of kinship, less than 14 years of age, plus the number of employees with 'another status' aged 14 years or over, plus half the number of employees with 'another status' under 14 years of age. The hired labor unit was obtained by adding the number of men and women: permanent employees aged 14 years and over, to half the number of permanent employees under 14 years of age, plus partner employees of 14 years and above plus half of the number of employees of less than 14 years of age, plus the result of dividing the number of daily wages paid in 2006 by 260, plus the result of dividing the number of contract days by 260 (IBGE, 2006).

Tab. 1. Descriptive statistics of variables used in the analysis, per agriculture and livestock farm size.

Variables	Mini (N=3,283,982)		Small (N=694,133)		Medium (N=208,806)		Large (N=72,962)		Total (N=4,259,963)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
prodval(R$)	10,189	218,338	37,304	412,398	98,849	702,204	430,706	3,700,359	26,157	571,345
valprop (R$)	51,794	466,192	285,477	965,981	1,021,292	2,435,663	4,954,006	1,18e+07	221,372	1,848,835
totinput (R$)	2,065	193,793	10,014	102,411	36,867	688,611	246,885	7,307,546	9,260	984,657
finance (R$)	829,94	9,036	3,845	20,343	13,018	91,645	58,949	806,783	2,914	108,409
prodarea (ha)	7.60	10.20	49.59	43.64	206.74	167.32	1,158	1,993	43.91	305.57
totarea (ha)	10.36	13.51	69.7	54	286	214	1,716	3,102	62.76	468
laboru (units)	2.52	5.84	2.89	4.26	3.77	13.07	6.62	19.42	2.71	6.67
stocku (units)	6.88	21.55	34.02	58.75	124.15	175.46	593.11	1,140	27.09	176
tech (%)	*0.16*	*0.367*	*0.375*	*0.484*	*0.452*	*0.498*	*0.588*	*0.492*	*0.217*	*0.412*
irrig (%)	*0.06*	*0.24*	*0.069*	*0.25*	*0.073*	*0.26*	*0.08*	*0.27*	*0.062*	*0.24*
storage (%)	*0.16*	*0.366*	*0.298*	*0.458*	*0.27*	*0.444*	*0.248*	*0.432*	*0.189*	*0.392*
coop (%)	*0.397*	*0.489*	*0.474*	*0.499*	*0.424*	*0.494*	*0.411*	*0.492*	*0.411*	*0.492*
rural (%)	*0.895*	*0.307*	*0.801*	*0.399*	*0.696*	*0.46*	*0.661*	*0.474*	*0.866*	*0.341*
exper10 (%)	*0.626*	*0.484*	*0.707*	*0.455*	*0.645*	*0.479*	*0.586*	*0.492*	*0.64*	*0.48*
school (%)	*0.542*	*0.498*	*0.653*	*0.476*	*0.571*	*0.495*	*0.499*	*0.5*	*0.561*	*0.496*
tenant (%)	*0.0505*	*0.219*	*0.0328*	*0.178*	*0.0398*	*0.196*	*0.0321*	*0.176*	*0.0468*	*0.211*
partner (%)	*0.0348*	*0.183*	*0.00767*	*0.0872*	*0.00606*	*0.0776*	*0.00356*	*0.0596*	*0.0284*	*0.16*
occupier (%)	*0.105*	*0.307*	*0.0236*	*0.152*	*0.0181*	*0.133*	*0.00796*	*0.0889*	*0.0858*	*0.28*

Note: SD=Standard deviation.
Source: Drawn up by authors based on microdata from the 2006 Agriculture and Livestock Census.

It was also necessary to consider Brazil's regional differences in the analysis of the technical efficiency of farms as Brazilian territory is heterogeneous not just in terms of natural conditions but also in terms of factors such as historical occupation. With that in mind, regression was estimated considering fixed effects at state level in order to control this spatial heterogeneity. To do so, a dummy (E_h) for each unit of the federation was included in the model, which was given a value of 1 when the farm belonged to that unit of the federation and 0, otherwise.

In terms of the analysis of the determinants of productive efficiency, total farm area (*totarea)*, in logarithm, its quadratic term (*totarea2),* was included in the model, as well as the main variable, to see if the effect of farm size was non-linear. In addition, in order to control the heterogeneities due to the specific characteristics of the farmer or farm, the following variables[18] were also considered: access to technology, represented by the *irrig* dummy was given a value of 1 if the farm had access to irrigation; access to public institutes and bodies, defined by the variables total amount financed (*finance)*, in logarithm; and access to technical assistance, represented by the dummy *tech* was given a value of 1, if the farm had access to any type of technical assistance, either occasionally or regularly; presence of a storage unit on the farm, represented by the dummy *storage* was given a value of 1 if the farm had a storage unit; participation in information networks via participation in cooperatives and/or class entities such as farmers' unions, associations or movements, represented by the *coop* dummy was given a value of 1 if the person in charge of the farm participated in cooperatives and/or class associations; residence of the farm head in a rural area, represented by the dummy *rural* was given a value of 1, if the head of the farm lived in the rural area, which for purposes of the study, are considered proxies for the presence of social capital on the farm; and variables related to human capital, such as the years of experience of the head as administrator of the farm, represented by the dummy *exper10* was given a value of 1, if the head had spent more than 10 years administering the farm, and schooling (*school).* As for the latter, it should be emphasized that it is a measure of little schooling, indicating whether the farm head became literate as an adult, did or did not have complete primary education or had no formal education whatever, but can read and write. It is thus expected that this will have a negative impact on the productive efficiency of the farms. This choice was

[18] The variables were selected using studies by Helfand and Levine (2004), Rada and Valdes (2012) and others.

made because it is basically the most frequent situation among farm heads. Finally, the status of the producers in relation to the land (*tenant, partner, occupier*) were considered dummies with the status of owner used as a basis. Table 1 presents the descriptive statistics per farm size of the variables considered in the analyses.

The data presented in Table 1 show that output value, value of goods, costs of inputs and total amount financed increase according to the size of the farm. The minifundia contain a mean of 7.6 ha of productive area, which is about 7 times smaller than that of the small farms (49.59 ha). When compared to medium and large properties, the average productive area of the minifundia was about 27 and 152 times smaller, respectively.

It was seen that access to technical assistance increases as farm size increases, as only 16% of the minifundia had access, while for large farms this percentage reached almost 60%. As regards access to irrigation technologies, it was seen that access is still limited for Brazilian farms, as the mean percentages varied from 6% for the minifundia to 8% for large farms.

On the question of social capital on the farm, in terms of participation in cooperatives and/or class entities such as producers' unions, associations or movements, it was seen that those responsible for small farms were the most participative. This was followed by the medium and large farms and the minifundia. In addition, about 70% of those in charge of farms classified as small had 10 years' experience or more as farm head. This was the highest percentage. Large farms presented the lowest percentage, namely 58.6%. As regards schooling, most farm heads had low levels (up to primary level completed), corresponding to 65%, 57% and 54% respectively, of the heads of the small and medium farms and minifundia. For the large farms, 50% of farm heads presented this level of schooling.

3. RESULTS AND DISCUSSION

3.1. Stochastic Frontier Production

As shown in Section 3, five stochastic frontier production functions were estimated, one referring to Brazil as a whole and the other four to different groupings of farms according to area: minifundia (minis), small, medium and large. It should be noted that the specified functional form was that of Cobb-Douglas and the parameters were obtained via maximum likelihood.

The results of the stochastic frontier estimates are presented in Table 2. It must be remembered that, as all variables were transformed into their natural logarithm, the estimated coefficients refer to the elasticities of the factors of production and should be interpreted in percentage terms. To better visualise the expression, the coefficients of fixed effects for the federal units were omitted. In terms of adjustment to the model, the Wald statistic result indicated that the null hypothesis of joint insignificance of the variables was rejected at a level of 1%, in all functions, which showed that the models estimated were adequate.

One of the advantages of using the Cobb-Douglas functional form in its log-linear form is that it is possible to identify the returns to scale of the production function by means of the direct sum of the elasticities of the productive factors (CHAMBERS, 1988). Thus, it was seen that the sum of the elasticities was 1.02 for the function estimated for Brazil, that is, the returns from the technology used are close to the constant returns to scale. In terms of returns of the specific functions for the minis, small, medium and large farms, the sum of elasticities was 1.02, 1.07, 1.00, 1.07, respectively, without any great differences in the returns of the factors of production even when considering farms of different sizes (Tab. 2).

From the results presented in Table 2, it was seen that the effect of the productive area differed for the different-sized groups of farms. The largest elasticities for this factor were seen at the limits of the medium and large farms, which indicates that a 10% increase in area was associated with a 2.64% and 2.91% increase in production values, respectively. This result suggests that such farms, even those with a larger total area than the others, are still basically dependent on the land factor in the productive process. For the small farms, productive area was the factor which least contributed to production value.

The variable used as proxy of the capital factor, *valuecap*, presented a positive sign and was statistically significant in all functions estimated. As expected, the highest elasticity seen for this factor was in the model referring to the large farms. The capital factor also contributed most to production value for this group of producers, which indicates that a 10% increase in the value of improvements, buildings and other facilities would raise the GPV by 3.43%, on average.

To represent the labor factor, the sum of family and hired workers on each farm was considered. On analysing the model estimated for rural Brazil as a whole, it was seen that of all the productive factors, this variable presented the highest elasticity, thereby playing a significant role in the formation of the national GPV. As regards the models estimated for each farm group, it was seen that the effect of labor in generating the value of production was highest for the minifundia, small and medium producers, and this factor also presented the

Tab. 2. Stochastic Frontier Production for Brazilian minifundia, small, medium and large farms.

	Brazil	Mini	Small	Medium	Large
Lnprodarea	0.203***	0.201***	0.203***	0.264***	0.291***
	(0.0010)	(0.0013)	(0.0031)	(0.0077)	(0.0102)
Lnvalprop	0.207***	0.194***	0.235***	0.234***	0.343***
	(0.0011)	(0.0011)	(0.0032)	(0.0056)	(0.0089)
Lnlaboru	0.372***	0.339***	0.402***	0.355***	0.310***
	(0.0015)	(0.0016)	(0.0036)	(0.0044)	(0.0092)
Lntotinput	0.245***	0.220***	0.312***	0.287***	0.261***
	(0.0005)	(0.0007)	(0.0018)	(0.0030)	(0.0062)
Lnstocku	-0.0123***	0.0606***	-0.0866***	-0.137***	-0.133***
	(0.0006)	(0.0009)	(0.0014)	(0.0019)	(0.0037)
Small	0.139***	-	-	-	-
	(0.0023)				
Medium	0.336***	-	-	-	-
	(0.0044)				
Large	0.637***	-	-	-	-
	(0.0071)				
Constant	5.374***	5.895***	4.550***	5.140***	3.874***
	(0.0333)	(0.0519)	(0.0637)	(0.0904)	(0.1180)
Usigma	1.635***	1.540***	1.704***	2.016***	2.224***
	(0.0014)	(0.0017)	(0.0035)	(0.0057)	(0.0108)
Vsigma	0.164***	0.260***	-0.175***	-0.352***	-0.351***
	(0.0021)	(0.0023)	(0.0067)	(0.0086)	(0.0233)
Lambda	9.969	5.923	9.737	5.727	6.336
Wald Test	1.06E+10	3.96E+09	409,325	319,197	136,178
Nº Obs.	4,259,963	3,283,982	694,133	208,886	72,962

Note: *** significant at 1%; Standard deviation in brackets.
Source: Drawn up by authors based on microdata from the 2006 Agriculture and Livestock Census.

highest returns for these groups. Such a result is not surprising, as these types of farm, especially the minifundia, are, in most cases, associated with lower levels of investment, capital stock and have other limitations and, thus, using more labor is one of their main strategies for increasing agricultural income in the short term.

As for input expenses, represented by the variable *totinput*, it was seen that, as expected, higher costs for inputs in productive processes are related to the higher production values of the farm, especially for small farms, which presented the highest elasticity for this factor of production.

A positive relationship was only seen in the minifundia between the variable representative of the livestock on the farm (*stocku*), and production value in the minifundia. A 10% increase in livestock was associated with a 0.6% higher GPV, on average. For the other functions, what was found was contrary to what was expected. However, it must be stressed that, when using the number of animals on the farm as a proxy for the livestock factor, as an independent variable, the importance of this factor in the productive process could be camouflaged, as it does not provide any information on how the livestock is used, or on the characteristics of this stock. If livestock is improperly used by the farm, such as in densities beyond the capacity of the farm, problems involving insufficient feeding and even disease could lead to lower production values.

Tab. 3. Mean technical efficiency of farms, per size.

Size	Technical Efficiency
Minifundia (<1 FM)	0.334
Small (1 to 4 FM)	0.304
Medium (>4 to 15 FM)	0.272
Large (>15 FM)	0.289

Source: Drawn up by authors based on microdata from the 2006 Agriculture and Livestock Census. FM=Fiscal module.\

Another significant result from Table 2 is the *Lambda* parameter estimate obtained by dividing the inefficiency variance (*Usigma*) by the variance of the random error component (*Vsigma*) which allows one to test the presence or absence of technical inefficiency. Values greater than 1 found in all the functions estimated indicate that most of the error is due to inefficiency, that is, discrepancies seen between the products and the optimal frontiers are primarily due to technical inefficiency.

After estimating the production frontiers for each area group selected, technical efficiency scores were obtained (Tab. 3).

With regard to technical efficiency, the mean values show that those agriculture and livestock farms classified as minifundia were technically more efficient than farms of other sizes. It is also seen that small farms were more efficient than either the medium or large. These results suggest an inverse relationship between farm size and technical efficiency. This issue is discussed in greater detail in the following section.

In addition, since the value 1 (one) represents an absence of technical inefficiency, the low values seen in all the size classes considered indicate that farms were still quite inefficient, despite the differences between them.

3.2. Determinants of technical efficiency of agriculture and livestock farms per efficiency level

After obtaining the efficiency scores, the quantile regression technique was used to verify the determinants of the productive efficiency of the representative farms, considering five quantiles or efficiency groups (0.10; 0.25; 0.50; 0.75; and, 0.90). It is important to highlight that, in addition to identifying the relationship between the variables used and productive efficiency, these results also allow one to verify the variation in the power of determination of these variables on the performance of the producers for different levels of efficiency, represented by each quantile of the sample. The results are shown in Tables 4, 5 and 6.

To check if the effects of the variables selected are in fact heterogeneous in relation to the quantiles of the sample, the Wald test was carried out. The result calculated for the F statistic of the models estimated for the total sample (Brazil), minifundia, small, medium and large farms were significant at 1%, and thus the null hypothesis of equality of parameters was rejected. This means that the explanatory power of the variables with respect to technical efficiency changes, depending on the level (range) of efficiency of the farms, indicates that the estimation via quantile regression is more adequate, to the detriment of estimation by least squares or any other method.

It should be remembered that, as specified in Equation 5, total farm area was included as a determinant of efficiency with a view to statistically verifying the relationship between productive performance and farm size. However, as seen in the literature on the subject (Helfand, Levine, 2004; Teryomenko, 2008), the relationship between productive performance and farm size can be non-linear. Thus, a quadratic term of the area was added to statistically test this hypothesis of non-linearity (Tabb. 4, 5 and 6).

The results in Table 4 present a negative and significant relationship between technical efficiency and total area for less (q10 and q25) and more efficient (q75 and q90) farms for Brazil. The positive result found for the medium-sized farms (q50) confirms how important it is to analyse the determinants, taking existing heterogeneities between different levels of efficiency into consideration. Estimates based solely on the sample mean can omit relevant information about the effect of area (and other determinants) on the productive performance of the farm. In addition, a nonlinear relationship between these variables was only seen in farms with higher levels of technical efficiency, which indicates that the increase in area reduces the efficiency of the farm up to a minimum level, after which farm productivity increases. Helfand and Levine (2004) found a similar result when analysing determinants of technical efficiency of farms in Midwestern Brazil.

As regards the other variables, it was seen that irrigation technology (*irrig*), the presence of storage units on the property (*storage*) and the fact that the producer was a member of some type of cooperative (*coop*) exerted a significant and positive effect on technical efficiency, especially of those farms associated with lower levels of efficiency (q10 and q25).

Tab. 4. Determinants of technical efficiency according to Brazilian levels of efficiency.

Variables	BRAZIL				
	q10	q25	q50	q75	q90
Lntotarea	-0.229***	-0.0006	0.0071***	-0.0081***	-0.0116***
	(0.0027)	(0.0011)	(0.0004)	(0.0003)	(0.0003)
Lntotarea2	-0.0268***	-0.0087***	-0.00261***	0.0007***	0.0011***
	(0.0006)	(0.0002)	(7.69e-05)	(4.26e-05)	(3.36e-05)
Lnfinance	0.156***	0.0415***	0.0152***	0.0053***	0.0011***
	(0.0012)	(0.0002)	(0.0001)	(5.41e-05)	(6.42e-05)
Irrig	1.160***	0.477***	0.221***	0.135***	0.0900***
	(0.0123)	(0.0024)	(0.0008)	(0.0010)	(0.0008)
Storage	2.068***	0.499***	0.155***	0.0449***	-0.0011
	(0.0088)	(0.0019)	(0.0007)	(0.0006)	(0.0007)
School	-0.107***	0.0191***	0.0371***	0.0175***	0.0006
	(0.0064)	(0.0016)	(0.0005)	(0.0004)	(0.0005)
Coop	1.375***	0.339***	0.0641***	0.0013***	-0.0142***
	(0.0106)	(0.0021)	(0.0007)	(0.0005)	(0.0004)
Rural	1.624***	0.755***	-0.0520***	-0.0646***	-0.0394***
	(0.0097)	(0.0127)	(0.0016)	(0.0008)	(0.0006)
exper10	1.014***	0.299***	0.0404***	-0.0051***	-0.0092***
	(0.0070)	(0.0018)	(0.0006)	(0.0005)	(0.0006)
Tech	0.455***	0.360***	0.188***	0.0917***	0.0412***
	(0.0091)	(0.0021)	(0.0008)	(0.0005)	(0.0005)
Tenant	1.140***	0.616***	0.238***	0.118***	0.0919***
	(0.0209)	(0.0039)	(0.0017)	(0.0012)	(0.0011)
partner	1.539***	0.668***	0.253***	0.118***	0.0705***
	(0.0122)	(0.0036)	(0.0022)	(0.0012)	(0.0016)
occupier	1.296***	0.443***	0.137***	0.0487***	0.0220***
	(0.0080)	(0.0032)	(0.0013)	(0.0010)	(0.0010)
constant	-7.996***	-3.338***	-1.294***	-0.772***	-0.531***
	(0.0090)	(0.0135)	(0.0021)	(0.0010)	(0.0008)
Nº Obs	4,259,963	4,259,963	4,259,963	4,259,963	4,259,963

Note: *** significant at 1%; Standard deviation in brackets.
Source: Drawn up by authors based on microdata from the 2006 Agriculture and Livestock Census.

The results estimated for each group of producers in relation to farm size (minifundium, small, medium, and large) are presented in Tables 5 and 6. In terms of total farm area, it was seen that, irrespective of the type of producer, those farms related to intermediate efficiency quantiles (q25, q50 and q75) presented a positive relationship between productive performance and farm size, with the greatest effect of this variable seen for medium-sized producers. Another interesting result is that, as the producer reaches higher levels of technical efficiency, the effect of total area decreases, which indicates that this farm is becoming less dependent on the land factor. Other studies, such as those by Tauer and Mishara (2006), Alvares and Arias (2004), Gonçalves *et al.* (2008) and Kumbhakar *et al.* (1991) also found a positive relationship between these variables.

However, in the case of the minifundia and small groups, it was seen that for producers related to lower levels of efficiency (q10), an increase in total area was associated with a reduction in their technical efficiency. This result is surprising, as it questions whether land redistribution policies are effective in improving the productive performance of poorer farmers, and the results seen in the present study indicate that they are not. In addition, the hypothesis of non-linearity between efficiency and total area was also confirmed in the four groups analyzed.

It was seen that an increase in the total financing variable (*Lnfinance*) increased the technical efficiency of all farms analysed, especially those in the larger area class. In the same vein, Magalhães *et al.* (2011) report that credit is a productive factor which reduces technical inefficiency, as it allows for greater access to and better use of resources, so that, in effect, it increases the productivity of the property.

That the effect of financing is greatest for large producers can be explained by the fact that these farmers are associated with better levels of schooling and greater access to technical assistance services, which can lead to more efficient use of the resources acquired. Of the different levels of efficiency analysed, it was seen that less efficient producers (q10) were the main beneficiaries of the increase in the total amount of financing, which was also true in terms of irrigation. This shows the importance of increasing the availability of rural credit as a means towards reducing part of the existing heterogeneities in the Brazilian agriculture and livestock sector.

On considering the effects of the other determinants of technical efficiency, the coefficients estimated for the *irrig* variable indicated that farms which used irrigation technology were associated with higher levels of efficiency in all groups of producers analysed. A similar result was found by Khai and Yabe (2011), when analysing determinants of the technical efficiency of rice producers in Vietnam for the 2005/06 crop. In addition, in all cases, this technology was more important for increasing the productive performance of producers belonging to the lowest quantile of efficiency (q10), especially those classified as small.

The variable representative of the number of storage units on the farms (*storage*) was statistically significant and positive for all four groups analysed, which indicates that an increase in storage units is associated with an increase in technical efficiency, with the exception of the most efficient quantile (q90) of large farms. However, it was found that, in general, the effect of this variable is smaller for minifundia and small producers.

The relationship between schooling and technical efficiency of farms was found to be positive and significant for almost all levels of efficiency in all the groups considered. It must be remembered that this variable should be interpreted as an indicator of a low level of schooling, as it indicates the percentage of farmers who either became literate as adults or who had completed or did not complete primary schooling or had no schooling whatever but could read and write. Therefore, the result that was found indicates that such producers were associated with greater productive performance. Although this result was the opposite of what was expected for Brazilian agriculture and livestock farming, it could indicate that experience in production could have a greater effect than the schooling itself.

Among the variables used to identify the contribution of social capital to the productive performance of farms, the fact that the farmer participated in cooperatives and/or class entities such as unions, associations or producer movements (*coop*) contributed to higher levels of efficiency irrespective of farm size, with the exception of those farms associated with the highest levels of technical efficiency (q90), as at these levels the estimated coefficient was negative. This result is interesting because it shows that the benefits arising out of cooperation could be limited to those farms already using their productive inputs efficiently, while they are highly advantageous for relatively inefficient producers, given the high coefficient seen for the lower efficiency quantile (Q10), in all class sizes considered. The importance of organizing farmers into cooperatives was also seen by Galawat and Yabe (2012) when they identified that farmers who joined associations or cooperatives incurred less profit loss, and achieved greater efficiency. According to Baron (2007), participation in associative organizations increases rural producers' access to information, technology and rural extension services, and thereby contributes to greater efficiency in farming.

The fact that the head of the farm lived in the rural area (*rural*) was related to higher levels of technical efficiency solely for the minifundia and small producers, relating to quantiles q10 and q25, and medium-sized farmers, relating to quantile q10, when compared to farms where the head resided in an urban environ-

Tab. 5. Determinants of technical efficiency per efficiency levels for minifundia and small farms.

Variables	MINI					SMALL				
	q10	q25	q50	q75	q90	q10	q25	q50	q75	q90
Lntotarea	-0.638***	0.0941**	0.120***	0.0045	-0.0215**	-0.199***	0.0106***	0.0065***	-0.0053***	-0.0080***
	(0.112)	(0.0476)	(0.0191)	(0.0090)	(0.0108)	(0.0023)	(0.0011)	(0.0004)	(0.0002)	(0.0002)
Lntotarea2	0.0817***	-0.0106*	-0.0143***	0.0018	0.0050***	-0.0393***	-0.0144***	-0.0029***	0.0009***	0.0011***
	(0.0147)	(0.0062)	(0.0024)	(0.0011)	(0.0013)	(0.0010)	(0.0004)	(0.0001)	(5.53e-05)	(6.29e-05)
Lnfinance	0.0984***	0.0403***	0.0145***	0.0044***	0.0004***	0.149***	0.0366***	0.0137***	0.0050***	0.0013***
	(0.0016)	(0.0005)	(0.0002)	(0.0001)	(0.0002)	(0.0015)	(0.0003)	(9.13e-05)	(6.45e-05)	(8.00e-05)
Irrig	0.591***	0.422***	0.157***	0.0744***	0.0353***	1.182***	0.468***	0.244***	0.160***	0.110***
	(0.0149)	(0.0063)	(0.0021)	(0.0016)	(0.0017)	(0.0121)	(0.0023)	(0.0012)	(0.0011)	(0.0011)
storage	3.285***	0.590***	0.184***	0.0638***	0.0115***	1.802***	0.429***	0.139***	0.0395***	-0.0019**
	(0.0465)	(0.0061)	(0.0018)	(0.0015)	(0.0014)	(0.0117)	(0.0026)	(0.0008)	(0.0007)	(0.0008)
School	0.0778***	0.0980***	0.0511***	0.0107***	-0.0096***	-0.133***	0.0217***	0.0367***	0.0217***	0.0067***
	(0.0157)	(0.0090)	(0.0027)	(0.0014)	(0.0013)	(0.0064)	(0.0021)	(0.0006)	(0.0004)	(0.0005)
Coop	1.667***	0.495***	0.0925***	0.0102***	-0.0168***	1.284***	0.271***	0.0496***	-0.0038***	-0.0148***
	(0.0418)	(0.0094)	(0.0024)	(0.0012)	(0.0012)	(0.0133)	(0.0025)	(0.0009)	(0.0006)	(0.0006)
Rural	1.634***	0.525***	-0.0474***	-0.0537***	-0.0298***	1.620***	1.892***	-0.0247***	-0.0636***	-0.0434***
	(0.0338)	(0.0174)	(0.0026)	(0.0014)	(0.0013)	(0.0089)	(0.0726)	(0.0016)	(0.0011)	(0.0009)
exper10	1.364***	0.580***	0.0611***	-0.0037***	-0.0097***	0.907***	0.214***	0.0322***	-0.00331***	-0.0062***
	(0.0242)	(0.0111)	(0.0022)	(0.0010)	(0.0012)	(0.0080)	(0.0026)	(0.0010)	(0.0006)	(0.0006)
Tech	0.456***	0.438***	0.203***	0.0856***	0.0324***	0.411***	0.293***	0.167***	0.0897***	0.0451***
	(0.0178)	(0.0063)	(0.0025)	(0.0012)	(0.0014)	(0.0099)	(0.0022)	(0.0010)	(0.0005)	(0.0006)
Tenant	0.206***	0.472***	0.185***	0.103***	0.128***	1.344***	0.554***	0.225***	0.110***	0.0840***
	(0.0315)	(0.0204)	(0.0057)	(0.0044)	(0.0050)	(0.0140)	(0.0031)	(0.0014)	(0.0012)	(0.0017)
partner	0.367***	0.315***	0.114***	0.0581***	0.0456***	1.616***	0.596***	0.235***	0.110***	0.0651***
	(0.0574)	(0.0240)	(0.0082)	(0.0061)	(0.0102)	(0.0139)	(0.0027)	(0.0014)	(0.0010)	(0.0015)
occupier	0.476***	0.154***	-0.0241***	-0.0238***	-0.0034	1.355***	0.400***	0.130***	0.0465***	0.0179***
	(0.0326)	(0.0085)	(0.0045)	(0.0048)	(0.0049)	(0.0096)	(0.0032)	(0.0014)	(0.0010)	(0.0008)
constant	-9.180***	-4.072***	-1.656***	-0.849***	-0.525***	-7.600***	-4.178***	-1.241***	-0.761***	-0.538***
	(0.208)	(0.0808)	(0.0372)	(0.0175)	(0.0214)	(0.0072)	(0.0716)	(0.0017)	(0.0010)	(0.0009)
Nº Obs	3,283,982	3,283,982	3,283,982	3,283,982	3,283,982	694,133	694,133	694,133	694,133	694,133

Note: *** significant at 1%, ** significant at 5%; Standard deviation in brackets.
Source: Drawn up by authors based on microdata from the 2006 Agriculture and Livestock Census.

ment, keeping other attributes constant. The greater effect of this variable for minifundia and small farms was expected, as a large number of them involve family farming where, as Guanziroli *et al.* (2001) reported, productive performance depends more on the physical ability of family members to perform the agricultural tasks needed for production, and so the head of the farm participates directly in the work. Nevertheless, the negative relation found for large farms is not surprising in the sense that, when living in an urban location, the big producer has greater access to information about the market, banking institutions to obtain credit and other services.

