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Abstract

Vegetable oil market is becoming of increasing interest in the global biofuel industry. This phenomenon has also interested the European Union (EU), where the growing expansion of biofuel production is affected by political interventions promoting fuel security and environmental goals. Yet, empirical evidence on the impacts that changes in price of one commodity may have on the supply of another commodity are rather scant. We investigate these dynamics for the major sources of biodiesel in the EU and conclude on cross-commodity linkages for palm, rapeseed, soy, and sunflower oils. We also examine the acreage response of domestically produced feedstocks to changes in prices of vegetable oils. Our findings suggest strong and diversified path dependencies among vegetable oils that should be considered in planning sustainable biofuel policies. In particular, the empirical analysis reveals the great relevance of sunflower and soy oils, which show a high price responsiveness, and the high competition in end uses of domestically produced vegetable oils (i.e. rapeseed, soy, and sunflower oils), that tend to be net substitutes in supply. In terms of land use effects, we find that an increase in the price of imported palm oil results in a displacement effect in land devoted to rapeseed cultivation, whereas a surge in the price of sunflower oil decreases the use of land for rapeseed. Land use effects would be relevant in northern EU countries where the production of rapeseed is the most intense. A policy measure in the EU, incentivising the production of renewable and environmental-friendly fuel from sustainable feedstocks, would be positive for the domestic market to the extent that it stimulates the production of vegetable oils (soy and sunflower oils) with the highest direct and indirect emissions saving. However, the expansion of oil palm plantations in extra-EU producing countries and of imports to the EU would determine important impacts in terms of indirect land use change emissions and direct emissions due to increased transports.

Keywords: Biofuel; Land Use Change; Price elasticity; Vegetable oils.

JEL codes: O13, P28, Q21, Q42.

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Price responsiveness of supply and acreage in the EU vegetable oil markets: policy implications

1. Introduction

Global warming issue due to the combustion of fossil fuel pushes the world to produce renewable and environmental-friendly fuel from sustainable feedstock. Accordingly, the production of biofuel experienced a substantial increase over the last decades (OECD-FAO, 2019). This increase has been mostly driven by biofuel policies implemented in dominant economies, such as the Unites States (US), the European Union (EU), Brazil (Oliveira et al., 2017). The main scope of these policies is to favour the use of biofuels, in order to reduce the dependency on fossil fuels and greenhouse gas (GHG) emissions (OECD, 2008), although their net impact also depend on GHG emissions from indirect land use change (ILUC)[1] (Searchinger et al., 2008; Britz and Hertel, 2011). Indeed, some biofuels are successful in addressing environmental concerns, but some others create scepticism on their global sustainability (Humalisto, 2015).

Biofuel policies have a great impact on the vegetable oil sector, the major source of first-generation biodiesel. In 2018, about 77% of biodiesel was based on vegetable oils (30% soybean oil, 25% palm oil, 18% rapeseed oil) and about 12% of global vegetable oil supplies went to biodiesel production (OECD-FAO, 2019). Using biodiesel to increase the share of renewable and sustainable alternative for conventional fuels may be both beneficial and detrimental (IMF, 2007). Biodiesel may have impacts on environmental, economic and social dimensions of sustainability (Singh and Singh, 2010). By lowering countries' reliance on fossil fuels, it contributes to mitigate their GHG emissions, increase the competitiveness of their production, expand employment and promote rural development and social welfare (Elbehri et al., 2013). However, using edible oils to produce biodiesel has fostered the competition for land (Cai et al., 2010; Vasile et al., 2016). Converting existing cropland for biodiesel production might strain supplies of available land and aggravate

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[1] While biofuels contribute to GHG reductions, biofuel production typically takes place on cropland that was previously used for other agricultural uses, such as growing food or feed. In order to recover this agricultural production, biofuel may lead to ILUC, that is the extension of agriculture land into non-cropland. Therefore, ILUC may limit the GHG savings that result from increased biofuels (Searchinger et al., 2008).

water stress caused by land use changes; in addition, biodiesel puts end uses of vegetable oils in competition with products intended for human and animal consumption, or livestock (Tomei and Helliwell, 2016; Santeramo et al., 2020). The use of edible oils for biodiesel has intensified the link between these feedstocks, with spillover effects on agri-food prices and impacts in terms of land use change (Peri and Baldi, 2013).

An expanding biodiesel industry and a consequent increasing demand for major feedstocks, due to biofuel policies, puts high pressure on agricultural commodity prices (Banse et al., 2008; Araujo Enciso et al., 2016). For instance, higher biofuel demand in the US and the EU has not only led to higher soybean prices, but it has also increased the prices of competing crops and the costs of livestock feed, incentivising to the switch from less profitable to more profitable crops (IMF, 2007). By altering the equilibrium price, policies incentivising biofuel demand may induce displacement effects across vegetable oils (Hamulczuk et al., 2019). The substitution and displacement responses of vegetable oils supply to higher commodity prices allows to mitigate the impacts due to the increase in demand of feedstocks for the biodiesel industry (Delta, 2011). The substitution and displacement effects are influenced by the supply responsiveness to price changes and by entrepreneurs' decisions to switch crops (Go and Lau, 2017). In addition, land in any country may be converted to the production of oilseed crops in order to accommodate the increased demand, driven by pro-biofuel policies (Kim and Moschini, 2018). The consequences on GHG emissions, related to the potential land use effects, may be detrimental (Searchinger et al. 2008; Haile et al., 2016). All in all, the linkages across vegetable oils markets may have environmental and policy implications that should not be neglected (Santeramo and Searle, 2019, 2020).

With a focus on the EU market, the article addresses the following questions: which price relationships link the supplies of major inputs of first-generation biodiesel? What can be learned from the responsiveness to price changes of vegetable oils supply and land allocations of related oilseed crops on the future development of sustainable