On the question of the experience of farm heads (*exper10*), the estimated coefficient was statistically significant and presented a positive relation with technical efficiency for the first quantiles (q10, q25 and q50) for all four groups of producers. For these farms, producers with more than 10 years' experience in managing the property were more productive than those with less experience, which indicates that with experience the producer uses inputs more efficiently. Other studies, such as those undertaken by Abdulai *et al.* (2013) and Oyewol (2009), have also found a significant and positive relationship between productive efficiency and experience. However, for the most efficient farms (q90) in each group considered, the results indicated a negative relationship between experience and technical efficiency.

The impact of technical assistance (*tech*) as a determinant of productive performance was also statistically

Tab. 6. Determinants of technical efficiency per efficiency levels for medium and large farms.

Variables	MEDIUM					LARGE				
	q10	q25	q50	q75	q90	q10	q25	q50	q75	q90
Lntotarea	0.185	1.214***	0.344***	0.0413*	-0.0276	-0.0698	0.331**	0.326***	0.0789***	0.0097
	(0.231)	(0.142)	(0.0424)	(0.0232)	(0.0199)	(0.325)	(0.165)	(0.0846)	(0.0243)	(0.0303)
Lntotarea2	-0.0139	-0.114***	-0.0310***	-0.0013	0.0042**	-0.0090	-0.0341***	-0.0235***	-0.0042**	0.0003
	(0.0225)	(0.0136)	(0.0040)	(0.0021)	(0.0018)	(0.0234)	(0.0119)	(0.0059)	(0.0017)	(0.0021)
Lnfinance	0.148***	0.0566***	0.0220***	0.0070***	0.0009***	0.184***	0.0673***	0.0234***	0.0068***	0.0004
	(0.0030)	(0.0008)	(0.0004)	(0.0002)	(0.0002)	(0.0080)	(0.0015)	(0.0007)	(0.0005)	(0.0004)
Irrig	0.732***	0.432***	0.156***	0.0826***	0.0379***	0.469***	0.380***	0.155***	0.0788***	0.0506***
	(0.0416)	(0.0139)	(0.0063)	(0.0051)	(0.00474)	(0.0428)	(0.0313)	(0.0120)	(0.0072)	(0.0075)
storage	4.866***	0.782***	0.228***	0.0742***	0.0175***	4.202***	0.692***	0.168***	0.0330***	-0.0054
	(0.0815)	(0.0121)	(0.0045)	(0.0025)	(0.0029)	(0.290)	(0.0294)	(0.0062)	(0.0039)	(0.0052)
School	0.142***	0.0969***	0.0354***	1.57e-05	-0.0102***	0.108**	0.0046	-0.0121	-0.0099	-0.0121*
	(0.0248)	(0.0160)	(0.0046)	(0.0022)	(0.0027)	(0.0432)	(0.0292)	(0.0119)	(0.0074)	(0.0064)
Coop	1.611***	0.655***	0.150***	0.0311***	-0.0085***	2.433***	0.748***	0.190***	0.0373***	-0.0089*
	(0.0963)	(0.0187)	(0.0052)	(0.0030)	(0.0023)	(0.361)	(0.0493)	(0.0138)	(0.0062)	(0.0046)
Rural	0.443***	-0.0218	-0.0902***	-0.0496***	-0.0214***	-0.0352	-0.208***	-0.120***	-0.0349***	-0.0072
	(0.0348)	(0.0181)	(0.0042)	(0.0026)	(0.0036)	(0.0552)	(0.0362)	(0.0102)	(0.0043)	(0.0045)
exper10	1.137***	0.798***	0.0812***	-0.0158***	-0.0303***	1.006***	0.801***	0.129***	0.0207***	-0.0017
	(0.0639)	(0.0282)	(0.0033)	(0.0026)	(0.0023)	(0.112)	(0.0464)	(0.0110)	(0.0063)	(0.0039)
Tech	0.410***	0.652***	0.277***	0.115***	0.0426***	0.655***	1.142***	0.435***	0.154***	0.0469***
	(0.0383)	(0.0149)	(0.0049)	(0.0031)	(0.0024)	(0.137)	(0.0576)	(0.0118)	(0.008)	(0.0065)
Tenant	0.252***	0.551***	0.184***	0.0805***	0.0656***	0.0715	0.342***	0.182***	0.0901***	0.0619***
	(0.0822)	(0.0347)	(0.0084)	(0.0064)	(0.0057)	(0.219)	(0.0433)	(0.0222)	(0.0135)	(0.0134)
partner	0.421***	-0.167	0.0505	0.0488***	0.0672***	0.177	0.122	0.197***	0.176***	0.134**
	(0.141)	(0.163)	(0.0472)	(0.0159)	(0.0171)	(0.296)	(0.236)	(0.0583)	(0.0297)	(0.0557)
occupier	1.054***	0.0271	-0.191***	-0.0456**	0.0282***	0.441	-0.315	-0.279***	-0.0448	0.0864*
	(0.0968)	(0.0593)	(0.0311)	(0.0196)	(0.0087)	(0.362)	(0.229)	(0.104)	(0.0392)	(0.0522)
constant	-11.71***	-7.439***	-2.576***	-1.063***	-0.524***	-10.83***	-5.555***	-3.028***	-1.326***	-0.681***
	(0.583)	(0.364)	(0.110)	(0.0613)	(0.0535)	(1.073)	(0.570)	(0.293)	(0.0888)	(0.106)
Nº Obs	208,886	208,886	208,886	208,886	208,886	72,962	72,962	72,962	72,962	72,962

Note: *** significant at 1%, ** significant at 5%, * significant at 10%; Standard deviation in brackets.
Source: Drawn up by authors based on microdata from the 2006 Agriculture and Livestock Census.

significant and presented the relationship expected for all models and efficiency levels estimated. In addition, it was seen that the greatest effect of this variable was seen for more inefficient farms (q10 and q25), which shows the relevance of the Technical Assistance and Rural Extension services for the country, especially for those producers facing greater challenges to convert productive inputs into production (or production value) itself. According to Anderson and Feder (2004) and Christoplos (2010), this is due to the role of technical assistance in encouraging the adoption of new technologies, which give producers access to more modern production factors. In addition, the flow of information generated by this service also contributes to raising the human capital of the producer, and has a direct impact on managerial skills, and as a result provides welfare gains in the countryside.

Finally, the effect on levels of productive efficiency of the employment status of the farm head in relation to the land was analysed. It is important to note that since the status of owner was used as a basis, a negative relationship found for a given status would indicate that a non-owner producer would be less efficient than an owner producer. The results show that, for all groups analysed, producers with the status of tenant, partner or occupier (in some cases) were relatively more efficient than owners. This result was not expected, as properties with definitive tenure have greater guarantees for acquiring credit and other services, as land is considered a tangible guarantee for loan repayment (BESLEY, 1995). In addition, the owner's incentive to invest long-term in innovation technology, which could contribute to increasing productive efficiency, is greater and, thus, it was expected that such producers would be related to better productive performance.

4. CLOSING REMARKS

The literature presents divergent results for the relationship between productive performance and farm size. Hence, the aim of this research was to verify this relationship, considering different size classes of Brazilian farms, using microdata from the 2006 Agriculture and Livestock Census. In addition, the study identified the main determinants of the productive performance of these properties considering each area group (minifundium, small, medium, large) in separate production frontiers.

The results of technical efficiency, obtained by estimating the stochastic frontier production function, indicated that the level of technical efficiency presented a negative and non-linear relationship with farm size solely for those minifundia and small producers related to the 10% less efficient and the 90% more efficient farms. This result is surprising because it questions the effectiveness of land redistribution policies in increasing the productive performance of small farmers, as the results shown here indicate that this would be true only for those who already had better productive performances. For medium-sized and large farms, there was a positive and significant relationship between technical efficiency and total area. The quadratic term was also significant and negative, and confirms the non-linear relationship between size and productive performance. This means that an increase in medium and large farm areas is directly associated with an increase in efficiency; however, from an optimal level onwards, that relationship becomes negative.

As for the other explanatory variables, which determine the productive efficiency of the representative units, it was seen that factors, such as access to irrigation technology, technical assistance, presence of storage units on the farms and membership of cooperatives and/or class entities and others, were crucial in increasing the productive performance of Brazilian farms, especially those related to low levels of technical efficiency. In this sense, the formulation of public policies for increasing the supply of such resources and services is vital, especially for small farmers. Greater availability of credit, for example, could contribute to more efficient use of resources available, and thus bring the production of the property closer to the optimal frontier of production.

However, if the inefficiencies seen in Brazilian agriculture and livestock rearing are to be reduced, much more is needed than merely providing greater access to production factors. Policies should concentrate on issues which allow for a more adequate use of these factors. For example, there is no point in enabling the rural producer to buy more inputs if he does not know that when they are improperly or excessively used, they can have negative effects on agriculture and livestock production. Thus, policies on technical assistance, qualification of the workforce, improvement of the managerial capacity of farm heads, among others, could reduce the levels of inefficiency on farms, with minimum change in the quantity of production factors, as they make for a more rational use of these factors.

In addition, the government should also encourage the setting up of cooperatives by producers, as this allows less efficient producers to have easier access to markets and new technologies, as well as managing to get better business deals. Such policies are crucial for increasing the productive performance of agriculture and livestock farms and to ensuring greater equity between small and large Brazilian producers.

In general, the results found indicate that land redistribution alone would not be sufficient to reduce rural inequalities. According to the estimates obtained, this may not be the most effective mechanism, since even if there are producers with relatively large properties, if they are using it efficiently a reduction of their land would lead to a worse balance than the one presented by scenario of land concentration. This analysis reinforces the argument that there may be efficient producers of all sizes, and in this case, applied public policies on determinants of productivity may be more effective, and less costly, to reduce inequality between small and large farms, if compared to agrarian reform.

As suggestions for future research, it becomes relevant to expand the analysis to verify the productive heterogeneity between each Brazilian region separately. Although the present research has controlled the bias caused by fixed characteristics of each region, detailed analysis could demonstrate to what extent the relationship between productive performance and farm size is sensitive to technology and / or other regional particularities. One of the paper's limitations was to consider each farm size class associated with a specific technology. It would be interesting to consider the existence of a meta-frontier of production, that is, to consider the possibility of having an optimal technology available to all producers. This investigation would also allow us to identify how far family farmers are from the optimal technology and what is the impact of this on the relationship between their productive performance and the farm size.

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Investment returns from hybrid poplar plantations in northern Italy between 2001 and 2016: are we losing a bio-based segment of the primary economy?

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Abstract. This work estimated financial returns at aggregate level from hybrid poplar plantations in northern Italy between 2001 and 2016. The results suggest that poplar can represent one of the most profitable investments among forest plantations in Europe, although the range of potential returns is rather large, including negative returns. The decrease of expected returns over the last 15 years has negatively undermined the attractiveness for new investments, increasing the market risk component. We also assessed the effects of external variables such as public subsidies, land cost, opportunity cost, and insurance cost. Land use and opportunity costs appear to be crucial variables, as well as public subsidies, which have undergone substantial changes over the period.

Keywords: Hybrid poplar, fast-growing species, timber production, investment analysis, Italy.
JEL codes: Q23, Q56, L73.

1. INTRODUCTION

Poplar is one of the most fast-growing species at temperate latitudes, and its cultivation in productive forest plantations is widespread and of key importance in several geographical areas, i.e. North America, Europe, India, and China. The area covered by poplar plantations is estimated to be 8.6 million hectares at global level (FAO, 2012). In Europe, poplar plantations reach almost one million hectares, with the highest shares in France, Turkey, Italy, Spain and Hungary (Nervo *et al.*, 2011).

In Italy, hybrid poplar plantations represent the most important segment of industrial timber production for the plywood, packaging, pulp and paper, and wood-based panels industries, providing more than 50% of the industrial hardwood domestic supply (Assopannelli, 2012; MIIPAF, 2012; Coaloa *et al.,* 1999; Coaloa, 2014). The large majority of these plantations, over 90%, is grown in the alluvial plains of northern Italy, in particular in the Po valley (ISTAT, 2016). The most suitable sites for poplar plantations are medium to high fertility arable agricultural land and river bends. Conventional poplar cultivation in northern Italy is characterized by intensively managed monospecific plantations, with short rotations cycles (9-12 years) and 278 to 330 trees per hectare. The cultivation techniques make hybrid poplar plantations more similar to agricultural crops rather than forestry in terms of energy and water inputs. Plantations are established from hybrid clones, where the predominant one has been since decades the *Populus x canadensis* "I-214", attaining on average a Mean Annual Increment (MAI) between 20 and 27 m^3 per hectare per year. The largest part of hybrid poplar plantations is intended for the production of plywood and veneer logs, with an overall yearly domestic production of over one million cubic meters of industrial roundwood which is processed and used in Italy for the production of high quality plywood and food packaging. Nevertheless, it is estimated that domestic supply is able to cover less than half of the industry domestic demand, which heavily relies on roundwood imports, largely from France and Hungary (FLA, 2018).

Despite the importance of this species for the industry, investments in poplar plantations have been undergoing a significant decline, started in the 1980s and more accentuated in the last two decades, reflected in the reduction of cultivated areas (Coaloa, 2008; Lapietra *et al.,* 1995). According to the data of the Agricultural Census of the Italian National Institute of Statistics (ISTAT), that considers only agricultural farm areas, poplar cultivated surface decreased from 83,368 hectares in year 2000 to 39,308 ha in year 2010 (-52.9%), while the number of farms cultivating poplar decreased by 59.3% (ISTAT, 2016). The last two National Forest Inventories, which comprise also hybrid poplar plantations outside agricultural farms, reported in year 1985 a cultivated area of 110,700 ha and in year 2005 of 66,270 ha (IFN, 1985; Gasparini, Tabacchi, 2011). This decline has been influenced by both economic variables directly related to the production, such as stumpage prices, management costs and land cost, suppliers' fragmentation and smallholder's weak contractual power, as well as external variables, i.e. the high opportunity costs related to alternative agricultural land-use (in particular for cereals production), environmental restrictions to cultivate in river bends (area which are in many cases identified as Site of Community Importance or Special Protection Area), non-effective subsidy policies (those related to the European Union's Common Agricultural Policy and its Rural Development Plans), and the growing risk component related to extreme weather events and pest attacks (Coaloa, 2009; Nervo, 2009; Castro, Zanuttini, 2008; Borelli, 1997).

In this context, investigation in the economic and financial aspects of hybrid poplar cultivation can contribute to a better understanding of this market segment evolution and its dynamics over time. In particular, the research questions that we aimed to answer with this study were: how profitability of hybrid poplar plantations has changed over the past 15 years as a result of the evolution of the key economic variables of investment costs and timber prices? And how external variables could have influenced this trend?

Therefore, the objective of the study presented in this paper was to: i) estimate and analyse the evolution of financial returns at aggregate level from hybrid poplar plantations in northern Italy between 2001 and 2016; and ii) assess the impact of the major policy and market factors on the financial returns evolution, i.e. public subsidies, an explicit land cost, opportunity costs of alternative agricultural land-use, and insurance policy cost.

Given the importance of this species at global level, various authors in the literature tackled the topic of cost-effectiveness of productive poplar plantations. i.e. Anderson and Luckert (2006) in Canada, Tankersley (2006) in southern United States, Keća *et al.* (2011) and Keća *et al.* (2012) in Serbia, Aunos *et al.* (2002) Diaz Balteiro and Romero (1994), Esteban López *et al.* (2005) and Del Peso *et al.* (1995) in Spain.

In Italy, studies on financial aspects of hybrid poplar plantations are not recent. The most recent work on the profitability of poplar plantation is related to the ECO-PIOPPO project, where the potential financial performances of conventional cultivation have been compared against those based on an experimental environmentally-friendly management standard (Coaloa, Vietto, 2005; Regione Piemonte, 2002). Other studies can be found in Borelli (1997), Borelli and Facciotto (1996) or in Prevosto (1969 and 1971). It has to be noted that in recent years, a considerable interest was given to financial performances of hybrid poplar in Short Rotation Coppice plantations aimed at the production of biomass for energy and for panel production (Coaloa, Facciotto, 2014; Di Candilo, Facciotto, 2012; Manzone *et al.*, 2009), unfortunately with limited impacts on the real investments in this sector.

A preliminary version of this work has been published in Italian language in a national-level technical forest journal (Pra, Pettenella, 2017).

2. METHODOLOGY

We defined a representative management regime for hybrid poplar plantations in northern Italy, follow-

Tab. 1. Representative silvicultural regime used in the analyses.

Flow	Category	Operation	Year											
			0	1	2	3	4	5	6	7	8	9	10	11
Costs	Site preparation	Ploughing	1											
		Ripping	1											
		Harrowing	1											
	Planting	Seedlings purchase and transport	1											
		Mark. dig and planting	1											
		Localized irrigation	1											
	Silvicultural management	Disk harrowing		3	3	3	2	2	2	1	1			Land recovery year
		Phytosanitary treatment *Marssonina brunnea*		2	2	2	2	2						
		Phytosanitary treatment *Saperda carcharias L*			1	1	1							
		Phytosanitary treatment *Cryptorhynchus lapathi*			1	1								
		Phytosanitary treatment *Phloeomyzus passerinii*							1	1	1	1		
		Weeding		1	1	1	1	1	1	1	1	1		
		Fertilization		1	1	1	1	1						
		Pruning		1	1	1	1	1						
		Irrigation		1	1	1	1	1	1	1	1	1		
	Cleaning	Stumps trituration and cleaning											1	
Revenues	Standing tree sale											1		

Note: numbers refer to the number of operations carried out annually.
Source: own elaboration.

ing an approach similar to the one used by Sedjo (1983) and Cubbage *et al.* (2007) for the estimation of timber investments returns for selected species at global level. We decided to use a representative management regime since the study's objective was not to carry out a site-specific or an exhaustive analysis, but rather to estimate the financial returns evolution over the period 2001-2016 at aggregate level, assuming a management regime which could represent the most frequent situation for poplar growers in northern Italy, based on the Typical Farm approach used in rural appraisal. In fact, poplar cultivation is rather homogeneous in northern Italy and it is based on a consolidated practice, i.e. same clone, same rotation period, same pruning regime, etc., with no much innovations in the last two decades (e.g. Borelli, 1997; Borelli, Facciotto, 1996; Coaloa, Vietto, 2005).

The data and information on management regime and investment costs used in this study were provided by three industrial and four non-industrial professional private poplar growers in Friuli Venezia-Giulia (Udine), Veneto (Rovigo) and Lombardy (Mantua) (interviewed face-to-face between January 2016 and February 2017), completed and adjusted with data from farms archives, regional bulletins and agricultural contractor's rates. When no historical data were available, due to the lack of book-keeping by poplar growers, we used the FAOSTAT (2018) Agricultural Producer Price Index for Italy to estimate missing data and complete the time series.

The silvicultural regime is presented in Table 1. The analysis was carried out considering a plantation established from *Populus* × *canadensis* 'I-214' with a 6x6 planting spacing (278 trees per hectare, assuming a 5% of mortality at the end of the rotation) and 11 years rotation, including one year of land recovery. We assumed average site conditions and ordinarily efficient implementation according to the typical professional management standards.

Investment costs cover the period 2001-2016 and include preparation, planting, silvicultural management costs and cleaning costs. Harvesting costs were not included because trees are typically sold as standing trees to external buyers. We considered two cost ranges, one related to a situation of minimum investment costs (Cmin) and one to maximum investment costs (CMAX).

Regarding the poplar timber stumpage prices, we used the range of prices recorded by the Chambers of Commerce of Mantua (2018) and Chambers of Commerce of Alessandria (2018) which are available for the period 2001-2018. In this case we also considered a range of minimum stumpage prices (Pmin) and maximum stumpage prices (PMAX). The large price variation between Pmin and PMAX is due to the number of variables that can influence prices, i.e. quality, location, and land owner's contractual power. Poplar stumpage prices are recorded by Chambers of Commerce in Euros per ton. Based on poplar growers data, reviewed by experts, we assumed an average poplar timber production of 185 tons per hectare, using a conversion factor of 0.7 tons per tree.

Both cost and price values include the Value Added Tax (VAT) and have been converted from nominal values into real values using the inflation index provided by the Italian Institute of Statistics (ISTAT, 2017).

Based on the input data on investments costs and stumpage prices we considered four situations: maximum investments costs and minimum stumpage prices (CMAX-Pmin); maximum investments costs and maximum stumpage prices (CMAX-PMAX); minimum investments costs and minimum stumpage prices (Cmin-Pmin); minimum investments costs and maximum stumpage prices (Cmin-PMAX).

To carry out the financial analysis, we firstly elaborated the cash flow tables considering costs and timber prices in terms of market prices. Secondly, we calculated three capital budgeting indicators to estimate financial returns: Net Present Value (NPV), Internal Rate of Return (IRR), and Land Expectation Value (LEV). The references used for the calculation and interpretation of such approaches can be found in Zinkhan and Cubbage (2003), Klemperer (2003), Bullard *et al.* (2011) and Wagner (2012). The formulas for these indicators are the following:

$$NPV = \sum_{n=0}^{N} \frac{R_n - C_n}{(1+i)^n}$$

$$IRR = i : \sum_{n=0}^{N} \frac{R_n}{(1+i)^n} = \sum_{n=0}^{N} \frac{C_n}{(1+i)^n}$$

$$LEV = \frac{NPV}{((1+i)^N - 1)}$$

Where:
n = year
R = revenues at year n
C = costs at year n
i = annual discount rate
N = rotation length

We decided to use the NPV and IRR as they are the two most widely spread and accepted decision indicators in sectorial literature. The NPV represents the present value of future cash flows and is generally considered as a preferable indicator to be used when analysing short term forestry investments (Klemperer, 2003; Wegner, 2012). The IRR represents the discount rate (i) at which the NPV of the investment equals zero. Finally, we included the LEV (or Soil Expectation Value) as it is a useful indicator for estimating the theoretical land value. In practice, the LEV represents the present value of all future costs and revenues assuming that the rotation cycle will be replicated an infinite number of times into the future.

We calculated these indicators for each year along the period 2001-2016, combining two different calculation approaches: *ex-ante* and *ex-post*. The *ex-ante* approach allows us to estimate the expected returns, answering the question: what was the return's expectation at the time the investment was carried out? Thus, indicators are calculated based only on values of the year when the investment was carried out. For example, in the case of a plantation established in 2001, the NPV would be calculated as follows:

$$NPV\ ex\ ante_{2001} = \frac{R_{2001}}{(1+i)^{11}} - \frac{C_{2001}}{(1+i)^{1}} - \frac{C_{2001}}{(1+i)^{2}} - \frac{C_{2001}}{(1+i)^{3}} - \ldots - \frac{C_{2001}}{(1+i)^{11}}$$

Where R_n and C_n are the sum of revenues and costs at year n.

On the other hand, the *ex-post* approach provides us the actual evolution of costs and prices throughout the years along the investment horizon, for example:

$$NPV\ ex\ post_{2001} = \frac{R_{2011}}{(1+i)^{11}} - \frac{C_{2001}}{(1+i)^{1}} - \frac{C_{2002}}{(1+i)^{2}} - \frac{C_{2003}}{(1+i)^{3}} - \ldots - \frac{C_{2012}}{(1+i)^{11}}$$

Therefore, the *ex-post* estimates provide information on the actual financial returns according to input variables evolution throughout the years. However, it has to be considered that we did not carry out any future projection, thus the values from 2016 for costs and 2018 for prices are assumed to be constant. This combined approach allowed us to estimate the variation between the *ex-ante* financial returns expectations and the *ex-post* returns.

In financial analysis, the choice of the discount rate in financial analysis is ultimately a decision of the investor who looks at the market prices with a discount rate that represents its opportunity cost for using its capital. In our study, for the NPV and LEV we decided to use a real discount rate of 3.5% (HM Treasury, 2003). How-

Tab. 2. Input data for sensitivity analyses.

Year	Missed revenues from corn cultivation in northern Italy (EUR/ha/year)*	Average annual land rent cost for selected types for land in the Po valley (EUR/ha/year)	Reimbursement percentage of site preparation and planting costs according to Rural Development Plan measures (%)	Insurance cost (EUR/ha/year)
2001	….	378.60		
2002	….	368.20		
2003	….	347.30	*60%* according to Measure H of RDPs 2000-06 (Reg. ECC No. 1698/1999)	
2004	….	347.30		
2005	….	352.50		
2006	….	307.70		
2007	….	317.10		
2008	150.70	312.90		
2009	-65.40	310.80		
2010	304.90	326.50	*70%* according to Measure 221 of RDPs 2007-13 (Reg. ECC No. 1968/2005)	
2011	394.40	333.80		
2012	433.40	328.00		
2013	242.30	315.00		
2014	234.40	383.00		
2015	112.90	338.00	*60%* according to Measure 8.1 of RDPs 2014-20 (Reg. ECC No. 1305/2013)	
2016	….	350.00		1st to 3rd year: 83 EUR/yr 4th to 6th year: 167 EUR/yr 7th to 10th year: 278 EUR/yr

* Direct payments from the Common Agricultural Policy excluded.
Source: own elaboration.

ever, different discount rates in the range 2%-12% (ECB, 2016; Keča *et al.,* 2011) were also tested to allow the readers to compare the results with their own references.

The analysis is carried out before income- and land-tax. This choice is motivated by the fact that the Italian tax regime varies substantially depending on the legal status and the business model of the investors.

We firstly assumed a baseline scenario not including opportunity cost, subsidies, and land cost (i.e. rent), assuming thus that the investors already own the land.

Secondly, we carried out sensitivity analyses in order to test the effects of different hypothesis:

(a) public subsidies, with the inclusion of a reimbursement of site preparation and planting costs, according to the afforestation measure grants by the regional Rural Development Plans (RDP);
(b) an explicit land costs, with the inclusion of an annual land rent;
(c) opportunity costs of alternative crop production, with the inclusion in the cash flow of missed revenues from the alternative corn cultivation;
(d) the combination of (b) and (c);
(e) risk insurance costs, including the cost of an insurance policy that protect the land owner against losses due to pests, fire, windstorm and hail.

The sensitivity analyses input data are presented in Table 2.

For what concerns public subsidies (a) we referred to the average level of grant-based contribution of the RDP afforestation measures of the northern Italian regions (Emilia-Romagna, Friuli Venezia-Giulia, Lombardy, Piedmont and Veneto), co-funded by the European Agricultural Fund for Rural Development (EAFRD). The contribution consists in a reimbursement of a percentage of the plantation establishment costs (site preparation and planting costs). In the current programming period 2014-2020, derived from the reg. ECC 1305/2013, the average reimbursements percentage of the establishment costs is 60% (Measure 8.1). In the programming period 2007-2013 (ECC 1698/2005), it was 70% (Measure 221), and in the programming period 2000-2006 (reg. ECC 1698/1999), 100% of the establishment costs were covered (Measure H). We excluded premiums criteria related to the use of environmentally-friendly clones and voluntary forest certification schemes. The reimbursement was included in the cash flow as a benefit at year 1.

Regarding the annual land rent cost (b), we elaborated the data from the Agriculture Annual Review of CREA (former INEA), calculating the average values for the years from 2001 to 2016 of selected types of lands in the provinces of Alessandria, Mantua and Udine (CREA, 2016). The land rent cost was included in the cash flow as an annual cost from year 1 to 11.

For the third sensitivity analysis (c) we estimated the yearly net missed revenues from corn production using the data of the Farm Accountancy Data Network (FADN) (RICA, 2017). We elaborated the net missed revenues from corn production year by year from the farm accounts including an explicit cost for labour for five northern Italian Regions between 2008 and 2015. Outliers were removed using a standard mathematical procedure based on boxplots (excluding those values that resulted beyond the quartiles by one-and-a-half interquartile range). Direct payments of the Common Agricultural Policy (CAP) were not included. The missed revenues from corn production showed a large variation among the years, presenting even a negative value in 2009 (-65.40 EUR). The net missed revenues were included in the cash flow as a cost from year 1 to 11.

Finally, the cost of an insurance policy () protecting the land owner against losses caused by pests, fire, windstorm and hail was provided by an industrial poplar grower. The cost corresponds to the 2% of the timber stumpage value in the plantation (where the timber stumpage value is defined at 15 EUR per tree in the first three years of rotation, 30 EUR per tree from year four to year six, and 50 EUR per tree from year seven to the end of the final harvest). Although insurance policies are not widely used among poplar growers in northern Italy, there is an increasing number of insurance companies offering these types of policies. We decided to assume the insurance cost as a proxy for including the risk-component in the analysis.

3. RESULTS

Results are presented in the following order: 1) evolution of investment costs and timber stumpage prices; 2) financial return estimates according to the baseline scenario; and 3) sensitivity analyses results.

3.1 Evolution of investment costs and timber stumpage prices

Table 3 summarizes investments costs, with reference to year 2016. The total investment costs vary between 6,614 EUR ha^{-1} (Cmin) and 9,636 EUR ha^{-1} (CMAX). We split investment costs in four categories: site preparation costs, planting costs, silvicultural management costs and cleaning costs. The total percentage difference between Cmin and CMAX is 37.2%, resulting to be particularly large for the silvicultural management costs (41.7%), followed by site preparation costs (33.3%), planting costs (26.1%) and cleaning costs (16.7%). For what concerns the incidence of the single categories on the total investment costs, silvicultural management costs are the most significant, accounting for a 69.3% (Cmin) and 72.6% (CMAX), planting costs are also important being concentrated in the first year (23.5% Cmin and 21% CMAX), while site preparation costs account for a 3.8% (Cmin) and 3.7% (CMAX), and cleaning costs for a 3.4% (Cmin) and 2.7% (CMAX). On average, investment costs have increased by 25.5% in the period 2001 to 2016, based on real values. If we look at the single categories, the largest increase results in the costs of planting and cleaning, respectively +38.0% and +37.0%, site preparation costs increased by 24.5%, and silvicultural management costs increased by 22.0%.

Table 4 presents the poplar stumpage prices (in EUR per ton^{-1}) evolution from 2001 to 2018, including the percentage difference between the minimum (Pmin) and maximum price (PMAX) and their annual percentage change over the period. The evolution of stumpage prices (in EUR per ton^{-1}) is presented in Figure 1.

In real values, prices have experienced a non-linear but overall decrease during the considered period. In the period 2001-2018 minimum prices decreased from 63.90 EUR per ton^{-1} to 60.00 EUR per ton^{-1} and maximum prices from 102.20 EUR per ton^{-1} to 95.00 EUR per ton^{-1}, which is a percentage decrease respectively of 6.5% and 7.6%. However, we can identify four major periodic phases in the evolution of stumpage prices: 2001 to 2005, 2005 to 2008, 2008 to 2015 and 2015 to 2018. Between 2001 and 2006 stumpage prices experienced a percentage decrease of 8.5% (Pmin) and 12.6% (PMAX). Between 2005 and 2008, they have increased in percentage terms by 5.1% (Pmin) and 8.6% (PMAX). The strongest reduction took place between 2008 and 2015, with Pmin and PMAX decreasing respectively by 17.7% and 15.6%. In the period 2015-2018, prices have increased considerably by 18% (Pmin) and 15.9% (PMAX). Regarding the percentage difference between Pmin and PMAX, which is the variance in percentage terms between the minimum and maximum price registered, the lowest variance is registered in 2003 (37.4%), while highest in years between 2012 (49.6%) and 2015 (47.5%), with the peak in year 2013 (51.9%).

3.2 Financial return estimates according to the baseline scenario

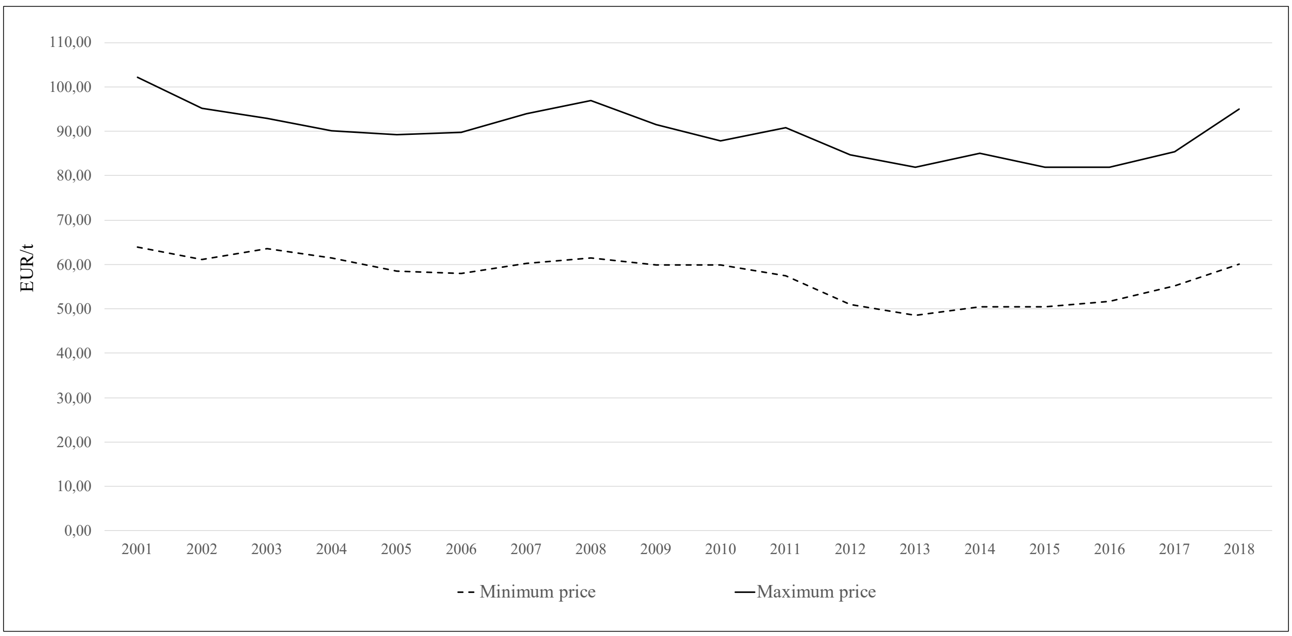
The capital budgeting indicators estimates are presented in Table 5, based on 2016 values. In the baseline

Tab. 3. Investment costs, 2016.

Category	Operation	Cmin (EUR/ha)	CMAX (EUR/ha)	Percentage difference Cmin-CMAX	Percentage incidence on total costs	
					Cmin	CMAX
Site preparation	Ploughing	151.50	222.20	*37.8%*		
	Ripping	60.60	70.70	*15.4%*		
	Harrowing	40.40	60.60	*40.0%*		
	Total	252.50	353.50	*33.3%*	*3.8%*	*3.7%*
Planting	Seedlings	842.30	1,066.60	*23.5%*		
	Mark. dig and planting	631.30	853.50	*29.9%*		
	Irrigation	80.80	101.00	*22.2%*		
	Total	1,554.40	2,021.10	*26.1%*	*23.5%*	*21.0%*
Silvicultural management	Disk harrowing	858.50	1,287.80	*40.0%*		
	Phytosanitary treatment *Marssonina brunnea*	848.40	1,131.20	*28.6%*		
	Phytosanitary treatment *Saperda carcharias L*	181.80	212.10	*15.4%*		
	Phytosanitary treatment *Cryptorhynchus lapathi*	171.70	191.90	*11.1%*		
	Phytosanitary treatment P*hloeomyzus passerinii*	282.80	363.60	*25.0%*		
	Weeding	181.80	227.30	*22.2%*		
	Fertilization	404.00	656.00	*47.5%*		
	Pruning	656.50	1,111.0	*51.4%*		
	Irrigation	999.90	1,818.00	*58.1%*		
	Total	4,585.40	6,999.60	*41.7%*	*69.3%*	*72.6%*
Cleaning	Stumps removal and trituration	222.20	262.60	*16.7%*	*3.4%*	*2.7%*
TOTAL	6,614.50	9,636.40	*37.2%*			

Source: own elaboration.

Fig. 1. Poplar stumpage prices (EUR/ton), 2001-2018 (real values).



Source: own elaboration based on data from the Chambers of Commerce of Mantua and Alessandria.

Tab. 4. Poplar stumpage prices, 2001-2018 (real values).

Year	Pmin (EUR/ton)	PMAX (EUR/ton)	Percentage difference Pmin-PMAX (%)	Percentage variation 2001-2018 (2001=100)	
				Pmin	PMAX
2001	63.89	102.20	*46.1*	*100.0*	*100.0*
2002	61.10	95.25	*43.7*	*95.6*	*93.2*
2003	63.60	92.82	*37.4*	*99.5*	*90.8*
2004	61.51	90.17	*37.8*	*96.2*	*88.2*
2005	58.46	89.27	*41.7*	*91.5*	*87.3*
2006	57.91	89.72	*43.1*	*90.6*	*87.8*
2007	60.19	93.93	*43.8*	*94.2*	*91.9*
2008	61.48	96.95	*44.8*	*96.2*	*94.9*
2009	59.90	91.54	*41.8*	*93.7*	*89.6*
2010	59.83	87.87	*38.0*	*93.6*	*86.0*
2011	57.39	90.78	*45.1*	*89.8*	*88.8*
2012	51.01	84.66	*49.6*	*79.8*	*82.8*
2013	48.57	81.85	*51.9*	*76.0*	*80.1*
2014	50.45	85.09	*51.1*	*79.0*	*83.3*
2015	50.50	81.98	*47.5*	*79.1*	*80.2*
2016	51.69	81.81	*45.1*	*80.9*	*80.0*
2017	55.19	85.35	*42.9*	*86.4*	*83.5*
2018	60.00	95.00	*45.2*	*93.9*	*93.0*

Source: own elaboration based on data from the Chambers of Commerce of Mantua and Alessandria.

scenario, NPV (at a 3.5% discount rate) varies from negative values in CMAX-Pmin (-1,921 EUR ha^{-1}) to positive values in the other three situations: 786 EUR ha^{-1} in Cmin-Pmin, 2,025 EUR ha^{-1} in CMAX-PMAX, and 4,732 EUR ha^{-1} in Cmin-PMAX. NPV standard deviation among the four situations in the baseline scenario is 2,763 EUR ha^{-1}. IRR values range from negative results (CMAX-Pmin) up to 11.9% (Cmin-PMAX). LEV results 2,496 EUR ha^{-1} in Cmin-Pmin, 6,428 EUR ha^{-1} in CMAX-PMAX and 15,020 EUR ha^{-1} in Cmin-PMAX, while it indicates a negative value in CMAX-Pmin (-6,097 EUR ha^{-1}). (Barnes, 2002). LEV standard deviation among the four situations is 5,237 EUR ha^{-1}.

The trend over the 2001-2016 period is presented in Figure 3, also in this case using NPV as dependent variable. The full lines represent the *ex-ante* estimates, while the dotted lines the *ex-post* estimates. If we consider the *ex-ante* results, representing the expected financial returns at the year the investment was carried out, these show a decline over the 15 years period and this trend is homogeneous for all the four situations. In 2001, the NPV is ranging between -460 EUR ha^{-1} (CMAX-Pmin) and 7,344 EUR ha^{-1} (Cmin-PMAX), while in 2016 is respectively -1,921 EUR ha^{-1} and 4,732 EUR ha^{-1}. The NPV average decrease from 2001 to 2016 is -2,036 EUR ha^{-1}. IRR values decreased from 15.1% (2001) to 11.9% (2016) in Cmin-PMAX, from 9.6% to 6.5% in CMAX-PMAX, and from 8.5% to 5.3% in Cmin-Pmin. LEV decreased on average by 6,463 EUR ha^{-1} from 2001 to 2016. Concerning the *ex-post* estimates, NPV shows two periodic trends: a decline from 2001 to 2005 (2003 in Cmin-Pmin and CMAX-Pmin), and an increase from 2005 to 2008. From 2008 onwards, the lines flatten because we assumed constancy of values from 2018 onwards for prices. The negative peak is in 2003 when associated with minimum prices and in 2005 when associated to maximum prices. The NPV average decrease from 2001 to 2005 is 1,052 EUR ha^{-1}. From 2005 to 2008, NPV increases on average by 1,597 EUR ha^{-1}, due to the stumpage price substantial increase between 2016 and 2018. In overall terms, NPV raised from values that in 2001 were between -1,270 EUR ha^{-1} (CMAX-Pmin) and 5,869 EUR ha^{-1} (Cmin-PMAX), to values between -772 and 6,555 EUR ha^{-1} in 2016. IRR values raised from 6.7% in 2001 to 7.5% in 2016 in Cmin-Pmin, from 13.4% to 14.1% in Cmin-PMAX, from 7.9% to 8.8% in CMAX-PMAX. LEV decreased on average by 3,339 EUR ha^{-1} from 2001 to 2005 and increased by 5,068 EUR ha^{-1} from 2005 to 2008.

3.3 Sensitivity analyses results

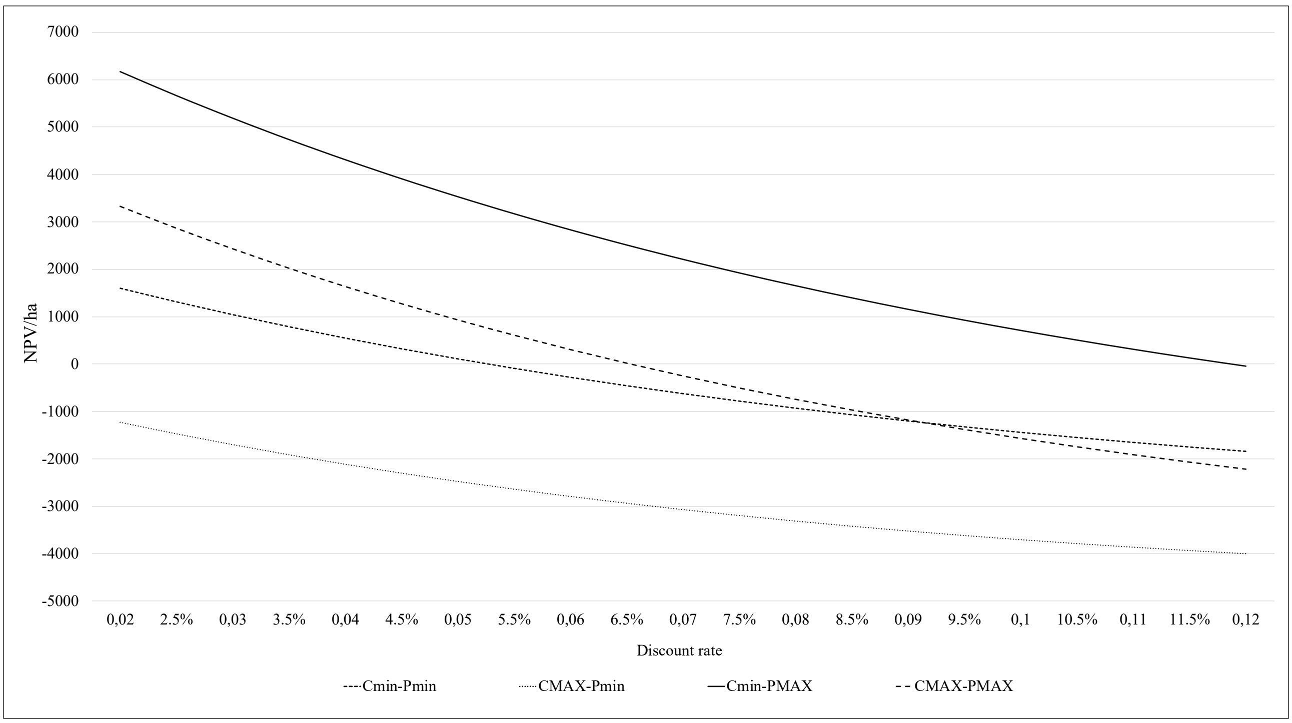
The results of the sensitivity analysis testing different hypothesis on the NPV are presented in Figure 4, based on 2016 values (as Tab. 5).

Tab. 5. NPV (EUR/ha), IRR and LEV (EUR/ha) (i= 3.5%) according to the different scenarios, 2016.

Scenario	Criteria	Cmin-Pmin	CMAX-Pmin	Cmin-PMAX	CMAX-PMAX	Standard deviation
Baseline	NPV	786	-1,921	4,732	2,025	2,763
	IRR	*5.3%*	*n.a.*	*11.9%*	*6.5%*	
	LEV	2,496	-6,097	15,020	6,428	5,237
(a) with subsidies	NPV	1,834	-544	5,780	3,402	1,695
	IRR	*8.3%*	*n.a.*	*15.2%*	*9.3%*	
	LEV	5,821	-1,727	18,345	10,797	8,442
(b) with land rent cost	NPV	-2,124	-4,832	1,821	-886	2,763
	IRR	*n.a.*	*n.a.*	*6.5%*	*n.a.*	
	LEV	-6,743	-15,336	5,782	-2,811	8,770
(c) with opportunity cost*	NPV	-152	-2,860	3,793	1,086	1,892
	IRR	*n.a.*	*n.a.*	*10.0%*	*5.1%*	
	LEV	-484	-9,077	12,040	3,447	5,475
(d) with land rent cost and with subsidy	NPV	-1,077	-3,455	2,869	491	2,660
	IRR	*n.a.*	*n.a.*	*8.7%*	*4.3%*	
	LEV	-3,418	-10,967	9,106	1,558	8,443
(e) insurance cost	NPV	-669	-3347	3,247	539	2,737
	IRR	*n.a.*	*n.a.*	*9.2%*	*4.3%*	
	LEV	-2,220	-10,813	10,305	1,712	8,677
Standard deviation NPV	1,400	1,793	1,470	1,469		
Standard deviation LEV	4,392	4,661	6,424	4,661		

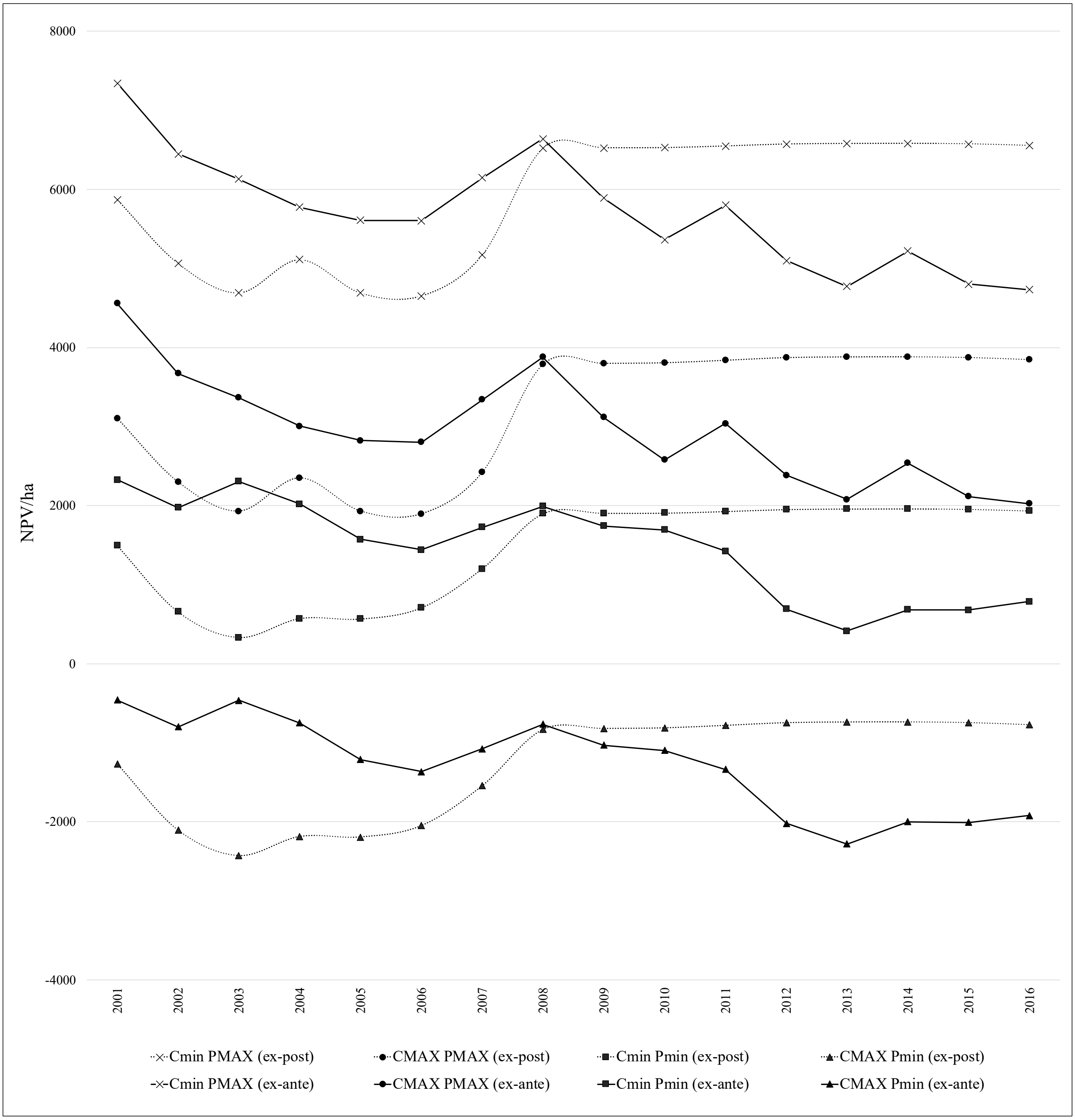
Note: results are based on 2016 data calculated with the *ex-ante* approach.
*Based on 2015 data.
Source: own elaboration.

Fig. 2. Changes in the NPV (EUR/ha) in relation to alternative discount rates, 2016.



Source: own elaboration.

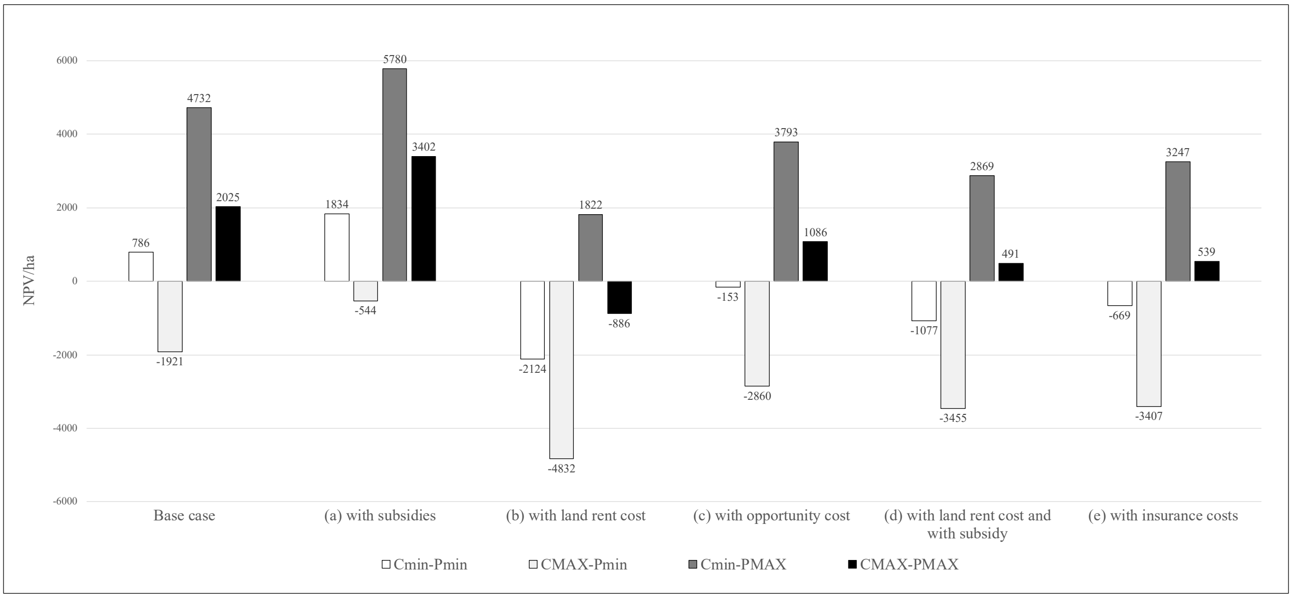
Fig. 3. NPV (EUR/ha, *i*= 3.5%) in the baseline scenario, 2001-2016 (real values).



Source: own elaboration.

When public subsidies are included in the baseline scenario (a), the NPV raises to 1,821 EUR ha^{-1} in Cmin-Pmin, 5,780 EUR ha^{-1} in Cmin-PMAX, 3,402 EUR ha^{-1} in CMAX-PMAX and -544 EUR ha^{-1} in CMAX-Pmin (remaining negative). The average NPV increases from the baseline scenario values do amount to 1,212 EUR ha^{-1}. IRR values increase on average by 3.0%, reaching up to 15.2% in the best situation (Cmin-PMAX). LEV reaches 5,821 EUR ha^{-1} in Cmin-Pmin, 18,345 EUR ha^{-1} in Cmin-PMAX, 3,402 EUR ha^{-1} in CMAX-PMAX, and -1,727 EUR ha^{-1} in CMAX-Pmin, with an average increase from the baseline scenario of 3,847 EUR ha^{-1}.

Fig. 4. Sensitivity analysis results.



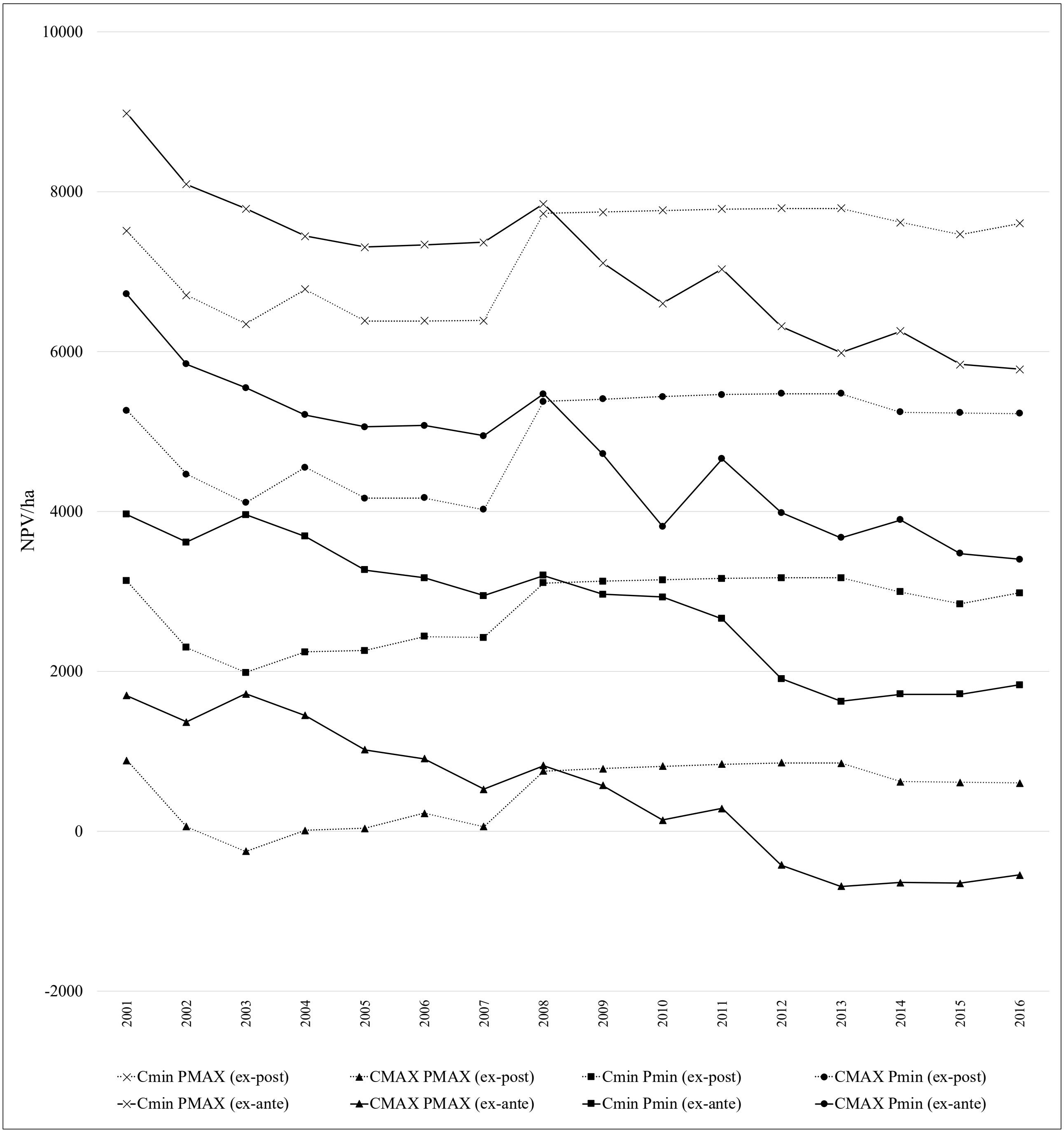
Source: own elaboration.

Figure 5 shows the NPV trend when public subsidies are included in the analysis from 2001 to 2016. From the *ex-ante* curve the negative trend is accentuated due to the reduction, firstly in 2007 (from 100% to 70% reimbursement of establishment costs) and secondly in 2004 (from 70% to 60% reimbursement of establishment costs) of the average contribution level. In this case the NPV decreases on average by 2,722 EUR ha^{-1} in the period 2001-2016 of.

When we add to the baseline scenario an annual land rent cost (b), financial returns are positive only for the Cmin-PMAX situation (NPV of 1,821 EUR ha^{-1}, IRR of 6.5% and LEV of 5,782 EUR ha^{-1}). All the other three situations decrease to negative values, with an average decrease of 2,911 EUR ha^{-1} in terms of NPV, and 9,239 EUR ha^{-1} in terms of LEV. The NPV trend from 2001 to 2016 is presented in Figure 6. Land rent cost shows a declining trend from 2001 (379 EUR ha^{-1} per year) to 2006 (307 EUR ha^{-1} per year) followed by an overall increase up to 350 EUR ha^{-1} per year in 2016. When considering the *ex-ante* results, the four situations decrease on average by 1,089 EUR ha^{-1} from 2001 to 2016, with a decrease more accentuated between 2008 and 2016 (-1,707 EUR ha^{-1}). In the *ex-post* results, the land rent cost trend lowers the NPV increase along the period, which is on average +1,217 EUR ha^{-1} (2001-2016).

When we include in the baseline scenario the opportunity cost (c) considering net missed revenues from corn cultivation, NPV decreases on average by 932 EUR ha^{-1} and LEV by 5,392 EUR ha^{-1}. NPV goes negative in Cmin-Pmin and CMAX-Pmin , respectively -152 EUR ha^{-1} and -2,860 EUR ha^{-1}. In the other two cases, the NPV in Cmin-PMAX is 3,793 EUR ha^{-1}, while in CMAX-PMAX is 1,086 EUR ha^{-1}. LEV is a particularly important indicator in assessing the opportunity cost of land use. In our sensitivity analysis it shows negative values for Cmin-Pmin (-484 EUR ha^{-1}) and CMAX-Pmin (-9,077 EUR ha^{-1}), while in Cmin-PMAX results 12,040 EUR ha^{-1} and in CMAX-PMAX 3,447 EUR ha^{-1}. It has to be considered that CAP direct payments to agricultural crops are not included in the analysis. Figure 7 shows the NPV trend when the opportunity cost is included in the analysis. In this case the time series is 2008-2015. The net missed revenues from corn cultivation trend reflect the situation of high volatility of corn prices in recent years, with a negative peak in the 2009. This trend is very well revealed in the *ex-ante* NPV estimates evolution, which presents a positive peak in 2009 (NPV of -438 EUR ha^{-1} in CMAX-Pmin, 2,337 EUR ha^{-1} in Cmin-Pmin, 3,707 EUR ha^{-1} in CMAX-PMAX and 6,482 EUR ha^{-1} in Cmin-PMAX) and a negative peak in 2012 (NPV of -5,670 EUR ha^{-1} in CMAX-Pmin, -2,957 EUR ha^{-1} in Cmin-Pmin, -1,263 EUR ha^{-1} in CMAX-PMAX and 1,460 EUR ha^{-1} in Cmin-PMAX). When considering the *ex-post* estimates, the inclusion of opportunity cost results in a positive directional effect on the curves, which show an average increase of 877 EUR ha^{-1} from 2008 to 2015.

Fig. 5. NPV (EUR/ha, *i*= 3.5%) in the sensitivity scenario with public subsidies (a), 2001-2016 (real values).

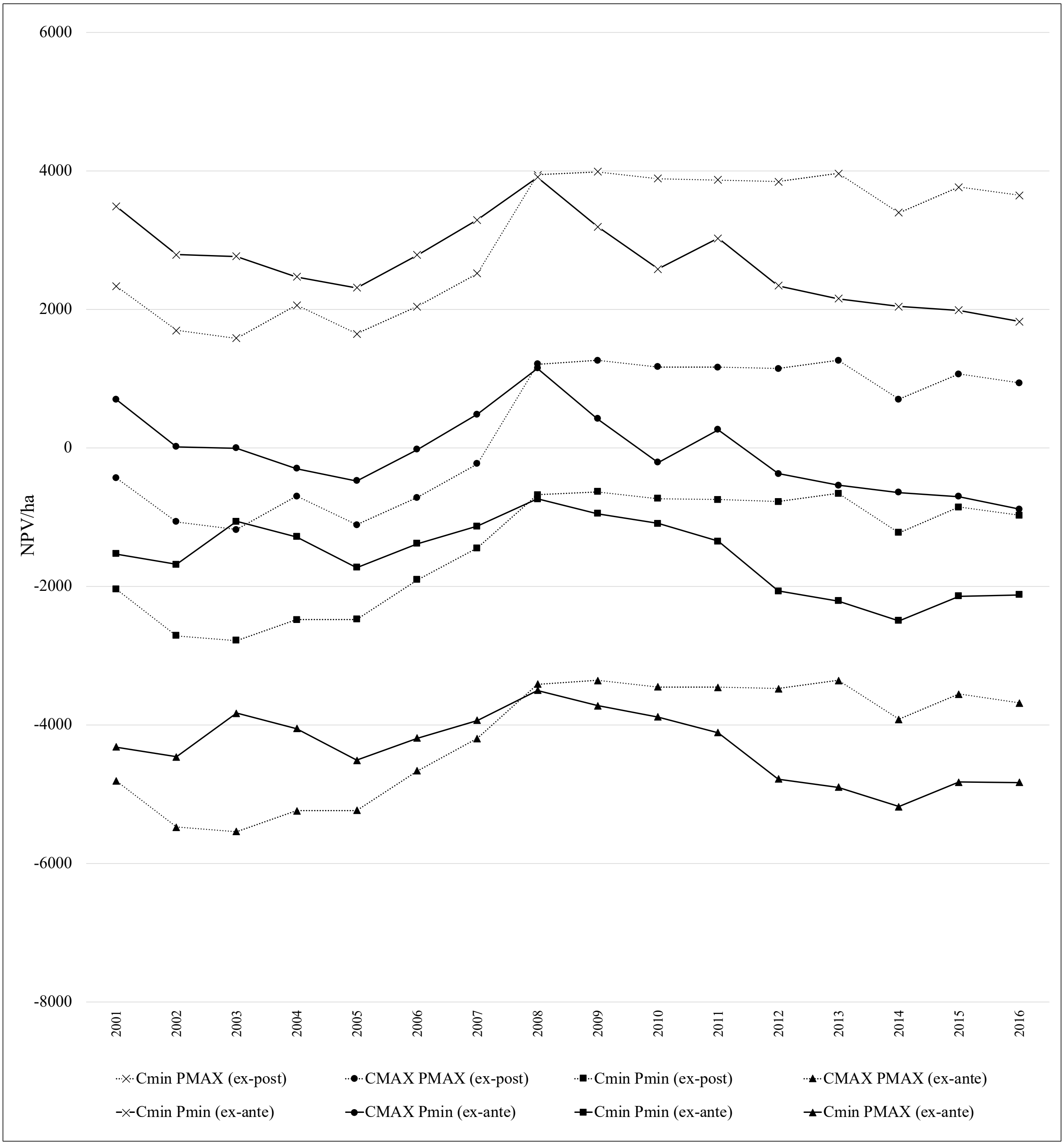


Source: own elaboration.

The fourth sensitivity analysis scenario (d) combines the inclusion of public subsidies (a) with annual land rent cost (b). In this case, NPV decreases on average by 1,699 EUR ha^{-1} and the LEV by 5,392 EUR ha^{-1} from the baseline scenario. NPV and LEV show negative values in Cmin-Pmin and CMAX-Pmin , while in Cmin-PMAX the NPV reaches 2,869 EUR ha^{-1} and LEV 9,106 EUR ha^{-1} and in CMAX-PMAX the NVP and LEV reach respectively 491 EUR ha^{-1} and 1,558 EUR ha^{-1}.

In the last sensitivity analysis scenario, we includ-

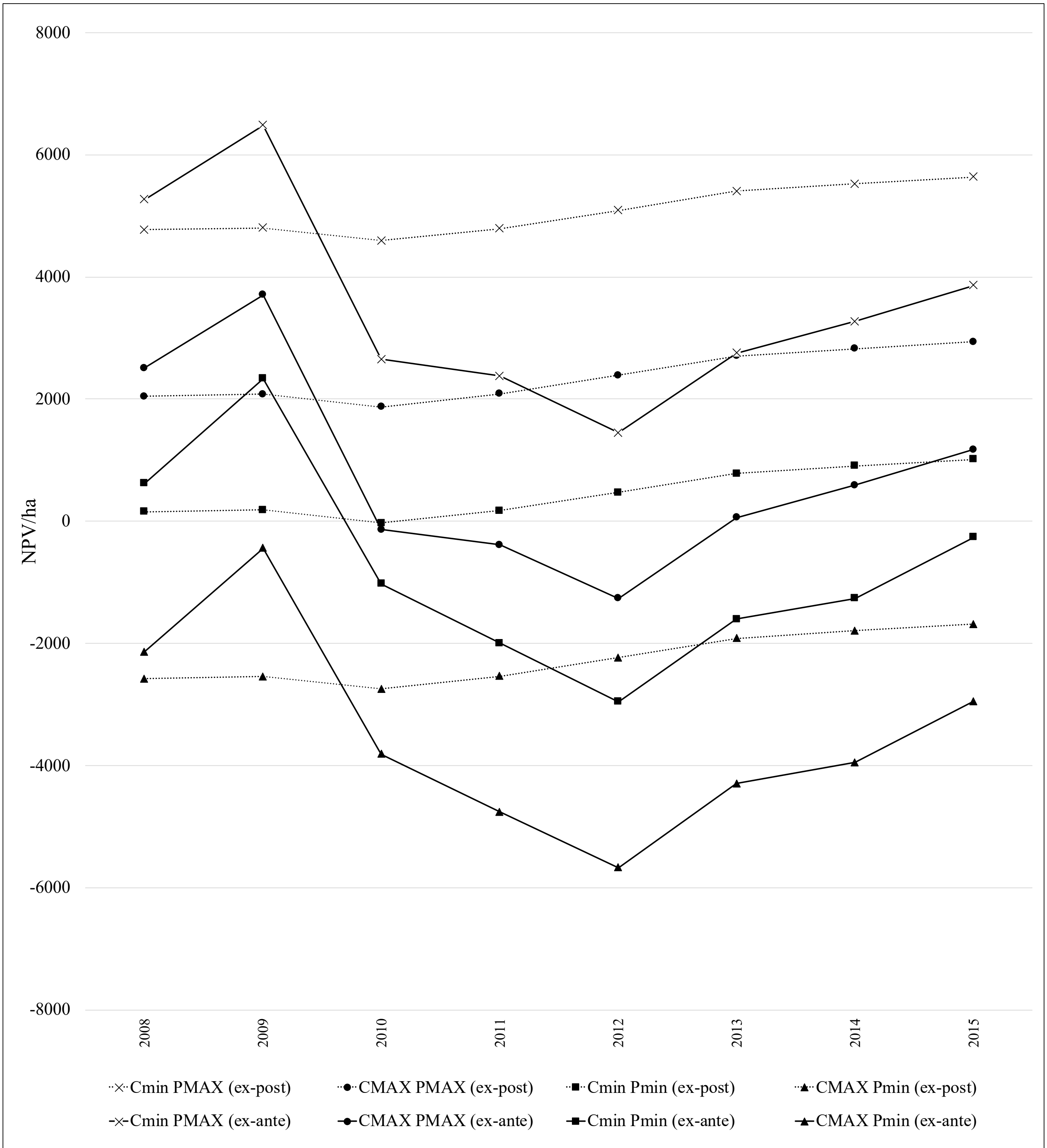
Fig. 6. NPV (EUR/ha, *i*= 3.5%) in the sensitivity scenario with land rent cost (b), 2001-2016 (real values).



Source: own elaboration.

ed an insurance cost (e). NPV results -669 EUR ha^{-1} in Cmin-Pmin, -3,347 EUR ha^{-1} in the CMAX-PMAX, 3,247 EUR ha^{-1} in Cmin-PMAX and 539 EUR ha^{-1} in CMAX-PMAX. On average, NPV decreased by 1,463 EUR ha^{-1}, and the LEV by 4,217 EUR ha^{-1} from baseline scenario values. IRRs decreased to 9.2% in Cmin-PMAX and to 4.3% in CMAX-PMAX.

Fig. 7. NPV (EUR/ha, *i*= 3.5%) in the sensitivity scenario with cost opportunity (c), 2008-2015 (real values).



Source: own elaboration.

4. DISCUSSION

This study was carried out based on a representative management regime and assuming average site quality and appropriate management conditions. Even though we aimed at representing the range of most frequent situations for poplar growers in northern Italy, evidently, our results cannot represent all specific cases. Therefore, it has to be considered that different assumptions in relation to site characteristics, management intensity and stumpage prices can lead to slightly different results than those we estimated.

We assumed a representative management regime based on *Populus x canadensis* 'I-214', 278 trees per hectare and a 11 years rotation. The total investment costs to establish and manage a poplar plantation in one rotation cycle range between 6,614 EUR ha^{-1} and 9,636 EUR ha^{-1}. Poplar plantations are characterized by a significant initial investment, with establishment costs (including site preparation and planting operations), accounting on average for 26.0% of the total investment costs. Silvicultural management is relatively intensive, in particular in the first five years of the rotation cycle, with annual management operations requiring high energy and water inputs. Silvicultural management costs between year 1 and 10, comprising disk harrowing, phytosanitary treatments, fertilizations, pruning and irrigations, account on average for 71.0% of the total investment costs. Between 2001 and 2016, investment costs have increased by 25.5% in real terms, where planting operations cost (+38.0%) and final stumps removal and trituration cost (+37.0%) showed the highest increment.

Poplar timber stumpage prices vary substantially depending on quality, location and contractual power of the land owner. The percentage difference between minimum and maximum price goes from 37.4% to 51.9%, depending on the year. Over the period 2001-2018, poplar stumpage prices evolution experienced an irregular trend. In particular, a strong decline has been observed between 2008 and 2015, with a percentage decrease by 17.7% in the minimum prices and 15.6% in the maximum prices. Then, from 2015 to 2018 poplar stumpage prices have experienced a substantial increase of 15.9% in the minimum prices and 18,0% in the maximum prices. These trends appear to be associated with a cycling nature of poplar timber prices already observed in the past (Garoglio, 1990). However, as highlighted already by Coaloa and Vietto (2005), in real terms poplar stumpage prices are on an overall downward trend. Coaloa and Vietto (2005) reported that average poplar stumpage prices in 2004 were already a 20.0% lower in real terms than those registered ten years before, which were already representing an historical minimum.

Financial returns were firstly estimated according to a baseline scenario, where no subsidies and explicit land cost were included. Based on 2016 data, NPV was estimated (at a 3.5% discount rate) in the range from -1,921 EUR ha^{-1} in the worst situation (associated with maximum investment costs and minimum stumpage prices), to 4,732 EUR ha^{-1} in the best situation (associated with minimum investment costs and maximum stumpage prices). LEV ranges between -6,097 EUR ha^{-1} and 15,020 EUR ha^{-1}. IRR values swing from negative values up to 11.9% in the best situation. When interpreting the results, it has to be considered that the estimates represent a "before tax" situation, not including Land Value Tax and Income Tax. Our estimates show that poplar plantations offer interesting financial performances when connected to high stumpage prices, whereas, when these are low, investments are on the threshold of the financial viability or at a loss, in particular in the case of high establishment and silvicultural management costs. In recent years, research on the development of new more environmentally friendly poplar clones, more resistant to pest and insect attacks and more adapted to specific soil characteristics (e.g. Vietto *et al.*, 2011; Facciotto *et al.*, 2014) as well as the development of management standards for reducing energy and water inputs (e.g. Coaloa, Vietto, 2005) showed encouraging results. Further developments in these areas of research could lead to a reduction of silvicultural management costs and consequently lower market risk.

In the past, Borrelli and Facciotto (1996) and Borrelli (1997) estimated IRR of poplar plantation in northern Italy in the range 2%-8%, while another study related to the ECOPIOPPO project, suggested for the Piedmont context an average IRR value of 3.6% (using a stumpage price of 64 EUR ton^{-1}), which could increase to 8.1% with public subsidies (Regione Piemonte, 2002). However, the authors highlighted that stumpage prices could have a large variability and, in the best situations, returns on investment could be considerably higher than those obtained in their simulations. In the best situations, hybrid poplar plantations in northern Italy showed to potentially provide higher financial returns than those estimated in literature for other contexts. In North America, average IRR values were estimated around 4.3% by Anderson and Luckert (2006) in Canada, while in southern United States between 6.4% and 9.1% by Tankersley (2006). In the context of Europe cultivation models are more similar to the one presented for northern Italy, in particular in Spain, although in all cases rotation cycles are longer (up to over 20 years).

Keča *et al.* (2011) and Keča *et al.* (2012) estimated IRR of poplar plantations in Serbia between 4.3% and 6.9%. In France, Vidal and Becquey (2008), suggested IRR values for poplar plantation around 7.5%. In the case of Spain, Aunos *et al.* (2002) estimated IRR between 3.9% and 8% in the Ebro valley (Huesca and Lleida Provinces), while in the context of the Duero valley (Castilla y Leon Region) Estaban López *et al.* (2005) estimated NPV (at a 5% discount rate) to range between 5,108 EUR ha^{-1} and 10,929 EUR ha^{-1}. In less recent studies, Diaz Balteiro and Romero (1994) estimated IRR values of poplar plantations potentially up to 19%, and Del Peso *et al.* (1995) estimated NPV (at a 3% discount rate)[1] to be between 2,255 EUR ha^{-1} and 9,783 EUR ha^{-1}.

For estimating the financial returns evolution between 2001 and 2016, we used two approaches: *ex-ante* approach, providing an estimation of the expected returns at the time the investments were carried out, and *ex-post* approach, providing an estimation of the actual returns considering the evolution of investment costs and stumpage prices throughout the years. From an *ex-ante* perspective, poplar plantations expected returns have experienced a significant and linear reduction in the period 2001-2016. In the baseline scenario, IRR values decrease on average by 3%, considering that in 2001 IRR values could reach 15.1%. NPV diminished on average by 2,036 EUR ha^{-1} between 2001 and 2016, from values that in 2001 were in the range -460 EUR ha^{-1} to 7,344 EUR ha^{-1}. LEV average decrease in the period was by 6,463 EUR ha^{-1}. In other words, from 2001 to 2016, financial returns expectations from investment in hybrid poplar plantations in northern Italy have been steadily declining, and this is likely to be the main reasons that have determined a continuous reduction of investment in this cultivation. However, it is interesting to compare these results with the ones based on the *ex-post* approach. In this case, the increase of stumpage prices between 2015 and 2018 makes the financial indicators of plantations established between 2005 and 2008 raise substantially. It has to be considered that we assumed stumpage prices values to be constant from 2018 onwards. So, when looking at the *ex-post* estimates, results from 2008 onwards have to be considered only partial. When the two analyses are compared, it emerges that until 2008 the expected returns at the time the investment was carried out were higher than the actual returns ten years after, while for those plantations planted in 2008 the actual returns were higher than what it was expected. However, actual returns for those plantations established from 2009 onwards will strongly depend on the future evolution of poplar stumpage prices. Besides the cycling nature of poplar stumpage prices, the high increment between 2015 and 2018 is likely to be associated to the expansion of the Italian plywood industry. Although data on plywood production and poplar removals are available only until 2011, this trend can be supported by international trade data. Eurostat (2018) reports that export of plywood from Italy has steadily increased from 2012 to 2016 (last year available), passing from 75,941 m^3 per year to 113,015 m^3 per year. In addition, import of poplar roundwood showed an increase from 178,480 m^3 per year in 2015 to 213,802 m^3 per year in 2016, which might be an additional symptom of the shortage of domestic supply due to the decreasing investments in hybrid poplar plantations in northern Italy. In a recent market survey carried out by Levarato *et al.* (2018), it resulted that 70% of the Italian plywood industries have experienced increasing difficulties over the last ten years in the procurement of poplar roundwood from domestic sources. Therefore, it can be suggested that the evolution of poplar stumpage prices in the upcoming years will ultimately depend on the competitiveness of the Italian plywood industry. However, in spite the data on the export can suggest an optimistic evolution, there are several other factors influencing competitiveness which must be taken into account, Nevertheless, it is interesting to highlight that Levarato *et al.* (2018) reported that 9 Italian plywood industries out of 10 are planning either to expand the use of poplar timber in their production in future years or to keep it as constant. In addition, 8 out of 10 of these industries are (or would be, if available) prioritizing supply from domestic plantations.

Sensitivity analyses allowed us to assess the impact of some of the major policy and market factors on hybrid poplar plantations financial returns. As public subsidies we considered the average grant-based contribution of the regional RDP's afforestation measures, which result in the reimbursement of a percentage of plantation establishment costs. This percentage was 100% in the programming period 2000-2006 (reg. EEC 1698/1999), 70% on average in the programming period 2007-2013 (reg. EEC 1968/2005), and 60% on average in the programming period 2014-2020 (reg. EEC 1305/2013). Based on 2016 values, public subsidies have the effect of raising NPV by 1,212 EUR ha^{-1} on average, with IRR reaching up to 15.2% in the best situation. These results highlight the determining role of this variable for investments' decisions. Looking at the effect on the financial indicators, it is easy to understand that land owners consider public subsidies as a critical variable for investing, especially under uncertain market

[1] Our conversion from Pesetas to Euros, using a conversion of EUR 1 = ESP 166.386

developments. However, it has to be considered how the use of the RDP's afforestation measures to support hybrid poplar plantations has become more and more complex in the last two programming periods. The reason is the debate on the environmental impact of hybrid poplar plantations. On the one hand, some authors claim that poplar plantations still represent an environmental improvement compared to the alternative annual intensive agricultural crops (Chiarabaglio *et al.*, 2009, Chiarabaglio *et al.*, 2014). On the other hand, the idea of setting up intensively-managed and fast-growing timber plantations has been considered a contradiction to the European Union objectives for rural development (that should inspire the national and regional RDP) that is increasingly oriented towards multifunctionality, the use of sustainability practices with low environmental impacts both in farming and in forestry. Besides the reduction of the average contribution level, this situation has produced an intricate framework in terms of eligibility criteria and requirements for applying to the RDP afforestation measures grants (Tab. 6), in particular related to the use of voluntary forest certification schemes to guarantee responsible management practices and the use of new and more environmentally friendly poplar ('MSA' clones) clones, which are not yet widely accepted by Italian poplar growers and plywood industries (Castro and Giorcelli, 2012). As a consequence, RDP grants have showed to be less attractive for land owners: between 2007 and 2013, under the afforestation measures 221 and 223 (which comprise also medium-long rotation species plantation and permanent woodland), only 7,720 ha were planted (5,756 ha with poplar) out of the over 30,000 planned at the launch of the measures (Fig. 8), and only 1,333 beneficiaries were involved out of the target of 6,527 (Fig. 9). More in general, the differences in terms of requirements and contribution level among Regions and the irregularity of grants in the last two programming periods (Tab. 6), have become a potential further element of market destabilization, with concrete effects on the evolution of the market (e.g. land owners planning only when grants are available) and consequently of stumpage prices.

When an annual land rent cost is included in the analysis, considering the average value for poplar cultivation's suitable land in northern Italy, it emerges that rarely poplar plantations are financially viable. Only in the best situation it shows a positive IRR value of 6.5%, NPV of 1,821 EUR ha^{-1}, and LEV of 5,782 EUR ha^{-1}, while indicators are negative for all the other situations, with an NPV average decrease from the baseline scenario of 2,911 EUR ha^{-1} and LEV of 9,239 EUR ha^{-1}. The need to rent land appears to have great negative effect on the investment, even in case the investment is supported by subsidies.

Considering the opportunity costs of poplar investments referred to corn production, which represents the main competitive crop in the northern Italy, we found that only in the best situations poplar cultivation can be more competitive (if we exclude CAP direct payment). The lower risk component of an annual investment such as an agricultural crop against a multi-year investment with no income until the end of the rotation cycle as a poplar plantation, plays an important role in favour of the first one. However, when analysing the recent trend, it has been observed that the volatility of corn prices in recent years has reduced the risk gaps between the two cultivations.

Finally, we also tested the effect of an insurance scheme covering damages against pests, fire, windstorm and hail. Despite these types of investments are not common among poplar growers (but are growing, in particular among industrial and large-scale land owners), we decided to assume this cost as a proxy of the investment risk component. The inclusion in the cash flow of an insurance cost has the effect of reducing on average the NPV by 1,463 EUR ha^{-1} and the LEV by 4,217 EUR ha-1 from baseline scenario values. Furthermore, it has to be noted that in the last years it has become more and more common to sell poplar stands before the end of the rotation period; an arrangement where the buyer (normally a middleman responsible of supplying the plywood industry) is able to manage a portfolio of poplar stands and the grower is payed for selling the immature trees and for keeping them growing till the buyer decide to harvest them.

5. CONCLUSIONS

In this study we estimated the evolution of financial returns from hybrid poplar plantations in northern Italy between 2001 and 2016, analysing how profitability indicators have changed over the past 15 years as a result of the evolution of the key economic variables of investment costs and timber prices. In addition, we assessed the effects of external variables such as public subsidies, an explicit land cost, opportunity cost of alternative agricultural land use, and insurance cost.

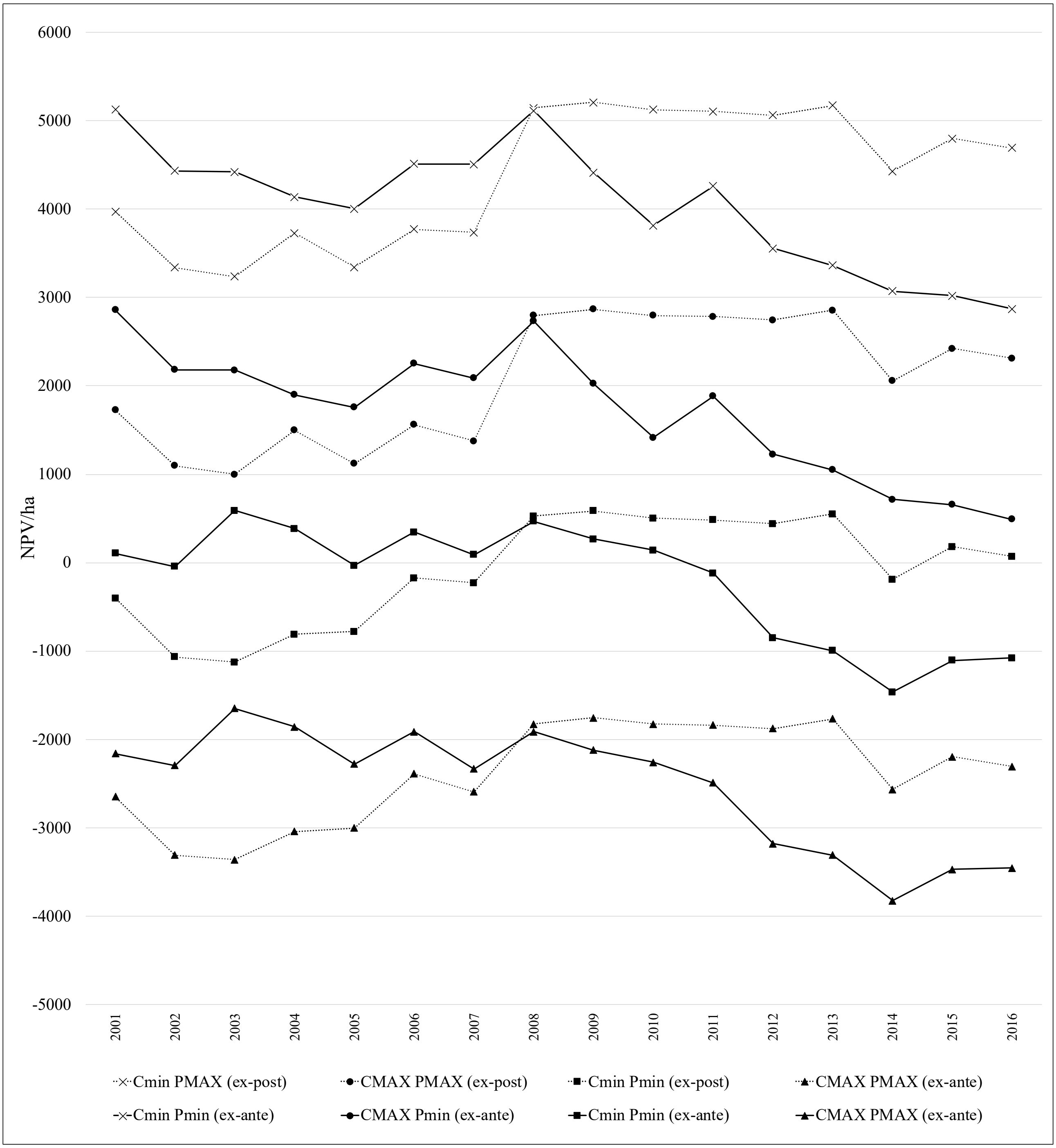
Financial returns were estimated at aggregate level, based on a management regime representative of the most frequent situation for poplar growers in the area and defining minimum and maximum levels of investment costs and stumpage prices. We carried out a financial analysis before-tax using Net Present Value (NPV),

Tab. 6. Synthesis and comparison of the eligibility criteria and requirements related to hybrid poplar plantations under the RDP 2007-13 and 2014-20 afforestation measures.

Region	Eligibility criteria	RDP Programming period 2007-2013 (Measure 221 and 223)	RDP Programming period 2014-2020 (Measure 8.1)	Grants (year of publication)
Emilia-Romagna	Clones diversification	-	>*50%* of 'MSA' clones	2008, 2010, 2011, 2012, 2016, 2017
	Certification	-	-	
	Minimum area	2 ha	1 ha	
	Grant contribution (establishment costs reimbursement percentage / cap)	*70%* / max 5,000 EUR	*70%* if using exclusively 'MSA' clones or if PEFC or FSC® certified, *40%* in all other cases / max 4,000 EUR	
Friuli Venezia-Giulia	Clones diversification	-	If >200ha: at least three different clones (>*10%* each)	2008, 2010, 2011, 2016
	Certification	-	PEFC or FSC® certification required (alternatively: environmentally-friendly management codes recognized by the Region, i.e. 'ECOPIOPPO' code)	
	Minimum area	0.5 ha	0.5 ha	
	Grant contribution (establishment costs reimbursement percentage / cap)	*45%* if individuals, *65%* if associated / max 5,000 EUR if PEFC or FSC® certified, 1,500 EUR in all other cases	*80%* / max 4,000 EUR	
Lombardy	Clones diversification	-	If >30ha: >*50%* 'MSA' clones, if <30ha: three different clones (two of them 'MSA' clones, representing >*50%* of the total)	2008-2013, 2016, 2018
	Certification	-	Priority to PEFC or FSC® certified applicants	
	Minimum area	1 ha	1 ha	
	Grant contribution	*80%* if PEFC or FSC® certified and in Natura2000 area, *70%* if only one of the two cases, *60%* in all other cases / max 3,500 EUR	*80%* if using exclusively 'MSA' clones or if PEFC or FSC® certified, *60%* in all other cases / min 1,667 EUR and max 3,440 EUR	
Piedmont	Clones diversification	-	<5ha: >*22%* 'MSA' clones, 5-15ha: > *33%* 'MSA' clones, >15 ha: >*50%* use 'MSA' clones	2010, 2016, 2018
	Certification	-	Priority to PEFC or FSC® certified applicants (or alternatively applicants following environmentally-friendly management codes recognized by the Region, i.e. 'ECOPIOPPO' code)	
	Minimum area	1 ha	1 ha	
	Grant contribution	*80%* if PEFC or FSC® certified and in Natura2000 area, *70%* in all other cases / max 3,500 EUR	*70%* if PEFC or FSC® certified, *50%* in all other cases / max 4,000 EUR	
Veneto	Clones diversification	-	<10ha: >*10%* 'MSA' clones, >10ha: at least 3 clones (2 of them 'MSA' clones) of which each one >*10%* of the total	2008, 2009, 2010, 2011, 2017
	Certification	-	-	
	Minimum area	0.5 ha	0.5 ha	
	Grant contribution	*80%* / max 4,300 EUR	80%	

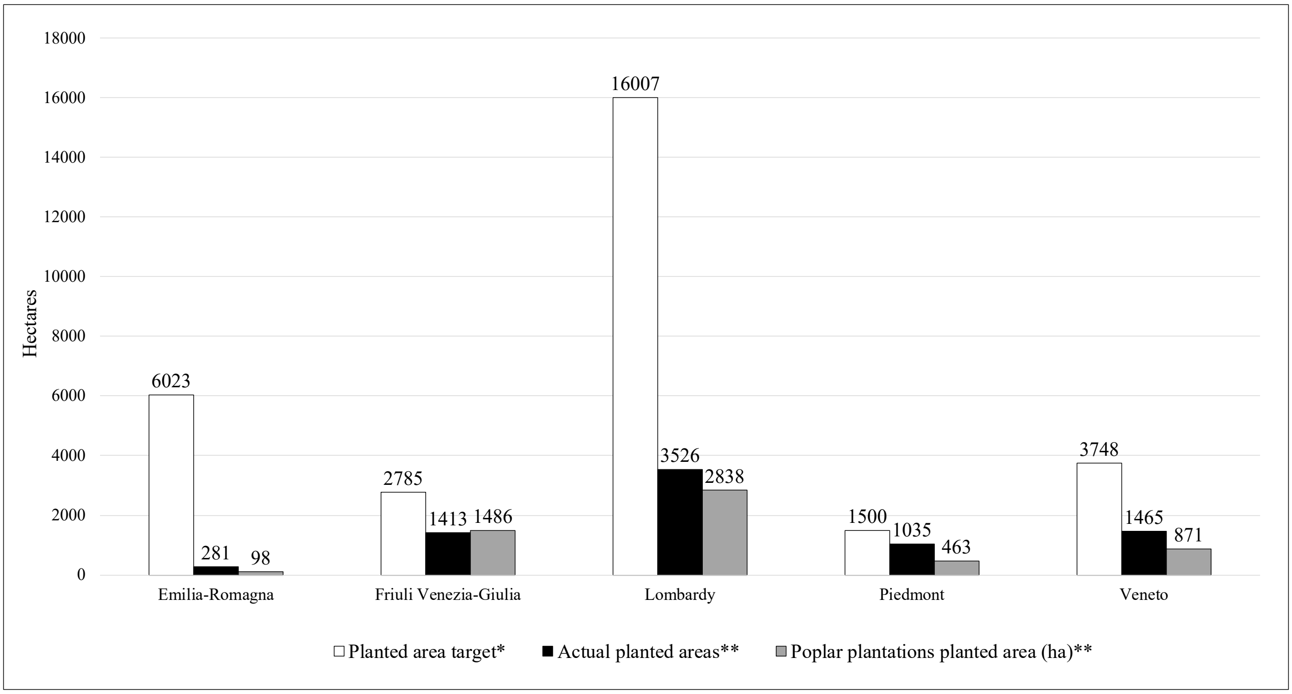
Source: own elaboration.

Fig. 8. Comparison of target, achieved planted area, and area planted with hybrid poplars with the afforestation measures 221 and 223 of the RDP 2007-13 in the northern Italian regions.



Note: Data refer to the overall measure 221 and 223, which includes: a) plantations with fast growing species, b) medium-long rotation species plantations and c) permanent woodlands.
* Official figures published by Regional administrations.
** Annual Monitoring Reports of the European Rural Development Network (at 31/12/2014).
Source: own elaboration based on data from Pra *et al.* (2016).

Fig. 9. Comparison of targets and actual beneficiaries with the afforestation measures 221 and 223 of the RDP 2007-13 in the northern Italian regions.



Note: Data refer to the overall measure 221 and 223, which includes: a) plantations with fast growing species, b) medium-long rotation species plantations and c) permanent woodlands.
* Official figures published by Regional administrations.
** Annual Monitoring Reports of the European Rural Development Network (at 31/12/2014).
Source: own elaboration based on data from Pra *et al.* (2016).

Internal Rate or Return (IRR) and Land Expectation Value (LEV) as capital budgeting indicators. The main input data and information on investment costs were obtained from poplar growers and farms archives, bulletins and agricultural contractor's rates, while data on stumpage prices were derived from Chambers of Commerce.

Our results show that the range of possible financial returns from hybrid poplar plantations in northern Italy is rather large. Financial returns vary depending on investment costs - determined by management intensity and cost of the operations - and stumpage prices. In general, our estimates show that when connected to high selling stumpage prices, poplar plantation can be profitable even in the case of high establishment and silvicultural management costs; on contrary, investments are at the limit of the financial viability or at a loss when connected to low stumpage prices. In the baseline scenario, where no subsidies nor land cost are included, IRR values go from negative up to a maximum of 11.9%, with intermediate values in the range 5.3%-6.5%.

The evolution of financial returns in the last 15 years, between 2001 and 2016, have been influenced by the evolution of investments costs – which experienced a linear increase over the period – and stumpage prices, which have been subjected to a cyclical behaviour but with an overall downward trend in real terms. Expected returns have decreased significantly over the period, and this is likely to have increased the market risk component and negatively undermined the attractiveness for new investments in poplar plantations. However, based on an *ex-post* perspective, the increase of poplar stumpage prices between 15.9% and 18% from 2015 to 2018 has determined a substantial increase of the actual returns for those plantations established between 2005 and 2008, which have been higher than the expected returns. Nevertheless, the evolution of poplar stumpage prices in the upcoming years will ultimately depend on the competitiveness of domestic plywood industry, which on the one hand is expanding its export production, but on the other hand has to face a continuous reduction of poplar timber domestic supply.

Public subsidies, based on the regional RDPs derived from the EU Rural Development Policy regulations, have a considerable positive effect on the financial indicators, demonstrating to be a determinant variable for investment decisions. However, in the last two RDP's programming periods (2007-2013 and 2014-2020) diminished contribution level together with the irregularity of grants and the growing limitations in terms of management requirements are representing an additional factor of destabilization of the sector. In the context of northern Italy, opportunity costs for alternative agricultural land use – considering that poplar plantations are established in medium to high fertility agricultural land and river bends – can be very high and unfavourable for poplar plantations. The recent increased volatility of cereals prices has probably having a positive effect on the investors' attitude towards poplar cultivation; however, the higher market risk associated to a 11 years investment might be still a major element of unattractiveness for land owners. In addition, also the need to rent land is rarely financially viable for poplar plantation, even if supported by subsidies. Finally, we have discussed the positive opportunities of risk reduction associated to insuring the plantations and to need selling system. All these results are a sign that poplar plantation investments in northern Italy, although they have faced serious financial problems in the last decades, can still represent the main segment for industrial timber production in Italy and one of the most profitable forest plantation investments in Europe.

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Special agricultural safeguards in the meat market and their impact on Brazilian economy

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Abstract. This study identifies the impact of special agricultural safeguards (SSG) for the global meat market and for the Brazilian economy. The tariff lines subject to SSG were selected and the period of analysis was from 1995 to 2015. The value of additional tariff was calculated for each of the most important tariff lines, as well as, their impact on imports and Brazilian exports. The most important markets that applied SSGs were the U.S. for beef and European Union for poultry. For the additional tariffs that were estimated, the results indicated that the impact of the value of the meat not exported by Brazil to EU and the U.S. due to SSG tariff was equivalent to the loss of BRL 3.7 billion of the economy's production value and almost BRL 2 billion of the Brazilian Gross Domestic Product.

Keywords: Beef, poultry meat, SSG tariff, input-output matrix, Brazil.
JEL codes: F13, C67.

1. INTRODUCTION

The Uruguay Round Agreement on Agriculture (URAA), concluded in 1995, is an important benchmark in international trade. One of the most significant results of the URAA was eliminating quantitative barriers, the so-called import "quotas", which were the most protectionist mechanisms used by developed countries against agricultural imports. In its place emerged the tariff quotas[1] (defined by the TRQ acronym, from the English name "tariff rate quota"). However, very high extra-quota tariffs may also be prohibitive for trade and, hence, work in the same manner of the quantitative quotas that existed before 1995. In addition, another mechanism was implemented along with the tariff quotas, which did not previously exist and was intended to be transient, the so-called special safeguards, known by the SSG acronym (from the English name "special safeguards").

[1] In this mechanism the same product has two different tariffs: one that is lower, applicable up to a certain level of imports (in-quota) and another higher tariff, applicable when the imported volume exceeds the quota limit (extra-quota)

The SSG consists in an additional tariff applied to the extra-quota tariff. However, unlike the extra-quota tariff, the additional SSG tariff is not a fixed value or percentage, but depends on certain conditions. There are two conditions in which it may occur: (i) when the import price is lower than a certain value (price trigger) or (ii) when the import volume is larger than a certain quantity (volume trigger).

During the Doha Development round between 2002-2006, the SSG mechanism did not receive any formal proposal for elimination or change. On the contrary, instead of eliminating or reforming this mechanism, what was proposed in that occasion and resumed in the discussions in the WTO Ministerial Meeting in Nairobi, in 2015, was a similar mechanism, which would be adopted by the developing countries, called SSM (acronym for the English name "Special Safeguard Mechanisms"). Some studies about the SSG action carried out in a way to subsidize analysis for building the SSM are: Pal & Wadhwa, (2006); Aznal, (2007); Harris, (2008); Finger, (2009); Wolf, (2009) and Hertel *et al.* (2010).

Among the studies developed with this purpose, only Harris (2008) made an in-depth analysis of the SSG. This author showed that the SSG, which should have been applied only during the implementation period of the Uruguay Round reforms, continued in use as a permanent mechanism. By analyzing the notifications of SSG in the period from 1995 to 2002 or 2007, depending on the existence of the notifications, this author verified that the most affected products were meat, dairy and sugar. The countries with highest use of such instrument for these products were the European Union (EU) and the United States (US), and they used the price-based mechanism (price SSG). Japan also presents a high application of the latter, but to a larger set of products and making use mainly of volume-based SSG. Harris (2008) also includes in his study some criticism to the values indicated for the triggers, in particular related to the reference price. These triggers were fixed by the average values observed in the period 1986-88 and never updated. At that period, the level of agriculture prices was relatively high. He adds that it would be of no use to cut the extra quota tariffs if this mechanism was not reviewed, since the additional SSG tariff could become more prominent and restrict trade in the same fashion.

The main difference that distinguishes the special agriculture safeguards (SSG and the SSM proposal) of the general safeguards is the fact that the former is automatic, while imposing the latter depends on proof of the damage. As they are automatic and, therefore, exempt from any damage-proving criterion, the agriculture safeguards may be applied without any justification.

A specific analysis of the SSG impact was carried out by Costa *et al.* (2015). These authors estimated that the impact of their use in the period from 1995 to 2013 over sugar exports in the US and EU was equivalent to a reduction in Brazilian sugar exports of 8 million tons of sugar (approximately 7 million not imported by the EU and 1 million by the U.S.) The authors also estimated that, if these exports had occurred, Brazil could have gained, in that period, approximately BRL 42 billion in production value for the entire economy, considering the direct, indirect and income effect impacts. As alerted by Harris (2008), the price triggers for sugar (average values observed in the period 1986-88) presented very high price levels, causing a practically constant application of the mechanism.

This study has the objective of a similar analysis to that made by Costa *et al.* (2015) but adjusted to another important group of agriculture products: meats. The next section (section 2) shows the behavior of international meat trade and the importance of Brazil in this market. Section 3 describes the methods and data used with the objective of identifying the impact of the additional SSG tariff and, in section 4, the empirical estimates of its usage impacts in the meat markets were analyzed. Finally, section 5 concludes the analyses and results presented.

2. THE INTERNATIONAL TRADE OF MEAT

According to OECD-FAO data (2015) on all global meat consumption, the share of beef, pork and poultry represents 22%, 38% and 35%, respectively. In that same report, there is a growth prediction of 12% in the consumption of beef and pork and 24% in poultry consumption. Regarding trade, according to FAO data (2018b), the global meat import value registered in recent years (2010-2013), represents 5% of the global agriculture imports. Of this total, 40% is beef, 32% poultry, and 26% pork. This section has the objective of identifying the top players in this market, in a way to stress the significance of this study's topic for the Brazilian economy, as well as identifying the importance of the countries that use special safeguard for meat products.

Figure 1 shows the major frozen beef exporters and importers for the most recent years. Figures 2 and 3 show this same profile, but for poultry and pork, respectively. As may be observed in these figures, Brazil stands out as the largest global exporter of beef and poultry, and one of the top in pork. It is verified in Figure 1(b) that the U.S., China[2], Russia, Japan and EU are the top

[2] The data from China correspond to the sum of the values of Hong Kong, Continental China, Macao and Taiwan.

beef importers. Due to geographic proximity, the North-American market should be the most important for Brazil. However, according to USITC (2018), in the entire period analyzed, the United States imported 49% of beef from Australia and 36% from New Zealand and no imports originating from Brazil. That distortion occurs due to the tariff rate quotas (TRQ) applied by the U.S. on the beef imports, as described in Table 1. Thus, this further stresses the importance of protectionist barriers applied in that market and the potential damage for Brazilian exports.

In the poultry market, Brazil also stands out as a global exporter (Fig. 2a). The top importers, described in Figure 2b are: Japan, China, Saudi Arabia and the EU. As for the pork market, the European Union (EU), the U.S. and Canada detain a higher share than Brazil in global export value (Fig. 3a). Among the top importers are Japan, China, Russia and the U.S. (Fig. 3b). This picture of these meats' global trades, which are the most commercialized and consumed in the world, demonstrates not only the importance of Brazilian exports but also the importance of importing countries that adopt trade barriers. Table 1 describes the products and the top importing markets, indicating which of them used tariff quotas (TRQ) and applied additional tariffs from the special safeguards mechanism (SSG) on their imports during the period of 1995, when these mechanisms were introduced, up to the latest notifications, which refer to 2015. Table 1 shows that most of the relevant importers do apply tariff quotas and have a right to apply an additional tariff due to the SSG.

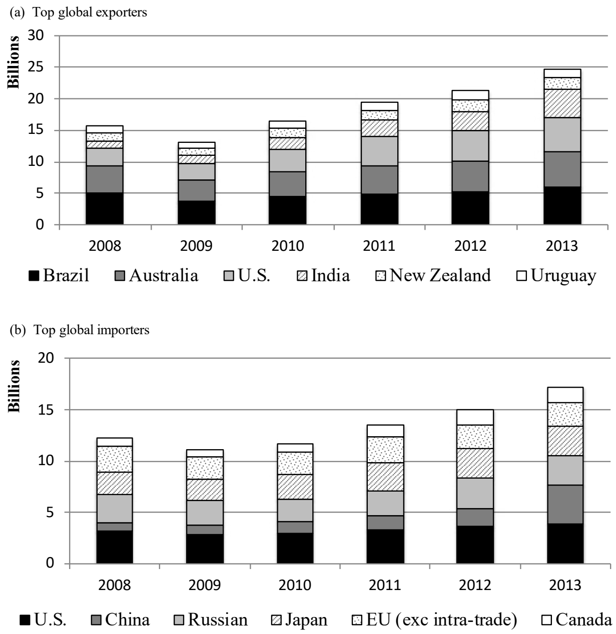
China, another market that has been prominent in the imports of some of these products, especially pork and poultry, does not apply TRQ or SSG for these products. However, China Taipei has a TRQ and right of use of SSG for these products. Despite the meat TRQ in this country being as a simple tariff, since the intra and extra quota tariffs are the same, there have been notifications of SSG use in these products for several years. As it is not possible to distinguish the imports of China from

Tab. 1. Use of tariff quota mechanisms (TRQ) and special safeguards (SSG) in the main meat and dairy importing markets, in the period from 1995 to 2015.

	European Union	United States	Japan	Canada	Russia
Beef	TRQ	TRQ / SSG	-	TRQ	TRQ
Poultry	TRQ / SSG	-	-	TRQ	TRQ
Pork	TRQ	-	-	-	TRQ

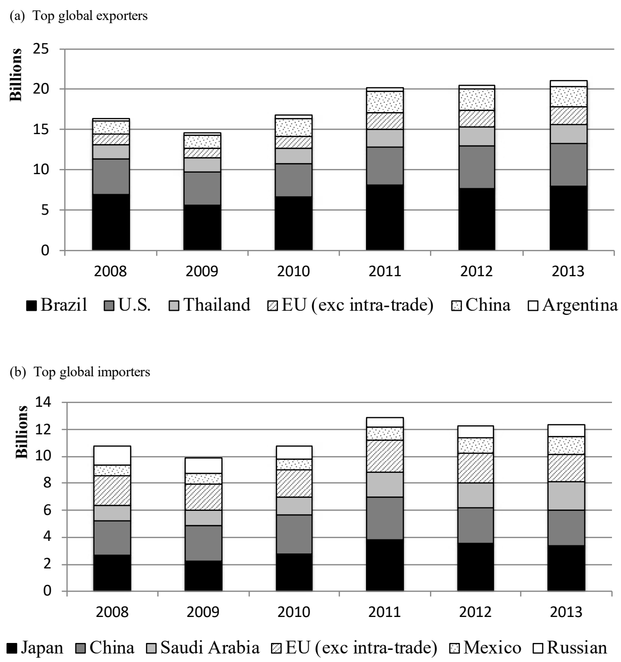
Source: WTO (2018a e b).

Fig. 1. Values, in USD, exported by the top global exporters and importers of frozen beef in the period between 2011 and 2013.



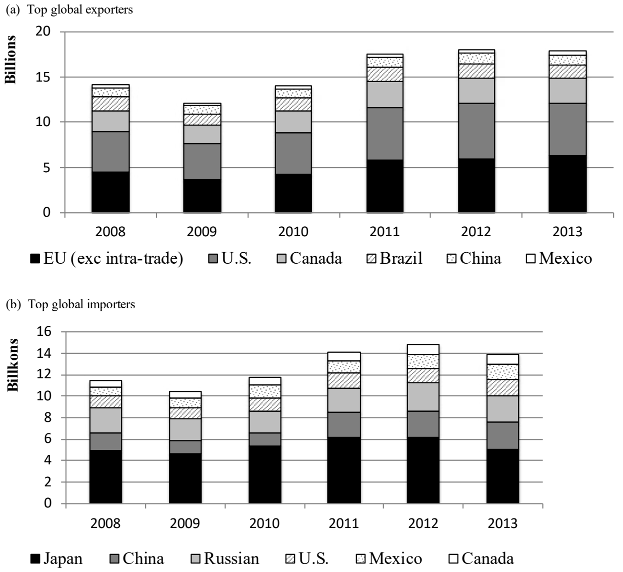
Source: Prepared by the authors, based on FAO (2018b).

Fig. 2. Values of poultry trade by the top global exporters and importers, in USD, for the period between 2011 and 2013.



Source: Prepared by the authors, based on FAO (2018b).

Fig. 3. Values of frozen pork trade by the top global exporters and importers, in USD, for the period between 2011 and 2013.



Source: Prepared by the authors, based on FAO (2018b).

those of China Taipei, according to the data available in United States (2018), it is worth noting that in this market as well there are high levels of protectionist barriers from these mechanisms that could have been put into practice.

The SSG is still a protectionist mechanism that lacks analyses in terms of its impact. Given the relevance of the meat market for Brazil and the use of this protection mechanism in markets of major relevance in their imports, this study sought to evaluate the impact of additional SSG tariff use in the main meat importing markets. The entire period during which this mechanism has been in place was analyzed, since 1996 until the latest notifications registered with the World Trade Organization (WTO), in 2015. The analyses carried out in this study, therefore, focused on the countries and products described in Table 1 that applied the additional tariff from the SSG and estimated their impacts, by means of the export level that would have been achieved if they had not been applied. The following section describes the methods and data used in this analysis.

3. METHOD AND DATA

This section presents the theory and method used to estimate the impact of the additional SSG mechanism applied on trade. Considering that the application of the additional SSG tariff should be obligatorily notified in a document with the WTO, the first stage consisted in identifying their application in this database (WTO, 2018a). The notifications indicate the tariff line affected and the year for each country. In parallel, the main tariff lines (TL) used on meat imports in the markets analyzed were identified for United States and European Union in the period 1995-2015. These data were obtained from Eurostat (2018) and USITC (2018). The SSG notification does not present the additional tariff value. Therefore, at second stage of the study an estimate of the additional tariff value is obtained.

The additional tariff depends on the nature of the SSG applied, i.e. if it was on volume or price. In the case of meat exports, the price-based SSG was the most important. As previously described, for the volume-based SSG, the additional tariff could be any value up to 33% of the tariff applied. For the price-based SSG there is a rule that was used to obtain estimates in this study. The rule is that if the import price falls below a certain limit, defined as a price trigger, in a value less than or equal to 10% of that trigger, no additional tariff is imposed; if the difference is within 10% and 40% of the trigger price, the additional tariff is 30% of the amount at which the difference has exceeded the 10% of the trigger price; if the difference is within 40% and 60% of the trigger price, the previous account is summed with an additional tariff of 50% of the amount at which the difference exceeds the 40% of the trigger price; if the difference is within 60% and 75% of the trigger price, the additional tariff is 70% of the amount at which the difference exceeds the 60% of the trigger price, summed to the increments described in previous intervals. Finally, if the mentioned difference is beyond 75% of the trigger price, the additional tax will be 90% of the amount at which the difference has exceeded the 75% of the trigger price, plus the integral increments corresponding to the previous intervals (FAO, 2002).

Therefore, it is verified that for these calculations, the import prices should also be identified. An average import unit value of the country in the year of application was used as a proxy, obtained by dividing the value and volume of imports of each tariff line, using data obtained from the sources: Eurostat (2018) and USITC (2018). Nonetheless, when there is a notification of SSG use and the identified price is not below 10% of the trigger price, we adopted a reference price from other major global importers, obtained from United States (2018).

Once the values of the additional tariffs were estimated for each year in which their use was notified, we use an economic formula to estimate the trade gains deriving from the price change. This formula is described in equation (1).

$$\Delta M = \eta^M * \Delta P * M_{BASE} \quad (1)$$

where M is the imported volume; P is the price paid by domestic consumers; η^M is the import price elasticity; and Δ represents a percentage variation. Thus, $\Delta P = \left(P_f - P_i\right) / P_i$. M_{BASE} is the quantum imported, considering the initial price P_i), i.e. the price paid by the consumer before a change in the import tariff, which directly impacts that price.

Considering that the variation is caused by the change in the country's import tariff, equation (1) can be rewritten as described in equation (2). Since it is necessary to use all tariffs imposed on the product, extra-quota tariffs were also considered in addition to the additional tariff. Thus, T_i is the initial import tariff, which represents the extra-quota tariff plus the additional SSG tariff and T_f is the extra-quota tariff without the additional SSG.

$$\Delta M = \eta^M * \frac{\left(T_f - T_i\right)}{\left(1 + T_i\right)} * M_{BASE} \quad (2)$$

The import tariff is given in percentage terms of the price of the imported product. In the case that the tariff is specific or mixed, the tariff equivalent was annually estimated, considering the same import price used to estimate the SSG for each year, or the country's annual average import price.

The value of the import price elasticity η^M), in turn, depends on the product's domestic demand η^d) and supply η^s) elasticities, as well as the ratio of the volume consumed (D) and produced (S) with the imported quantum (M). Equation (3) describes the formula to obtain the import demand price elasticity[3].

$$\eta^M = \eta^d * \frac{D}{M} - \eta^s * \frac{S}{M} \quad (3)$$

The elasticity data was obtained from Fapri (2018) and the domestic consumption and production data from FAO (2018).

By knowing the volume that was not imported due to the application of the SSG in each year, a part of this volume was adopted as potentially being supplied by Brazil. The percentage used to calculate the exports that Brazil ended up not sending to that country was based on the percentage that Brazilian exports X_{BR}) of that product group had within global exports X_W), in each year of the analysis. By multiplying the volume that the country ended up not exporting by the basic price (received by the producer - P_b) we obtain for each year an estimate of the value of the country's exports losses (y). Equation (4) describes this calculation. It can also be verified in this equation that, despite the variations in imports and Brazil's participation have been estimated year by year, the value that was not exported was calculated for the entire period analyzed (the subscribed "t" indicates the year analyzed). This was done so this value could be placed as a total impact to estimate other effects on the Brazilian economy, which is described below.

$$\sum_{t=1996}^{2015} \left[\Delta M * \left(\frac{X_{BR}}{X_W} \right) \right]_t * P_b = y \quad (4)$$

The value of y was then used as a demand shock (demand that did not occur) on the input-output matrix of the country. This relationship between demand shock and the impact on the economy can be obtained from equation (5), as described by Miller & Blair (2009). In this equation, the variable Y represents a demand matrix, where the value of exports that did not occur is entered[4]; X is the matrix that describes the impact of that demand on the production value of the entire economy and matrix (A) represents the technical relation in the intermediary demand.

$$X = (I - A)^{-1} Y \quad (5)$$

The impacts (X) estimated in this manner indicate the direct and indirect effects on the economy, also called type I multipliers. Type II multipliers were also obtained as type I plus the effect of a consumer income variation caused by the direct and indirect effects. In order to obtain type II multipliers, the matrix A of technical coefficients includes "families" as if it was another sector of the economy. The new matrix is described $\overline{A}$.

In addition to the impacts on the production value, the impacts on the value of remunerations (Z_R), of imports (Z_M), of the number of jobs (Z_E) and of the Gross Domestic Product (Z_{GDP}) were also estimated. For such, the result obtained from equation (5) was used to obtain the estimates described in equation (6).

$$Z_{(nx1),k} = [\text{diagonalized}(C_{(nx1),k})]_{(nxn),k} * X_{nx1} \quad (6)$$

[3] The derivative of this equation can be found in Orcutt (1950).

[4] The difference between y and Y is a value and Y is a vector-type matrix where, in the line corresponding to the meats sector that was not exported by the country, the value y found is included.

Where $k = R$ (remunerations value), M (imports value), GDP (GDP value) and E (number of people employed). The C_k coefficients were obtained at the actual input-output matrix.

The input-output matrix used in this study was estimated based on the data from the Brazilian National Accounts (Brazil, 2018) as described by Guilhoto and Sesso (2010) and Guilhoto and Sesso (2005). The productive structure, in terms of the value and the coefficients used, which were the structures required to obtain the results, refer to that observed in the country in 2013.

4. RESULTS

As described in section 2, the analysis made in this study focused on the countries and products described in Table 2, which made use of the SSG in the meat market. They are: the U.S. in the imports of beef and EU in imports of poultry. The additional SSG tariff is applied over the extra-quota tariff value. The extra-quota tariff applied in the U.S. on beef is 26.4%[5]. In the case of EU, there are mixed tariffs. In order to estimate an equivalent ad valorem value (EAV) of the mixed tariffs, it should be taken into account that their EAV changes depending on the import price reference. Figure 4 shows the EAVs calculated for the poultry extra-quota tariff in the EU for each year, using the average import price of each one of them. It may be observed in Figure 4 how the tariff equivalents change their protection level while changing the product price reference. In that sense, it is verified that a higher level of tariff protection is observed for lower price levels, which means increasing the protection in periods of global excess supply, which in turn also contributes to the even higher increase in this excess, causing a snowball-type effect. The same rationale applies to the impact of special price safeguards, whose additional tariff increases as the product import price decreases.

In order to make a comparison between the products' protection level, we therefore consider that in the EU, depending on the import price used, the EAV remained between: 50-70% for poultry; 70-90% for beef; and 25-30% for pork.

Despite indicating only one tariff for an entire product group, we actually have several tariff lines (TL), often with different tariffs, for each type of meat. The tariff described and used in this study in each group represents the most relevant TL in the country's imports. Likewise, for each of those products, in each country, we have some TLs where the SSG was applied. For the products analyzed, it was observed that the price SSGs were the most active and that there were nine tariff lines that stood out when observing their application: one TL in the U.S. (tariff line 02023010 and 02023080 – beef, frozen, intra and extra quota, respectively) and eight poultry TLs in the EU (they are: 02071290 – whole frozen chicken; 02071410 – boneless chicken, frozen; 02071450 – chicken breast, with bones, frozen; 02071460 – chicken legs, with bones, frozen; 02071470 – other chicken parts, with bones, frozen; 02072510 – whole turkey, frozen; 02072710 – turkey cuts, frozen and; 02073615 – duck or goose meat, frozen)[6]. This was the universe analyzed in this study[7].

Figure 4 shows the estimated values of the additional price-based SSG tariffs for this set of nine TLs that used this mechanism, along with the extra quota tariff applied at each year, for the period from 1996 to 2015. Since the price SSG is applied per ship and there is no way to identify the cargo's import price on which it was applied, the analyses were performed with average annual prices. The average extra quota import price was used (only the U.S. indicate the intra and extra quota imports separately), for it is on the extra quota imports that the SSG incurs. However, in the cases where the country declared use of SSG and the import price identified was not below the trigger price, a global import price was used for this estimate, as described in Section 3. For some TLs, however, it was observed that even using this resource for several years, despite the country having notified the use of price SSG, import price levels low enough to warrant an SSG activation were not found. All years where there was a notification of SSG activation and the price observed did not corroborate with their use were marked in Figure 4 charts with a square. A larger price variation can occur during some years and justify the use of an SSG, since this study used an annual average price. But if that was the case, as during most of the period analyzed, the use of a safeguard instrument wouldn't be expected.

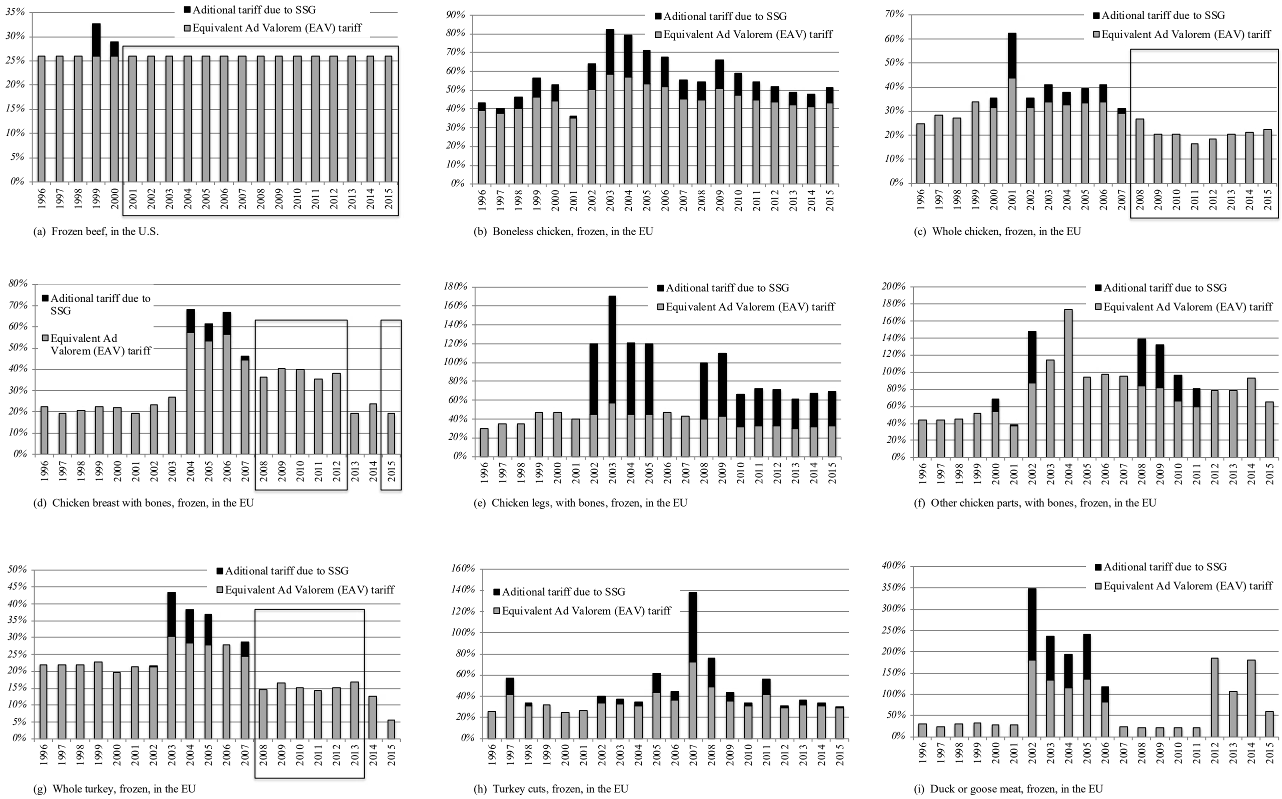
In those cases, since the import price is above the trigger price, as well as the global prices, it was not possible to estimate the corresponding additional tariffs. It

[5] The extra-quota tariff applied in the U.S. on beef imported by Australia is lower (21.1%) than the others.

[6] In the period analyzed (1995-2015) these tariff lines underwent some transformations. Therefore: the TL 02071210 was 02072110; the TL 02071290 was 02072190; the TL 02071410 was 02074110; the TL 02071450 was 02074151; the TL 02071460 was 02074171; the TL 02071470 was 02074171; the tariff line 02072510 was 02072210; the TL 02072710 was 02073931 and; the TL 02073615 was 02074515 and also 02074315.

[7] Japan, despite not having a tariff quota for pork meat, submitted a volume SSG usage notification for this product in 1997. This data was not estimated and stands as a mere observation in this study.

Fig. 4. Equivalent Ad Valorem tariff (EAV) estimated for the extra quota and additional tariff estimate from the use of price SSGs for the tariff lines analyzed, using the average annual price data for imports in the period 1996 to 2015.



Source: Prepared by the authors based on data from WTO (2018a and b), USITC (2018), United (2018) and Eurostat (2018).

is verified that this was more severe for beef in the U.S. This observation, which did not occur in an isolated manner, but persistently within the application of more significant special safeguards on the global meat trade, raises doubts whether the SSGs are really being applied within import price conditions below the trigger, and not only considering normal annual price variations. In that case, even reforms to this mechanism could fail to be effective to reduce the protection levels.

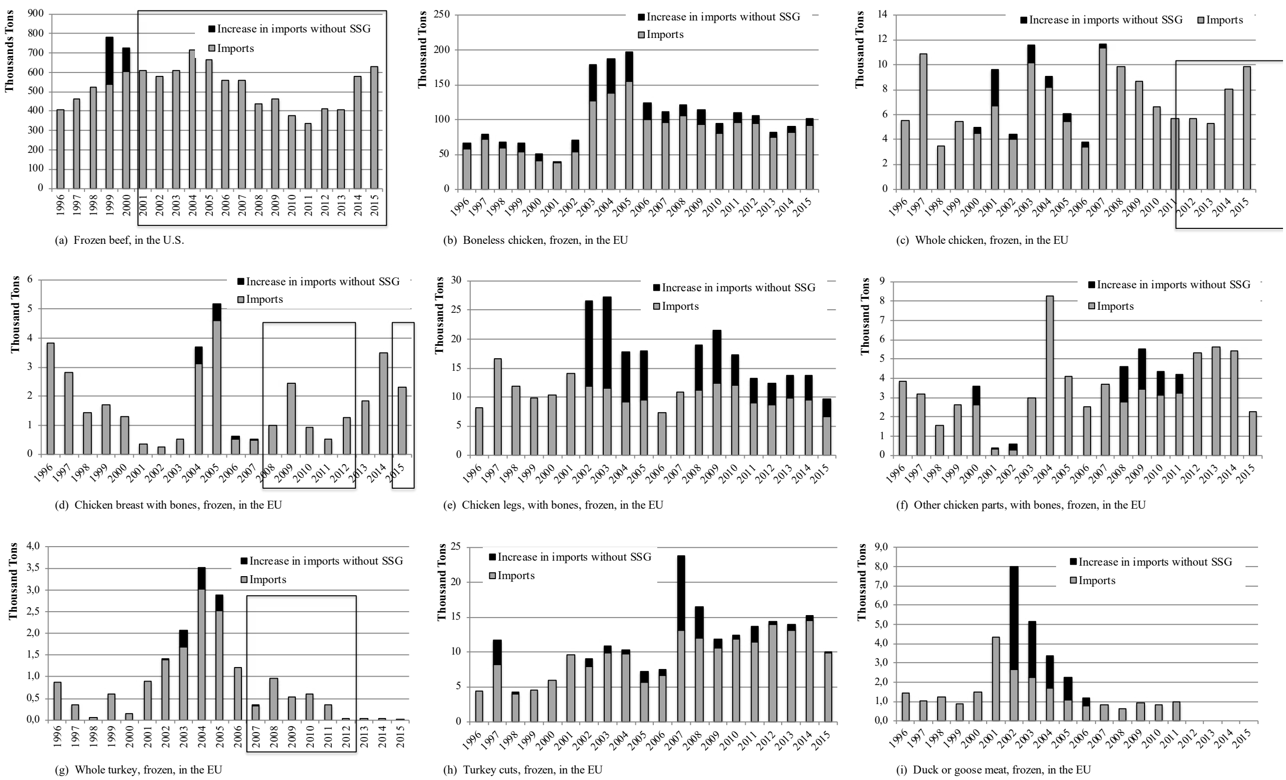
As previously mentioned, it is also verified in Figure 4 that the EAV extra quota tariff changes throughout the years, since different price levels are observed each year.

Figure 5 shows the volumes imported each year and the estimated volumes, calculated as described in equation (2), which were no longer imported due to the application of SSG. Since the import price elasticity is responsible for a significant share in the results, they are described in Figure 6. These values were calculated as presented in equation (3).

As expected, the estimated volume which was not imported due to the SSG is directly proportional to the scale of the additional tariff estimated and described in Figure. 4. However, the basic imported volume, which is the volume imported in the year of the SSG application is also important for this estimate, and the magnitude of the values, which can be observed in the axes of the charts in Figure 5, draws attention to this fact. The magnitude of the impact on the imported volume is observed in Figure 5(a) and 3(b) as quite superior to the others, indicating their greater significance for trade. Figure 5(a), which has the greatest import magnitude among the tariff lines analyzed, represents the SSG impact on beef imports in the U.S.

And, as presented above, this effect could only be estimated for the years 1999 and 2000, despite the U.S. having notified the use of SSG in all years up to 2015. Since this is a very large market, the magnitude of the impacts that could not be estimated, therefore, could be important for the global meats market. If we consider the impacts of beef and poultry reduction in the years of 1999 and 2000 due to the SSG estimated in this study, this value represents approximately 2.5 and 1.5% of the global trade of these meats, respectively, in the years 1999 and 2000. As for the other years, where only the

Fig. 5. Import volumes observed and estimate of what was not imported due to the application of an additional special safeguard tariff, applied by the U.S. and EU in the meats market, period 1996 to 2015.



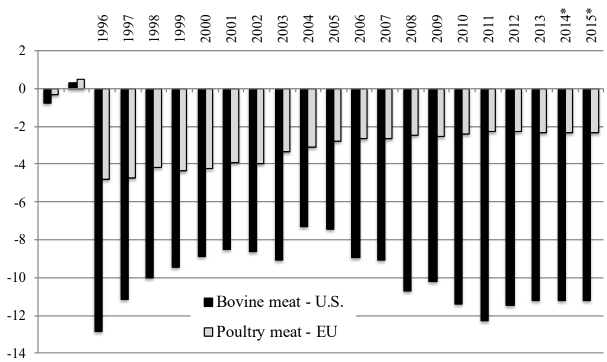
Source: Prepared by the authors based on data from WTO (2018a and b), USITC (2018), United (2018) and Eurostat (2018).

impacts on poultry were measured, the participation of these impacts in the global poultry market varied from 1.6% in 2003 to 0.1% in 2001, with an average of 0.5% for the period (except the years 1999 and 2000). These results also depend on the price elasticities considered.

Applying Brazil's participation in global exports of beef and chicken on each of the years studied for the estimated volumes that were not imported due to SSG application, we obtain an estimate of Brazilian exports that did not occur. Brazil's participation in beef trade varied from less than 10%, before 2000, to 20% from the mid-2000s decade. As for the poultry market, Brazilian participation was of 15% until the decade of 2000, and reached the threshold of approximately 35% from then on. By multiplying them by the basic prices of these products, which were obtained in Brazil's Input-Output Matrix of 2013, we obtain the demand shock values estimated for the Brazilian economy. The values of these shocks were approximately BRL 517 million for poultry and BRL 287 million for beef. Table 2 shows the results obtained from the impact of these values on the Brazilian economy.

The first observation about the results refers to the relatively low impact found in this study of the meat market when compared to those obtained for the sugar market (Costa *et al.*, 2015). In the latter, the impact in the period of 1995-2013 was approximately BRL 42 billion in gross production value (VBP) of the Brazilian economy and in the former, for an additional period of two years, from 1995-2015, the impact was less than BRL 4 billion in the VBP. Nonetheless, the trigger prices to activate SSG in sugar were quite high in regard to the prices practiced in the period, resulting in high levels of an additional tariff applied and, consequently, in the high impacts observed by Costa *et al.* (2015). In the case of meat, the trigger price was clearly higher only for one of the tariff lines analyzed (Boneless chicken, frozen, in the EU). As may be observed in the charts in Figure 4 and 5, most of the impacts could not be estimated due to prices observed above the trigger price. But in face of the fact that SSG applications were notified for those products and years, much of the impact certainly could not have been estimated in this study. This observation could be more important in this study than the impacts

Fig. 6. Values of the price elasticity of demand for imports (η^M) of beef in the U.S. and poultry in the EU.



Note: *The same value of the last year was considered due to the lack of data; is the demand price elasticity and the price elasticity of supply, both domestic, used as a basis to estimate the demand for imports.
Source: FAO (2018a); Fapri (2018).

estimated to show the relevance of minding the use of this mechanism.

The type I estimated impacts - which correspond to the direct and indirect effects of a demand shock, in addition to the actual sector that received the shock – were higher in the following sectors presented in decreasing order of impact: Other food products, Livestock, Trade. These sectors were the most impacted by the direct and indirect effects in all variables analyzed: production, GDP, remuneration/salary, employment and importation. However, as may be observed in Table 2, the impact of a growth in imports was quite small. This is a good result for the country's economy, for it is verified that the shock does not demand much from sectors highly dependent on imported products in the country.

It is verified that the impact with only the income effect, which is the difference between Type II and Type I impacts, represents an important portion of the total impact, corresponding to approximately 36% for GPV variables and number of jobs, and 47% for the remaining variables. Thus, while separating the income effect of the type II impact, we observe that the sectors most affected by this effect are different depending on the variable analyzed. Considering the gross production value (GPV), in addition to the actual sector that received the shock, the most impacted sectors in order of significance were: Trade, Real estate activities, Oil refining, Other food products, Food and Agriculture. In turn, considering the income effect of the impact on the GDP, the Real estate sector's activities were superior to those of Trade, followed by the sectors of Food and Agriculture. However, observing the impacts on employment, few sectors were relevant, with the following sectors standing out in this order: Trade,Livestock, Food, and Agriculture. Despite having a much lower impact than on those sectors, but still quite superior to the average of the country's sectors, and due to the income effect of the country's meat exports growth, the following sectors stood out in job creation: Associative organizations and personal services, Private education and Private health care.

5. CONCLUSION

The results illustrate how a trade protection mechanism, such as SSG – for which there are few analyses, and that should have been eliminated for having a transient character when adopted - presents expressive impacts on international meat trade and for the economy of a country that exports such products, as Brazil.

The use of special safeguards (SSG) for agricultural products has been an instrument with a high potential to enable increases in the consolidated tariffs at the WTO by member countries. Thus, it gains importance, mainly at periods of high relative supply of products and

Tab. 2. Estimated impact on the Brazilian economy of a demand shock in Brazilian meat exports: BRL 517 million for poultry and BRL 287 million for beef. Values in BRL million, at 2015 prices (for the "Job" variable, the results indicate number of people).

	Gross Production Value (GPV)	Number of people employed	GDP	Remuneration	Importation
Type I*					
Beef	817	9.721	344	120	31
Poultry	1.472	17.511	620	216	56
Type II*					
Beef	1.339	15.139	653	226	58
Poultry	2.411	27.272	1.176	407	104

Note: *Type I corresponds to the direct and indirect impacts and Type II to the impacts, besides those, also of the income effect.
Source: Research results.

reduced prices in the international market. In fact, when the prices of the international market are reduced, that increases the imported product's competitiveness in the importer country markets. With the reaction of these importers in the form of higher tariffs by the percentage provided in the agreements, there is a reduction in imports that increases an excess of the global supply, particularly when the countries that react are significant importers. As a result, prices could end up even lower in the international market. This characterizes a perverse effect associated to the deployment of SSGs, reinforcing the importance of measuring and analyzing its effects, as presented in this study.

It is worth noting that the transparency of the measurements for their evaluation could be improved, since the countries don't need to inform the value of the imposed tariff when notifying its application. Today, importers are only required to notify that they are using the SSG measure. Another aspect involves the fact that the price-based SSG is applied per ship, which also makes it difficult to obtain the actual cargo import price on which it was applied. An approximation consists in employing average annual prices for the commodity. Given such procedure cannot provide the exact value, there are cases in which the country declares the use of SSG and the actual import price calculated is not lower than the trigger price. Therefore, the results obtained can be underestimated, and it is important to analyze the results obtained with that reservation. This was identified, for example, in the case of the U.S. meats market. In that market, this effect could only be estimated for the years 1999 and 2000, despite the U.S. having notified the use of SSGs in all years up to 2015. Since it is a very large market, the magnitude of the impacts could not be estimated, therefore, they could be important for the global meats market and were not collected.

Despite these reservations, the results obtained in this study can subsidize future trade negotiations at the WTO. In addition, the study offers an analytic instrument that may be updated in a simple manner, providing a way to monitor the changes throughout different periods of time.

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Competing Interests: The Author(s) declare(s) no conflict of interest.

La convenienza economica alla coltivazione di OGM in Italia: un'analisi sul campione della rete italiana di contabilità agricola (RICA)

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Abstract. The present paper[1] examines the economic convenience of the cultivation of GMOs in Italy. In particular, a simulation was conducted on the effects of the adoption of GM corn for specialized Italian farms, through the comparison of the gross margin of GM and conventional maize. Results obtained on the sample of farms belonging to the Italian farm accountancy data network (FADN), in the 2013-2015 period, show that the gross margin obtainable with the use of GM corn is, on average, higher than that obtained with the use of the conventional one. Results obtained on the sample grouped according to the utilized agricultural area, show that bigger farms could benefit more from the cultivation of GM corn. Moreover, specialized farms located in traditional areas show the highest advantage from the cultivation of GM corn.

Keywords: Organismi geneticamente modificati, aziende agricole, convenienza economica, specializzazione aziendale, margine lordo.
JEL codes: Q18, Q12, C53.

1. INTRODUZIONE[1]

La produzione di mais GM è una questione alquanto controversa sia per i ricercatori che, più in generale, per l'opinione pubblica poiché si scontra con problematiche di natura etica, politica, ambientale ed economica. In particolare, una delle questioni di maggiore rilevanza è il problema specifico delle colture transgeniche, osteggiate dall'opinione pubblica per le preoccupazioni riguardo ai potenziali effetti, derivanti dal consumo di prodotti geneticamente modificati, sulla salute umana. Quest'ultimo fattore ha impedito la diffusione di produzioni transgeniche in Europa, diversamente da quanto accaduto in realtà come gli Stati Uniti dove il mais GM è, invece, stato ampiamente utilizzato per la produzione di alimenti destinati al consumo umano e animale. Sotto l'aspetto ambientale di recente si è sviluppato il dibattito circa la resistenza delle produzioni transgeniche agli erbicidi, che

[1] Il presente lavoro è stato elaborato nell'ambito del progetto "Biotecnologie sostenibili in agricoltura" finanziato dal Mipaaf. Si fa presente che le informazioni riportate nel testo sono aggiornate a Giugno 2018.

spingendo verso un maggiore impiego, limiterebbe fortemente i benefici ambientali ma anche economici legati a queste tipologie di coltivazioni. A livello europeo, la reticenza verso prodotti geneticamente modificati e la normativa in materia hanno, di fatto, impedito che si creasse un incentivo per gli agricoltori all'utilizzo di sementi GM. Infatti, l'unica semente di mais utilizzabile per la coltivazione nell'UE è quella prodotta dalla Monsanto[2] (MON 810), il cui impiego è permesso solo in un numero ridotto di paesi europei. Tuttavia, sono frequenti le importazioni in Europa di mais GM da paesi produttori di mais geneticamente modificato, specie per l'alimentazione animale. La normativa europea non vieta l'ingresso nel territorio dell'Unione di prodotti, ottenuti da OGM o a base di OGM, ma richiede soltanto che debbano essere autorizzati ai fini del consumo animale e umano. Con la direttiva 2015/412 l'Unione Europea ha accordato agli Stati Membri la possibilità di limitare o vietare la coltivazione di OGM sul proprio territorio o su parte di esso. L'Italia, in recepimento di tale direttiva, ha notificato alla Commissione europea la richiesta di esclusione dal proprio territorio della coltivazione di tutti gli OGM autorizzati a livello europeo. Il presente articolo intende fare luce sui possibili benefici derivanti dall'impiego di sementi GM di mais, da parte delle aziende agricole italiane, specializzate nella produzione di mais. I tentativi già fatti in tal senso sono piuttosto ridotti, in particolare per la mancanza di informazioni statistiche adeguate ad effettuare simili simulazioni. Nel lavoro verranno utilizzate le informazioni contenute nel campione della rete italiana di contabilità agricola (RICA) al fine di analizzare i benefici diretti derivanti dall'uso del mais GM senza, tuttavia, tener conto delle ricadute, in termini ambientali e sociali, ad esso legate. Nei paragrafi seguenti viene, in primo luogo, considerato il contesto internazionale e nazionale di riferimento relativo alla coltivazione di mais GM e, successivamente, viene descritto il campione utilizzato per l'analisi, la metodologia adottata e i risultati ottenuti.

2. IL CONTESTO INTERNAZIONALE E NAZIONALE

Nel 2016 circa 185,1 milioni di ettari di superficie agricola sono stati investiti con coltivazioni GM nel mondo, rispetto ad una superficie agricola mondiale utilizzata per le coltivazioni pari a 1,7 miliardi di ettari, con un incremento del 3% rispetto al 2015 (ISAAA, 2017). Il 91% della superficie investita con coltivazioni GM si concentra in 5 paesi: Stati Uniti con 72,9 milioni di ettari, Brasile con 49 milioni di ettari, Argentina con 23,8 milioni di ettari, Canada con 11,6 milioni di ettari e, infine, India con 0,8 milioni di ettari. Il mais resistente agli insetti (Bt) è la seconda coltura geneticamente modificata più diffusa nel mondo, ricoprendo circa 53,6 milioni di ettari di superficie e il 26% di quella investita a mais a livello mondiale (ISAAA, 2017). La coltivazione di mais GM interessa complessivamente 16 paesi ed, in particolare, gli Stati Uniti (con 30,1 milioni di ettari), il Brasile (15,6 milioni di ettari), l'Argentina (4,7 milioni di ettari), il Sud Africa (2,2 milioni di ettari) e il Canada (1,5 milioni di ettari). Come già ricordato nell'UE esiste una sola unica varietà autorizzata di mais transgenico (MON 810), prodotto dalla Monsanto, autorizzata per la coltivazione a livello UE e destinata soprattutto a uso mangimistico. La coltivazione di MON810 riguarda, in particolare, cinque paesi europei: Spagna, Portogallo, Repubblica Ceca, Slovacchia e Romania con una superficie totale investita per questa coltura pari a 116.870 ettari. Tuttavia, con l'entrata in vigore della dir. 2015/412/Ue è stata accordata agli Stati Membri la possibilità di limitare o vietare la coltivazione di OGM, sul proprio territorio o in parte di esso, in base a motivazioni diverse da quelle legate alla valutazione degli effetti negativi sulla salute e sull'ambiente. Nella situazione attuale, pertanto, i paesi UE possono proibire la coltivazione di OGM autorizzati dall'UE ma non la commercializzazione degli OGM presenti nei mangimi per animali e in alcuni alimenti destinati al consumo umano. Infatti, ad ottobre 2015 il Parlamento europeo ha respinto il progetto di legge comunitaria[3] volto a limitare la commercializzazione di prodotti con OGM, già autorizzati a livello UE, sottolineando la mancanza di valutazione sulle potenziali conseguenze nel mercato unico. L'intento della Commissione, che non intende ritirare la proposta ma sottoporla alla ridiscussione dei ministri europei, è raggiungere il giusto equilibrio tra il mantenimento del sistema di autorizzazione dell'UE, fondato su basi scientifiche e sulle norme in materia di etichettatura e la libertà di decisione degli Stati Membri riguardo all'uso degli OGM sul loro territorio. L'Italia, attraverso il d.l. 14 novembre 2016 n. 227, ha recepito la dir. 2015/412/UE, che modifica la dir. 2001/18/CE, vietando le coltivazioni transgeniche sul proprio territorio. In precedenza, il d.interm. del 12 luglio 2013 già sanciva il divieto di coltivazione del MON 810 in Italia. Sulla base di esso, il 6 febbraio 2015, il Consiglio di Stato aveva respinto il ricorso di un agricoltore friulano, Giorgio Fidenato, sostenitore delle colture di mais geneticamente modificato, che chiedeva il permesso di utilizzare questo tipo di sementi. La verten-

[2] Il marchio Monsanto verrà cancellato in seguito all'acquisizione di quest'ultima da Bayer.

[3] Relazione del 19.10.2015 PE 560.784v02-00 A8-0305/2015.

za è stata portata avanti alla Corte di giustizia europea, che, decidendo sul ricorso di Fidenato, il 13 Settembre 2017 ha pronunciato una sentenza in cui viene considerato ingiustificato il divieto di coltivazione del MON 810 previsto dal decreto interministeriale più sopra citato.

L'Unione europea non ha mai ritenuto necessario adottare misure di armonizzazione, a livello comunitario, in materia di coesistenza tra coltivazioni GM e coltivazioni di tipo convenzionale avendo, di fatto, riconosciuto e autorizzato la contaminazione accidentale e lasciato agli Stati Membri la discrezionalità di stabilire norme più restrittive sulla coesistenza, conformemente al principio di sussidiarietà[4]. Secondo gli orientamenti contenuti nella Raccomandazione 2003/556/CE, in parte ripresi dalla Raccomandazione del 13 luglio 2010[5], infatti, le misure nazionali destinate a garantire la coesistenza devono adeguarsi alla specificità dei diversi tipi di colture e agli aspetti regionali, riconoscendo priorità alle misure di gestione applicabili a livello di azienda agricola e alle misure destinate a stabilire una cooperazione tra aziende confinanti. Nella realtà agricola italiana, i cui territori sono caratterizzati da migliaia di piccole e medie aziende con un tessuto poderale estremamente polverizzato, la coesistenza tra coltivazioni transgeniche, convenzionali e biologiche pone dei seri problemi. L'Italia, nel mese di ottobre 2015 ha notificato alla Commissione europea la richiesta di esclusione pro-tempore dal proprio territorio della coltivazione di tutti gli OGM autorizzati sul territorio comunitario, come ricordato più sopra. Tuttavia, già con la l. 5/2005 l'Italia aveva di fatto "sospeso" la possibilità di coltivare OGM in attesa dell'adozione da parte delle Regioni dei cosiddetti Piani di coesistenza, cioè specifiche disposizioni tecniche e organizzative, in linea con quanto previsto dagli orientamenti comunitari in materia, che consentano, appunto, di evitare la commistione tra colture OGM, biologiche e convenzionali. Sebbene i Piani di coesistenza non siano mai stati adottati dalle Regioni, la Conferenza Stato-Regioni ha adottato a fine 2007 le "Linee Guida per le normative regionali di coesistenza tra colture convenzionali, biologiche e geneticamente modificate", predisposte dal Gruppo di Lavoro Tecnico Interregionale sugli OGM. Le linee guida prevedono la separazione fisica delle coltivazioni transgeniche da quelle convenzionali e biologiche, la presenza di un registro in cui annotare le seminatrici utilizzate per le sementi OGM nonché la duplicazione delle macchine e dei locali di stoccaggio in presenza di produzioni geneticamente modificate. Le linee guida prevedono anche una serie di obblighi, da parte degli agricoltori coltivatori di OGM, quali la necessità di informare i vicini e i proprietari dei terreni destinati alla coltivazioni di OGM, di seguire un corso sulla coesistenza, di pagare una tariffa regionale per ettaro di OGM coltivato[6] e di contrarre una polizza assicurativa per la copertura di eventuali danni arrecati. Le schede tecniche contenute nelle Linee Guida, si basano sui principali studi riportati in letteratura che hanno indagato programmi di studio e di ricerca sperimentale sviluppati in diversi paesi europei su iniziativa di enti pubblici e privati con l'obiettivo di indagare sulla coesistenza tra colture GM e non GM e, specificatamente, la diffusione di polline e la conseguente fecondazione incrociata tra campi, rispettivamente, di mais, di colza e di soia, con l'obiettivo di indicare opportune distanze di separazione utili per contenere la fecondazione incrociata sotto la soglia accidentale dello 0,9%. Secondo le Linee Guida, nel caso del mais l'elenco dei fattori che giocano un ruolo nel controllo della contaminazione è piuttosto lungo e comprende "le distanze di isolamento, la dimensione, la forma e l'orientamento dei campi, le caratteristiche dei venti e del clima locale, la pioggia, la vitalità pollinica, l'umidità del polline, l'epoca di fioritura, la destinazione commerciale del prodotto, le procedure di campionamento, i metodi utilizzati per studiare la dispersione del polline, il metodo di quantificazione e il tipo di materiale vegetale analizzato". Nella scheda tecnica si legge "Al fine di ridurre la quantità di polline GM capace di disperdersi, il campo di mais GM deve essere obbligatoriamente circondato da una fascia di mais non GM, della stessa classe FAO, di un'ampiezza pari ad almeno 10 file, comunque non inferiore a 7 metri. Tale fascia è considerata parte della coltura GM. Le distanze minime di separazione sono così definite: a) mille metri, quale distanza idonea a minimizzare il rischio di commistione, con l'obiettivo di garantire una contaminazione pari allo 0 tecnico (<0,01%) nei confronti delle coltivazioni di mais confinanti; b) trecento metri, quale distanza idonea a mantenere la commistione al di sotto di una contaminazione dello 0,9% nei confronti delle coltivazioni di mais confinanti. In ogni caso la distan-

[4] Al fine di aiutare gli Stati Membri nell'implementazione delle misure di coesistenza più efficienti, cioè in grado di mantenere la presenza di OGM in coltivazioni non GM nella soglia stabilita dalla normativa e ridurre i costi della stessa a carico degli agricoltori, è stato istituito nel 2008 l'European Coexistence bureau (ECoB). Il compito di quest'ultimo è di favorire lo scambio di informazioni scientifiche e tecniche sulle migliori pratiche di gestione della coesistenza.

[5] Raccomandazione 2010/C 200/01 del 22/07/2010. La raccomandazione riconosce inoltre la possibilità agli Stati Membri di stabilire una soglia accidentale e inevitabile di presenza di OGM diversa dallo 0,9% in coltivazioni non GM tenendo in considerazione la domanda da parte dei consumatori.

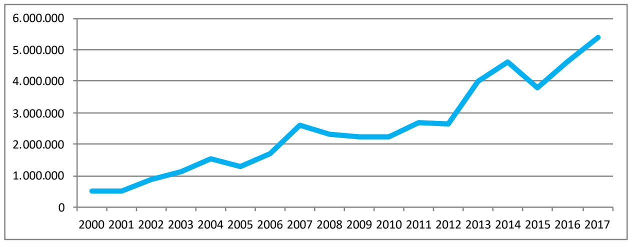
[6] Il ricavato del pagamento delle tariffe viene destinato alla costituzione di un fondo al quale le amministrazioni regionali attingono per sostenere le spese per l'attuazione delle coesistenza quali, ad esempio, il rilascio delle autorizzazioni.

za minima non potrà scendere al di sotto dei centocinquanta metri se sono seminate almeno 15 file, in ogni caso non meno di 10 metri, di mais convenzionale della medesima classe FAO, i cui prodotti sono, comunque, commercializzati come geneticamente modificati". Nel caso di mais GM BT "aventi caratteristiche specifiche che le rendono resistenti ad insetti fitofagi, attraverso sistemi che provocano la morte degli insetti bersaglio, il mais GM deve essere messo in coltura riservando, almeno il 20% dell'appezzamento, a varietà di mais convenzionale che costituirà l'area rifugio avente il fine di mantenere gli equilibri delle catene trofiche esistenti e non danneggiare gli insetti non bersaglio". Secondo le Linee Guida, al fine di migliorare la coesistenza (ma anche per la complessità delle procedure da seguire) possono essere necessari accordi tra gli agricoltori riguardo l'avvicendamento, le date di semina e la scelta di varietà a diversa precocità. Va, infine, considerato che sulla base delle linee guida qualora un agricoltore convertito ad OGM volesse ritornare alla coltivazione di colture convenzionali su di un terreno che nell'anno precedente aveva ospitato una specie di tipo geneticamente modificato, per i tre anni successivi e nel caso sia ripetuta la stessa coltura, questa viene considerata transgenica.

3. LA COLTIVAZIONE DI MAIS IN ITALIA

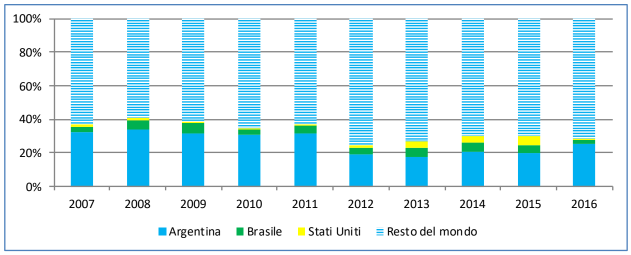
In Italia le aziende che coltivano mais sono circa 155 mila, secondo le informazioni del 6° Censimento dell'agricoltura italiana (ISTAT, 2010). Complessivamente, le superfici dedicate alla produzione di mais sono diminuite negli ultimi anni, analogamente al numero di aziende dedite a questa coltivazione. Gli ettari coltivati a mais, infatti, sono passati da 1.069.155 nel 2000 a 645.742 nel 2017; anche la produzione di mais si è ridotta, raggiungendo, nel 2017, i 61.140.970 quintali, con una flessione dell'11% rispetto al 2016. Quanto detto va riportato, da un lato, ai cambiamenti della politica agricola comunitaria che, con l'eliminazione degli aiuti accoppiati al settore dei seminativi, hanno disincentivato questa coltura. Dall'altro, anche le condizioni climatiche e l'emergenza delle aflatossine hanno inciso sulla riduzione della produzione del mais nel paese, rendendo anche meno conveniente per i produttori, soprattutto zootecnici, approvvigionarsi sul mercato nazionale e spingendo le imprese agroalimentari produttrici di alimenti a base di mais a rivolgersi, in misura maggiore, al mercato estero. Più dell'80% del mais prodotto in Italia è destinato, infatti, all'alimentazione degli animali. In tale contesto, la problematica delle aflatossine destinata all'alimentazione zootecnica è rilevante sia per la salute e il benessere degli

Fig. 1. Importazioni di mais in quantità (2000-2017), tonnellate.



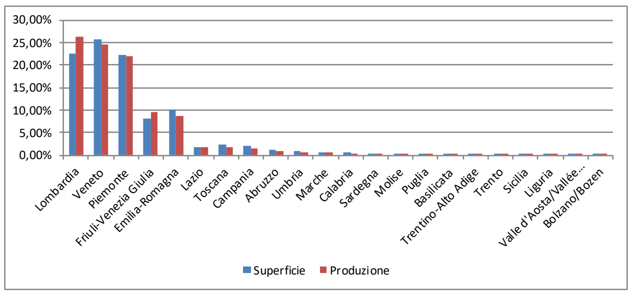
Fonte: Coeweb, ISTAT.

Fig. 2. Composizione delle importazioni di mangime dell'Italia per paese di origine dei prodotti (2007-2016), valori espressi in %.



Fonte: nostre elaborazioni su dati COMTRADE.

Fig. 3. Distribuzione della superficie e della produzione di mais in Italia (%) nel 2017.



Fonte: ISTAT.

animali che per la salute umana, considerato il consumo di alimenti di origine animale. Nel periodo 2000-2017, le informazioni sulle importazioni di mais evidenziano come le quantità di mais importate siano aumentate del 912%.

Per rispondere alle esigenze connesse all'alimentazione degli animali l'Italia ha continuato ad importare negli ultimi anni grandi quantità di mangimi e panelli sia da paesi europei (Francia, Germania, Spagna Paesi Bassi, Slovenia e Austria) che extra-europei (Argentina, Paraguay, Brasile, Stati Uniti), gran parte dei quali produttori di mais GM. A partire dal 2007, la composizione delle importazioni italiane di mangimi dal resto del mondo ha visto una dominanza dell'Argentina seguita dal Brasile e dagli Stati Uniti.

L'importazione dei mangimi contenenti OGM rappresenta una delle principali giustificazioni economiche per la coltivazione di mais transgenico in Italia, costituendo la spesa per mangimi una tra le prime voci di costo che le aziende zootecniche devono sopportare. Nell'ambito della filiera zootecnia il mais rappresenta il principale ingrediente delle diete per gli animali, per l'alimentazione dei quali si utilizzano sia la granella, come per l'alimentazione dell'uomo, ma anche sottoprodotti della coltura. Infatti, a livello regionale, la coltivazione di mais risulta prevalente specie nelle regioni settentrionali dedite alla zootecnia, in particolare in Lombardia (26%), Veneto (24%) e Piemonte (22%), che totalizzano il 70% della superficie dedicata al mais nel 2017. Al Sud e nelle isole la produzione di mais, cosi come gli ettari investiti per questa coltura, sono di gran lunga inferiori, pari rispettivamente al 4% e al 5% del totale nazionale nell'ultimo anno considerato.

4. LA CONVENIENZA ECONOMICA ALLA COLTIVAZIONE DI MAIS GM IN ITALIA

La letteratura sull'impatto dell'adozione di colture GM, a livello aziendale, è ampia e comprende studi realizzati sia a livello europeo che extra-europeo. Questo paragrafo presenta una panoramica degli studi condotti sull'impatto dell'adozione di colture GM, con particolare riferimento al mais, sia in termini di impatto sui ricavi che sui costi delle aziende, inclusa la coesistenza e le metodologie adottate nei vari casi con una sintesi dei principali risultati ottenuti.

Le rese del mais nei paesi maggiori produttori sono cresciute nel corso degli anni, in particolare in seguito all'introduzione delle colture geneticamente modificate. Infatti, i paesi che hanno una resa del mais più elevata sono gli Stati Uniti seguiti dall'Argentina, importanti produttori di mais GM. In tutti gli altri paesi, invece, le rese del mais sono mediamente più basse, in quanto in molti di essi le coltivazioni GM non sono autorizzate. Al riguardo, alcuni studi hanno evidenziato che le rese del mais Bt risultano superiori a quelle del mais non Bt in paesi quali: Stati Uniti, Spagna, Filippine e Repubblica Ceca (Areal *et al.*, 2013, Fernandez-Cornejo *et al.*, 2014, Qaim, 2009, Qaim, Zilberman, 2003). Numerosi studi sono stati condotti per valutare l'impatto dell'adozione del mais GM sulle performance aziendali, sia a livello europeo che per gli Stati Uniti. Alcuni di essi hanno effettuato confronti tra agricoltori che adottano e non adottano il mais Bt (Fernandez-Cornejo, Wechsler, 2012; Gómez-Barbero *et al.*, 2008a, 2008b; McBride, El-Osta, 2002; Pilcher, Rice, 1998; Riesgo *et al.*, 2012). In tali ricerche sono state utilizzate varie metodologie, che spaziano dal budgeting parziale a modelli econometrici. L'obiettivo di questi lavori è stato quello di valutare l'impatto della coltivazione di mais Bt sull'uso di insetticidi, sulla resa e sul margine lordo o di stimare le determinanti alla base dell'adozione del mais Bt (Areal *et al.*, 2012; Demont *et al.*, 2008a; Fernandez-Cornejo, Wechsler, 2012; Gómez-Barbero *et al.*, 2008a; McBride, El-Osta, 2002). In particolare, alcune ricerche hanno mostrato un incremento del margine lordo di coltivazione con la sostituzione del mais convenzionale con quello GM nei principali paesi coltivatori, tra cui USA, Sud Africa e Spagna (Fernandez-Cornejo *et al.*, 2014; Gouse *et al.*, 2005; Gomez Barbero *et al.*, 2008a; Hutchison *et al.*, 2010; Riesgo *et al.*, 2012), nonché in altri paesi, tra i quali Canada, Brasile, Argentina, Francia, Germania, Portogallo, Repubblica Ceca, Slovacchia, Romania, Filippine, Uruguay, Honduras, Colombia e Paraguay (Brookes, Barfoot, 2014). Uno studio condotto in Spagna su tre anni e su tre province ha, inoltre, mostrato che l'aumento delle rese derivante dall'adozione del mais Bt rispetto al mais convenzionale è, mediamente, pari al 10% (Gomez Barbero *et al.*, 2008a). Uno studio comparativo condotto in tre paesi (Italia, Spagna e Germania) sul confronto dei margini lordi di coltivazione del mais convenzionale e di quello GM ha evidenziato un incremento del margine lordo di coltivazione in tutti e tre i casi studio (Venus *et al.*, 2011). In tale ambito, sono stati considerati sia i ricavi potenzialmente ottenibili con l'impiego di mais GM sia i costi ed è stato, quindi, calcolato il margine lordo come risultato della differenza tra le due voci. L'impiego di mais GM comporta, infatti, un aumento dei costi di coltivazione dovuto all'acquisto della semente transgenica che ha, normalmente, un prezzo più elevato di quella convenzionale. I tre casi studio analizzati riguardanti Germania, Spagna e Italia hanno evidenziato un incremento del margine lordo di coltivazione: il potenziale aumento delle rese più che compensa l'aumento di spesa per l'acquisto della semente transgenica. In questo studio è stato ipotizzato un incremento delle rese ottenibili con mais GM pari all'8,7%: questo valore è sicuramente cautelativo, in quanto altri studi hanno mostrato un aumento delle rese, con mais GM, anche del 15% (Riesgo *et al.*, 2012 Degenhardt *et al.*, 2003). La metanalisi condotta da Klumper e Qaim (Klumper, Qaim, 2014) su 147 studi relativa all'impatto delle colture GM di soia, mais e cotone mostra che, in media, le colture GM incrementano le rese del 22% e i profitti degli agricoltori del

68%, riducendo i costi legati all'uso dei pesticidi del 37%. L'aumento delle rese e la riduzione dell'uso dei pesticidi è, in particolare, maggiore nel caso delle varietà OGM resistenti agli insetti. Inoltre, tra i costi delle coltivazioni GM, un ruolo di primo piano è rappresentato dai costi per assicurare la coesistenza tra queste tipologie di colture e quelle convenzionali o biologiche. Demont *et al.* (2008b) hanno mostrato come elevate distanze di isolamento, tra colture GM e non GM, scoraggino le imprese dall'adottare colture GM, generando un effetto domino. Quest'ultimo si riduce con la creazione di aree cuscinetto che possono essere applicate in modo più flessibile (Demont *et al.*, 2009). Talvolta i costi connessi alla coesistenza possono essere ridotti, attraverso accordi o altre soluzioni, volte a favorire la cooperazione tra gli agricoltori (Devos *et al.* 2009; Skevas *et al.* 2009; Consmuller *et al.* 2009). Infine, mentre in passato si riteneva che l'utilizzo di sementi GM potesse ridurre la spesa per diserbanti, essendo le piante GM meno soggette all'attacco di agenti fitopatogeni, la letteratura più recente ha evidenziato come, al contrario, tale spesa possa aumentare per la maggiore resistenza agli erbicidi delle coltivazioni geneticamente modificate. In particolare, la discussione maggiore verte attualmente sul glifosato, la sostanza attiva utilizzata in molti erbicidi venduti su scala mondiale. Gli OGM, appositamente modificati per essere resistenti al glifosato, sono conosciuti come "Roundup Ready" (RR). Queste varietà OGM/RR permettono agli agricoltori di irrorare le coltivazioni con l'erbicida, con l'obiettivo specifico di eliminare, in un colpo solo, praticamente tutte le erbe infestanti, senza intaccare le coltivazioni. Alcuni studi condotti negli Stati Uniti hanno verificato un aumento dell'uso di erbicidi dopo l'introduzione di colture GM (Food and water watch, 2013). I dati forniti da USDA hanno, infatti, confermato che la rapida adozione di colture GM, da parte degli agricoltori, ha incrementato l'utilizzo di erbicidi negli ultimi 9 anni negli Stati Uniti. Gli stessi risultati sono stati confermati da altri studi: in particolare, Benbrook (2012) ha analizzato l'evoluzione dell'utilizzo di erbicidi nel corso di 16 anni (1996-2011), verificandone un incremento complessivo del 7%. Ai costi derivanti dall'uso del glifosato, ma anche alla coesistenza tra coltivazioni GM e non GM, si uniscono altresì le misure amministrative che possono tradursi in ulteriori costi a carico degli agricoltori (Rizov *et al.*, 2014). Tra questi un esempio è dato dal costo per ottenere la certificazione per la crescita di colture GM, che dipende anche dal paese in cui la coltivazione viene realizzata. Inoltre, l'adozione delle colture GM potrebbe comportare un considerevole aumento della quantità offerta e determinare, di conseguenza, una diminuzione dei prezzi dei prodotti (Barrows *et al.*, 2014)

La diffusione di colture GM è legata a caratteristiche specifiche delle aziende e degli agricoltori ma anche al costo dell'innovazione stessa. Al riguardo, Griliches (1960) ha evidenziato come siano le variabili economiche a determinare il cambiamento tecnologico. Fernandez-Cornejo *et al.* (1998) hanno mostrato come aziende di maggiori dimensioni, guidate da agricoltori più istruiti, avessero risposto positivamente all'adozione di mais HT. Sulla stessa linea, Fernandez- Cornejo e Mcbride (2002) hanno analizzato un campione di aziende statunitensi evidenziando come l'adozione di mais HT fosse positivamente correlata alla dimensione dell'impresa. Ulteriori fattori, che incidono sulla decisione di impiegare o meno la semente GM, sono anche il grado di avversione al rischio da parte degli agricoltori e l'esposizione ad attacchi da parte di agenti fitopatogeni, che possono causare perdite del raccolto (Hyde *et al.*, 1999). Infine, Areal *et al.* (2013) sottolineano come l'impiego di sementi GM porterebbe gli agricoltori ad essere maggiormente dipendenti dalle multinazionali produttrici di queste innovazioni.

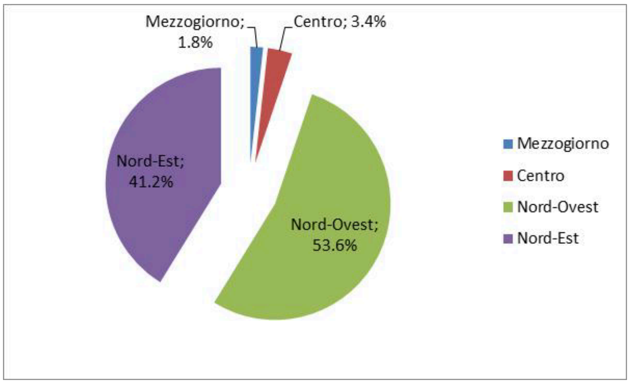
6. LA DESCRIZIONE DEL CAMPIONE

Come più sopra anticipato, l'analisi della convenienza economica alla coltivazione di OGM, in Italia, è stata effettuata attraverso l'utilizzo del campione Rete italiana di contabilità agricola (RICA)[7], che permette di avere informazioni sulle aziende agricole italiane, con dettaglio dei costi sostenuti sia le per coltivazioni che per gli allevamenti. In particolare, l'analisi è stata condotta sul campione delle aziende cerealicole, specializzate nella coltivazione di mais, con un valore della superficie agricola utilizzata, investita con questa tipologia di coltura, pari o superiore al 40% del totale nel triennio 2013-2015. Si tratta complessivamente di 1.018 aziende, collocate principalmente nelle regioni del Nord-Ovest (54%) e del Nord-Est (41%). Le aziende situate al Centro costituiscono, invece, il 3% del totale mentre quelle collocate al Sud e isole rappresentano la parte rimanente (2%).

Le aziende del Nord, soprattutto quelle localizzate nelle regioni del Nord-Ovest, ottengono i risultati economici migliori in termini di produzione lorda vendibile, di valore aggiunto netto e di reddito netto, mentre quelle ubicate nel Mezzogiorno sono, invece, caratterizzate da risultati economici più bassi. In particolare, la produzione lorda vendibile delle aziende collocate al Nord-Ovest supera gli 80.000 euro per azienda, mentre quella delle aziende del Nord-Est e del Centro supera i 70.000 euro.

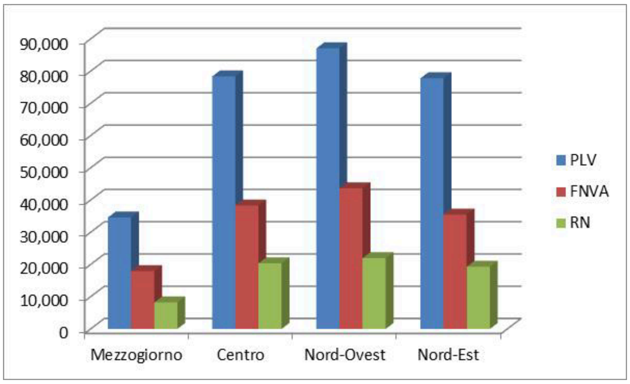
[7] La RICA ha come principale obiettivo il monitoraggio annuale dei redditi delle aziende agricole e la diffusione dei risultati sia agli operatori del settore che ai singoli cittadini.

Fig. 4. Collocazione geografica delle aziende cerealicole specializzate nella coltivazione di mais (medie 2013-2015), valori espressi in %.



Fonte: nostre elaborazioni su dati RICA 2013-2014-2015.

Fig. 5. Risultati economici delle aziende cerealicole specializzate nella coltivazione di mais (medie 2013-2015), valori espressi in euro.



Fonte: nostre elaborazioni su dati RICA 2013-2014-2015.

I risultati economici delle aziende collocate al Sud e nelle isole sono molto più bassi, con una PLV di poco superiore ai 30.000 euro in media. Quanto detto dipende, in parte, dalla maggiore specializzazione delle aziende settentrionali nella coltivazione di mais, rispetto alle realtà aziendali ubicate nelle regioni centrali e meridionali, ma anche alla dimensione ridotta delle aziende di queste ultime rispetto alle prime. Le aziende collocate al Nord-Ovest ed al Nord-Est hanno, in media, una dimensione fisica maggiore rispetto a quelle collocate nel resto d'Italia: la SAU è, mediamente, pari a 53 e 50 ettari, rispettivamente nelle aziende collocate al Nord-Ovest e al Nord-Est, mentre nel resto d'Italia la SAU media è pari a 44 ettari. Per quanto riguarda, invece, sia il valore aggiunto netto che il reddito netto, la differenza tra le varie circoscrizioni e, in particolare, tra il Nord e le regioni del Mezzogiorno è più attenuata, considerando i valori assoluti, rispetto a quella che si riscontra per la PLV. Infatti, le aziende collocate nelle regioni meridionali e insulari registrano un valore aggiunto netto pari, in media, a 18.000 euro e un reddito netto per azienda di circa 8.000 euro nel periodo. Per le aziende del Nord-Est il valore aggiunto netto sale a 36.000 euro, in media, ma il reddito netto registra un valore di appena 19.000 euro nel periodo 2013-2015. Le regioni del Nord-Ovest, al contrario, mostrano un valore aggiunto netto per azienda di circa 40.000 euro e un valore del reddito netto pari a circa 21.000 euro per azienda.

Inoltre, l'analisi del peso della spesa per sementi, difesa e concimi sui costi variabili di produzione, per le aziende del campione considerato, evidenzia che la spesa per concimi è quella che maggiormente incide in tutte le circoscrizioni geografiche. Tuttavia, essa supera il 38% dei costi variabili per le aziende situate al Nord-Est, mentre si colloca intorno al 30% per tutte le altre realtà regionali. Inoltre, la spesa relativa alla difesa, che include i diserbanti e antiparassitari è, in media, inferiore nelle regioni meridionali e insulari (8%), mentre raggiunge il 17% nelle altre circoscrizioni geografiche. Infine, la spesa per le sementi si attesta intorno al 25% dei costi variabili in tutte le aziende del campione analizzato[8].

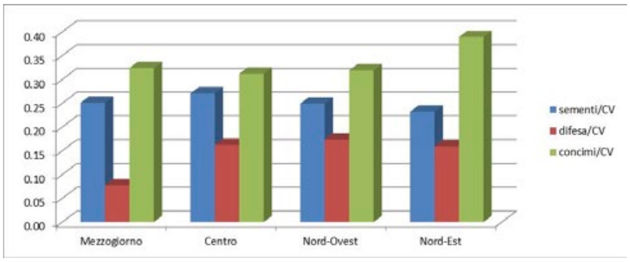
Suddividendo le aziende considerate nelle seguenti 4 classi di SAU: aziende con meno di 5 ettari, aziende con coltivazioni tra 5 e 15 ettari, aziende con SAU compresa tra 15 e 40 ettari ed, infine, aziende con più di 40 ettari, l'analisi mostra che i risultati economici tendono a crescere man mano che le dimensioni aziendali aumentano.

Infatti, le aziende che registrano i risultati economici peggiori sono quelle ricadenti nella classe di SAU inferiore a 5 ettari, mentre quelle con valori della produzione lorda vendibile, valore aggiunto netto e reddito netto più elevati riguardano le aziende con classe di SAU superiore a 40 ettari. Quanto detto va considerato nell'analisi della convenienza economica alla coltivazione del mais GM, poiché quest'ultima potrebbe essere legata alle dimensioni aziendali. Infatti, la riduzione della superficie coltivabile, derivante dalla necessità di rispettare le regole della coesistenza, tra colture convenzionali e GM, potrebbe incidere in maniera non omogenea sui vari gruppi di aziende, determinando così scenari differenti per le aziende di piccole, medie e grandi dimensioni.

Rispetto alla struttura dei costi aziendali sembra essere presente una correlazione tra dimensione aziendale e incidenza dei costi variabili di produzione. Infatti, la

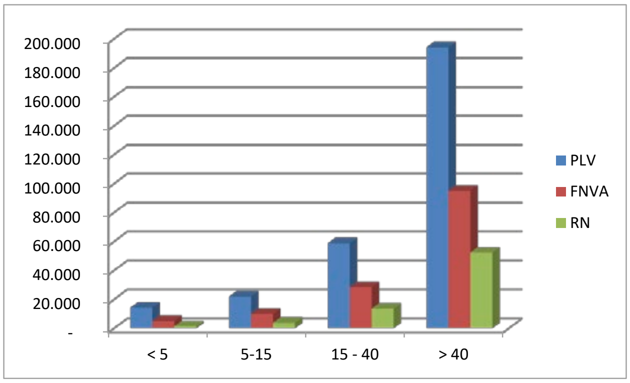
[8] Le tre voci di spesa non costituiscono il totale delle spese aziendali. Infatti, esiste una voce residua, comprendente gli altri costi aziendali, che non è stata riportata nei grafici 6 e 8.

Fig. 6. Incidenza delle principali voci di costo sui costi variabili per le aziende cerealicole specializzate nella coltivazione di mais per circoscrizione geografica, (media 2013-2015).



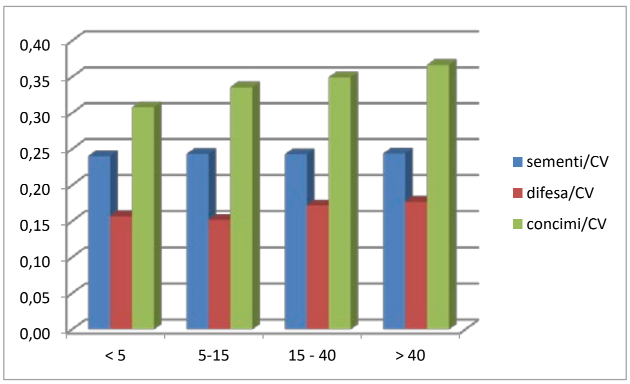
Fonte: nostre elaborazioni su dati RICA 2013-2014-2015.

Fig. 7. Risultati economici delle aziende cerealicole specializzate a mais per classi di SAU (media 2013-2015), valori espressi in euro.



Fonte: nostre elaborazioni su dati RICA 2013-2014-2015.

Fig. 8. Incidenza di sementi, concimi e difesa sui costi variabili delle aziende cerealicole specializzate a mais per classe di SAU, valori medi del periodo 2013-2015.



Fonte: nostre elaborazioni su dati RICA 2013-2014-2015.

voce di spesa relativa ai concimi si conferma essere quella che pesa di più sul totale dei costi variabili delle aziende, suddivise nelle diverse classi dimensionali, ma la sua incidenza tende a crescere all'aumentare della superficie agricola utilizzata dalle stesse. Analogamente, il peso dei costi relativi alla difesa, sul totale dei costi variabili, è più elevato al crescere della dimensione dell'impresa. Infine, l'incidenza della spesa legata alle sementi è, sostanzialmente, equivalente per tutte le aziende distribuite nelle varie classi di SAU.

7. LA METODOLOGIA ADOTTATA

La simulazione, effettuata sul campione di aziende appena descritto, ha riguardato gli effetti complessivi dell'utilizzo del mais GM in sostituzione di quello convenzionale, calcolato come variazione del margine lordo di coltivazione. Nel lavoro si ipotizza una sostituzione completa del mais convenzionale con quello GM, anche se la letteratura economica sul tema sottolinea come l'adozione di questa innovazione sia legata a fattori specifici sia degli agricoltori (età, titolo di studio) che delle imprese (dimensione ecc.). Inoltre, ai fini della simulazione, si è ipotizzata una resa del mais GM più elevata di quella del mais convenzionale di circa l'8%. Questo valore, come specificato più sopra, è cautelativo in quanto numerosi studi hanno mostrato un incremento della resa ottenuta con mais GM di gran lunga più elevata. La spesa per le sementi per ciascuna azienda è stata rivista al rialzo, ipotizzando un costo addizionale unitario, dovuto all'adozione della semente GM, pari a 23 euro (Venus *et al.*, 2011)[9]. La spesa per i fertilizzanti e quella per antiparassitari/diserbanti è stata, invece, rivista al ribasso del 10%, in quanto l'adozione del mais GM permette una diminuzione dei costi sia per la fertilizzazione che per i diserbanti, secondo quanto indicato dalla letteratura prevalente. Solo più recentemente, infatti, si è aperto un nuovo filone di ricerca secondo il quale l'adozione della semente GM comporterebbe un aumento della spesa per diserbanti (Benbrook *et al.*, 2012).

Al fine di rispettare le regole della coesistenza, è stata ipotizzata una perdita di SAU, necessaria per mantenere la distanza tra coltivazioni GM e non GM, cosi come previsto dalle regole contenute nelle linee guida stabilite dalla Conferenza Stato Regioni del 2007. In tale ambito, sono stati esaminati due diversi scenari di coesistenza:

Scenario 1. Con perdita di SAU pari a circa il 30%, necessaria per rispettare la distanza di 300 metri tra coltivazione GM e non GM e mantenere la presenza di

[9] Nello studio preso a riferimento di ipotizza un costo addizionale unitario pari a 23 euro per unità corrispondente a 50000 semi.

Tab. 1. Ipotesi alla base della simulazione del Margine Lordo di coltivazione del mais GM**.**

Ipotesi adottate	
Costo unitario sementi GM	23 euro
Spesa antiparassitari coltivazione GM	*-10%*
Spesa fertilizzanti coltivazione GM	*-10%*
Resa GM	*+8%*
SAU coltivata con mais GM	*70%* del totale nello scenario 1 *50%* del totale nello scenario 2
SAU coltivata con mais convenzionale (area cuscinetto)	*20%* del totale

Tab. 2. Scenari analizzati nella simulazione del margine lordo (ML).

	Scenario 1 *<0,9%*	Scenario 2 *<0,01%* ("zero tecnico")
SAU coltivata con mais GM	*70%* della SAU totale	*50%* della SAU totale
SAU coltivata con mais convenzionale (area cuscinetto)	*20%* della SAU totale	*20%* della SAU totale

OGM in coltivazioni non GM al di sotto della soglia dello 0,9%.

Scenario 2. Con perdita di SAU pari al 50% per rispettare la distanza di 1000 metri, tra coltivazione GM e non GM, necessaria per mantenere la presenza di OGM in coltivazioni non GM al di sotto della soglia dello 0,01% (zero tecnico).

La perdita di superficie coltivabile è, in parte, compensata in entrambi i casi dal fatto che la normativa prevede la necessità di coltivare con mais convenzionale l'area di confine tra le colture OGM e convenzionali (zone cuscinetto). La produzione in essa realizzata viene considerata come parte della produzione transgenica.

Per ciascuna azienda è stato quindi calcolato il margine lordo di coltivazione, realizzato con il mais convenzionale e con il mais GM, sulla base delle ipotesi discusse in precedenza. Il margine lordo di coltivazione è stato calcolato sottraendo dalla produzione lorda vendibile i costi espliciti di coltivazione. Per il calcolo del margine lordo ottenibile, nei differenti scenari, è stata seguita la metodologia applicata da Venus (Venus *et al.*, 2011). Nello specifico, la formula applicata per il calcolo del margine lordo è la seguente:

ML=PLV-(spesa semente +spesa diserbanti +spesa fertilizzanti)

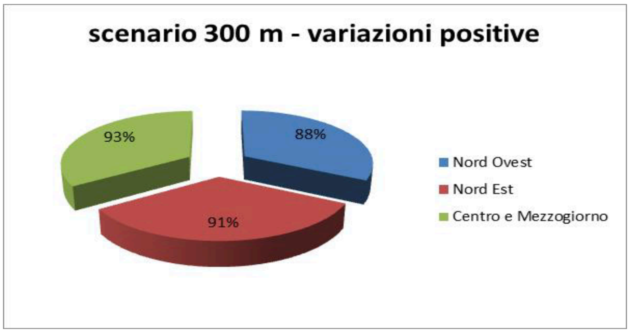
La formula utilizzata per il calcolo del margine lordo guarda solo agli effetti diretti della sostituzione della semente convenzionale con quella GM, in termini di rese e costi direttamente associati alla coltura del mais, senza considerare l'effetto complessivo che tale sostituzione potrebbe comportare sul bilancio aziendale. In particolare, viene mantenuto costante l'impiego di lavoro, anche se è ipotizzabile una variazione delle ore lavorate nel caso della produzione di mais GM, per i diversi costi collegati all'adozione di questa tecnologia (minore necessità di applicare diserbante per esempio). Viene, altresì, mantenuta costante la spesa per i reimpieghi che, per molte aziende con coltivazione di mais, comprende quella sostenuta per l'autoproduzione della semente. Quest'ultima, infatti, potrebbe ridursi con l'adozione della semente GM, che, diversamente da quella convenzionale, non può essere autoprodotta. Infine, viene mantenuta costante la spesa per l'energia dato che, le informazioni disponibili a livello aziendale, non consentono di avere maggiori dettagli sui costi per tipologia di impianti presenti in azienda (efficienza degli impianti di irrigazione ecc.). Analogamente, non viene considerato il diverso fabbisogno idrico delle colture GM rispetto a quelle non GM, considerando che quest'ultimo potrebbe variare in rapporto alle condizioni pedoclimatiche dell'area in cui è ubicata l'azienda. Infine, non si tengono in considerazione le possibili interazioni tra le variabili che compongono il margine lordo, che risultano complesse da analizzare sulla base della metodologia adottata. Come sottolineato in precedenza, il lavoro si configura come un'indagine preliminare, relativa ai possibili effetti dell'adozione della semente GM sui risultati economici delle aziende agricole italiane.

8. RISULTATI

I risultati, ottenuti con le simulazioni effettuate, mostrano che la variazione del margine lordo di coltivazione, con l'adozione del mais GM, è negativa per gran parte delle aziende con SAU inferiore a 5 ettari. In particolare, il 76% di esse, collocate nelle regioni del Nord-Ovest, presenta variazioni negative del margine lordo nello scenario relativo ai 300 m di distanza, valore che sale all'88% nello scenario dello zero tecnico. Per le piccole aziende, ubicate nel Nord-Est, tale percentuale è più bassa, pari al 36% con una distanza di 300 metri e al 55% nello scenario dello zero tecnico[10]. Quanto detto conferma

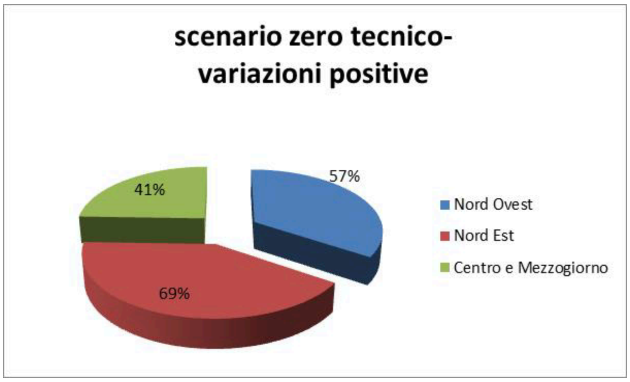
[10] Il risultato ottenuto con le simulazioni effettuate sulle piccole aziende, nelle altre circoscrizioni geografiche, conferma quello registrato per le

Fig. 9. Percentuale di aziende con variazioni positive del margine lordo di coltivazione con mais GM per circoscrizione nello scenario dei 300 m. Medie 2013-2015. Solo aziende superiori ai 5 ha.



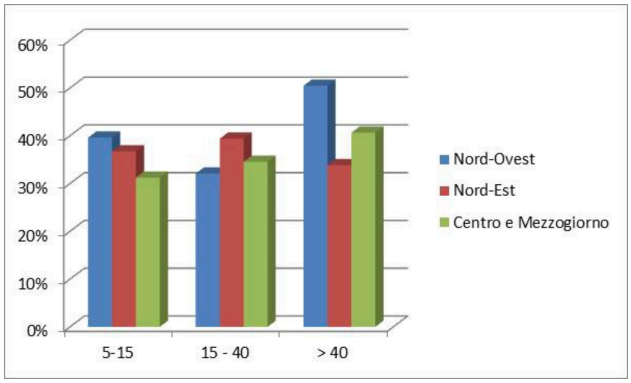
Fonte: nostre elaborazioni su dati RICA 2013-2014-2015.

Fig. 10. Percentuale di aziende con variazioni del margine lordo di coltivazione con mais GM per circoscrizione nello scenario dello zero tecnico. Medie 2013-2015. Solo aziende superiori ai 5 ha.



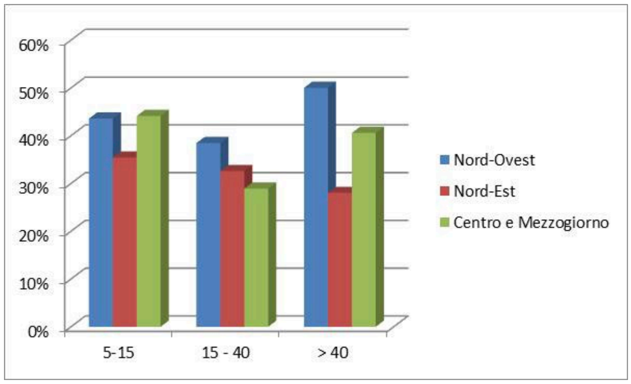
Fonte: nostre elaborazioni su dati RICA 2013-2014-2015.

Fig. 11. Variazioni del margine lordo di coltivazione con mais GM per circoscrizione e per classe di SAU nello scenario dei 300 m. Medie 2013-2015.



Fonte: nostre elaborazioni su dati RICA 2013-2014-2015.

Fig. 12. Variazioni del margine lordo di coltivazione con mais GM per circoscrizione e per classe di SAU nello scenario dello zero tecnico. Medie 2013-2015



Fonte: nostre elaborazioni su dati RICA 2013-2014-2015

quindi che, per questo gruppo di aziende, esiste poca convenienza a coltivare mais GM, specie nello scenario dello zero tecnico, in quanto la perdita di superficie impatta in modo negativo sui risultati da esse ottenuti. Per le rimanenti aziende del campione, che superano i 5 ettari di SAU, invece, i risultati ottenuti mostrano che, nello scenario relativo ai 300 m, la percentuale di aziende con variazioni positive del margine lordo è pari a circa il 90% in tutte le aree geografiche (Fig. 9). Nello scenario relativo allo zero tecnico, invece, tale convenienza riguarda poco più della metà delle aziende del campione (Fig. 10).

Infine, l'analisi della distribuzione per classi di SAU per circoscrizione geografica, per le sole aziende che superano i 5 ettari di superficie, evidenzia come la convenienza a coltivare mais GM si accresca con l'aumentare delle dimensioni fisiche dell'azienda. Infatti, la classe di aziende con SAU superiore a 40 ettari registra, in media, una convenienza maggiore a coltivare mais GM rispetto alle aziende delle classi inferiori (Figg. 11 e 12). Inoltre, le aziende situate al Nord-Ovest, nella classe di SAU più elevata, mostrano un incremento medio del 50% del margine lordo di coltivazione ottenuto con mais GM.

Ciò evidenzia come le aziende tradizionalmente vocate alla coltivazione del mais, ovvero quelle ubicate nelle regioni del Nord Italia e di dimensioni più elevate, potrebbero beneficiare, in misura maggiore, della coltivazione di mais GM, soprattutto con l'adozione dello

aziende settentrionali, anche se la percentuale di esse, collocate in tali aree, è molto piccola (2%) e quindi poco rappresentativa ai fini del presente studio.

scenario meno restrittivo, che prevede una distanza di 300 m tra le coltivazioni.

9. CONCLUSIONI

A livello internazionale sono stati condotti numerosi studi volti a esaminare la convenienza economica delle colture GM; contrariamente, nel contesto nazionale, è stata prodotta poca letteratura sul tema. Per questo motivo, la simulazione condotta sulle aziende agricole specializzate nella coltivazione maidicola, appartenenti al campione RICA, consente di arricchire con nuovi elementi il panorama delle ricerche esistenti in materia. L'analisi è stata realizzata calcolando la differenza tra margine lordo di coltivazione, ottenuto con mais convenzionale e con mais GM, sotto le ipotesi di riduzione della superficie coltivata necessaria per il rispetto dei limiti imposti dalla coesistenza. Dai risultati è emersa la convenienza a coltivare mais transgenico, soprattutto nello scenario meno rigido, che richiede una distanza, tra colture GM e non GM, di 300 metri. L'analisi svolta ha quindi evidenziato che esiste un vantaggio, nel passaggio dalla coltivazione convenzionale a quella GM, per le aziende di dimensioni maggiori, collocate nelle regioni tradizionalmente più vocate alla coltivazione di mais. Tale vantaggio è, invece, più piccolo per le aziende collocate fuori di tali aree. In tale ambito, va considerato che l'analisi realizzata ha un carattere preliminare, tenendo conto dei soli benefici diretti associati alla coltivazione di mais GM. Tra i principali limiti dello studio va ricordato, infatti, che non sono considerati gli effetti connessi alla variazione del lavoro impiegato a livello aziendale, conseguente all'adozione di colture transgeniche, ma anche l'ipotesi di costanza della spesa aziendale sostenuta per l'energia utilizzata. Quest'ultima è, a sua volta, connessa anche al diverso fabbisogno idrico delle colture GM rispetto a quelle convenzionali e risulta variabile in rapporto alla localizzazione geografica dell'azienda, oltre che ad altre caratteristiche aziendali (es: efficienza degli impianti irrigui). Ulteriori indagini, a livello microeconomico, in particolare su un campione di aziende, rappresentativo di un'area geografica più vocata alla coltivazione maidicola, permetterebbero di sviluppare i risultati di questo studio, tenendo conto dei fattori trascurati in questa sede. Inoltre, altri approfondimenti, sulla base della recente letteratura sul glifosato, consentirebbero una valutazione più ampia delle conseguenze delle colture GM sull'ambiente.

La normativa comunitaria, attualmente in vigore, permette agli Stati Membri di scegliere liberamente se consentire la coltivazione di OGM sul proprio territorio, a condizione di impiegare sementi GM autorizzate per la coltivazione a livello europeo. L'Italia ha notificato il suo divieto di coltivare OGM su tutto il territorio nazionale, anche se alle regioni è data la possibilità di assumere una diversa posizione rispetto allo stato centrale. Una scelta a livello decentrato permetterebbe cosi di tenere maggiormente conto della situazione territoriale, che risulta di particolare importanza vista la diversa rilevanza della coltura del mais nelle regioni italiane, ma anche le differenti condizioni pedoclimatiche con le quali esse si devono confrontare. L'adozione della semente GM potrebbe comportare un abbattimento di parte dei costi di produzione e un aumento dei ricavi per le aziende, specie nelle regioni settentrionali, più specializzate nella coltivazione maidicola, considerata anche l'incidenza della problematica delle aflatossine in queste aree, che impedisce l'utilizzo di gran parte del mais ivi coltivato. Quanto detto potrebbe, d'altra parte, portare ulteriori benefici per le aziende che combinano coltivazioni e allevamenti. In quest'ultimo caso la riduzione dei costi potrebbe essere più elevata di quello stimata nel lavoro, che non tiene conto della riduzione dei costi connessi alla preparazione dei mangimi per gli animali.

Va, infine, considerato che, in seguito alla riforma della PAC che ha eliminato quasi completamente gli aiuti accoppiati per i seminativi, c'è stata una progressiva riduzione delle superfici coltivate a mais in Italia, con un incremento delle importazioni di questo prodotto da altri paesi, in particolare per uso mangimistico. La possibilità di impiegare sementi GM di mais sul territorio italiano, potrebbe permettere la sostituzione, anche solo parziale, del mais importato, gran parte già GM, con quello prodotto sul territorio nazionale. Quanto detto consentirebbe un recupero di competitività per le aziende agricole italiane, anche in considerazione del fatto che alcune di quelle, ubicate in altri paesi europei, possono già beneficiare di questa innovazione. Si tratta degli operatori economici di Spagna, Portogallo, Repubblica Ceca e Romania i quali, già da diversi anni, impiegano la semente di mais GM. Ciò significa che la possibilità di coltivare mais GM consentirebbe di aprire nuove opportunità per le aziende agricole italiane di cui il decisore pubblico potrebbe tener conto per la definizione dei futuri orientamenti di policy.

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Book review

C. Besana, R. D'Errico & R. Ghezzi (eds.)
Cheese Manufacturing in the Twentieth Century. The Italian Experience in an International Context.
European Food Issues, P.I.E. Peter Lang, Bruxelles, 2017, pp. 406.

When approaching to the food sector, we need to consider and keep into account certain features that, despite not being new, still present innovative characters due to the particular situation in which they are evolving: The present food system (to say better: the several food systems interacting together) is multi-dimensional, globalized and interdisciplinary.

For what concern the first character, the agri-food sector entails a complex, multi-sectoral and multi-dimensional nature, as the food systems concern several heterogeneous interests and factors combing together (agricultural traditions and techniques; consumers' interests; economic production; trade; the environment; cultural believes, local tradition, malnutrition and the right to access to food; enhancement of quality and so on and so forth). The public governance of food safety, for instance, does not regard only the protection of health and the salubriousness of food and feed products, but also concerns and influences the regulation of other fields of society, such as trade of goods, consumers' information and expectations, protection of the environment, the development of agriculture and food security. Coherently, the International Assessment of Agricultural Knowledge Science and Technology for Development defines agriculture – that is evidently strongly connected to food production – as a *multifunctional* sector:

"Agriculture operates within complex systems and is multifunctional in its nature (…). Multifunctionality recognizes the inescapable interconnectedness of agriculture's different roles and functions, i.e. agriculture is a multi-output activity producing not only commodities, but also non commodity outputs such as environmental services, landscapes amenities and cultural heritages". (International Assessment of Agricultural Knowledge, Science and Technology for development (IAASTD), *Towards Multifunctional Agriculture for Social Environmental and Economic Sustainability. Issues in Brief*, unpaged, 2009).

Secondly, food systems are globalized, as food is produced, manipulated and traded all over the world with less and less obstacles: the globalization of markets, reducing or eliminating barriers to trade has favored the movement of food items all over the world, so that this sector has reached a strongly developed extra-national character. This needs common approaches, common rules, common visions: it needs harmonization and standardization. With the globalization of trade and the European common market, everything that concerns food must take into account the necessity to look at a common and shared global/regional (EU) space that goes beyond the State and responds to its own cultural, legal, economic and social rules. Such "food globalization", however, is not away from controversies and conflicts, as food is, at the same time, authentically local, as it is strongly and for tradition connected to the territory where it is produced and transformed. This causes a complex dialectic between a global and worldwide approach and the national and local differences and diversities, between homogenization on one side and traditions on the other.

Thirdly, the agri-food sector implies the interaction of several disciplines dialoguing among one other. Then we see: technical and hard-sciences' norms; civil law limitations, prescriptions of a penal-law nature, administrative regulations; cultural and traditional conditions; economic and social relationships among the actors involved. Therefore, food is not only multi-sectorial and extra national, but also interdisciplinary, as it needs to rely on the contribution of several scientific disciplines in order to have a clear and complete picture of the reasons why food is produced, transformed, sold and consumed in certain ways (on these three aspects allow me to mention D. Bevilacqua, *Introduction to Global Food-Safety Law and Regulation*, Groningen, Europa Law Publishing, 2015, p. v ff.).

The book "*Cheese Manufacturing in the Twentieth Century*" has the merit to keep in consideration all the three described characters of food, thus being a very useful tool for every scholar approaching to the study of this sector, as well as for any actor wanting to go deep into a specific sub-sector, such as the production of cheese and the dairy industry.

Firstly, it is interdisciplinary, with a detailed and technical approach coming from several authors, belonging to different scientific contexts (e.g. historians, economists, agronomists).

Secondly, it has a special consideration and attention for the international character of production and trade of food products. In addition, the authors use the comparative method in order to better define positive and negative aspects of the present methods of cheese manufacturing in Italy and in similar contests.

Finally, while concentrating on the specific sector of cheese manufacturing, entering in details and going deep in the analysis, the authors do not renounce to provide general considerations on food production in the XXI century, thus on innovation, on industrialization, on local typical products and on globalization; showing all the different interest and factors that we must consider when we approach such a theme.

As declared by the editors in the *Introduction*, the aim of the book is to stimulate further interest in the subject and inviting scholars to orient their research towards some of the underlying themes indicated in the titles of the volume's three sections (p. 22).

The chapters included in the first section ("The Experience of Different Nations during the Age of Globalization") compare various national scenarios in the midst of a period of transformation, when great technological advances were being made and markets were progressively becoming globalized. This first part is more international-oriented and use a comparative method to investigate the most important changes of last decades in the Dairy industry in Italy (p. 71 ff.) and in other countries (pp. 33 ff, 53 ff., 113 ff. and 129 ff.). A consideration is given to the EU institutions and their influence on the Italian Dairy Sector (p. 95 ff.) and a special focus is dedicated to a smaller reality, that of a city: namely, New York (p. 143 ff.).

The theme that brings together the chapters contained in the second section ("Terroir, Typicality and Market Openness") is the relationship between tradition, authenticity and innovation. This section shows, in a very interesting and problematic way, the dialectic between the need to preserve and protect the authenticity of local traditions and, at the same time, the will to conform to the industrialized and standardized approach of a global food market, trying to investigate if and when the protection of typicity becomes an unjustified barrier to the promotion and spread of a traditional cheeses. The chapters composing the second part of the book dedicate their attention to the history of a small group of cheeses that, while playing a prominent role in international trade, can also be considered typical expressions of unique local conditions and of ancient traditions that cannot be reproduced elsewhere.

The chapters included in the third section ("Forms of Enterprises in Italy in the Nineteenth and Twentieth centuries") highlight the changes occurring in Italy's dairy sector during the nineteenth and twentieth centuries, by tracing the history of some of its most important companies and describing the unique structures adopted by businesses operating in this sector. If the second part was dedicated to typical and artisanal production and traditions, the third part focuses on the industries, underlining their driving role for the whole sector and their contribution in the development of cheese production, not only in terms of quantity, but also for what concerns quality and promotion of typical products.

An important consideration – which could have been developed more in the book – concerns the necessity of having common (i.e. global) rules to protect and guarantee high quality standards and an exhaustive consumers' information about food: the need to import foreign raw materials to be transformed into typical food is not a problem *per se*; however, it could produce a diminution of food quality if the importing products are not controlled and assessed as they should be. For these reasons, we need uniformity and common rules of quality protection, but these must entail high standards and efficient mechanisms of enforcement. In addition, they can be adopted and implemented only if the same approach is shared and agreed; and this is a sector in which many different voices coexist and bargain.

All the mentioned themes and issues are well combined together, with an original and courageous approach, able to show contradictions and mythologies of the general opinion on food quality and on typical products. Moreover *Chees Manufacturing in the Twentieth Century* is clear, full of data and information and, despite being a collective book, it maintains a certain uniformity and coherence, which is another merit making it worthy of being read.

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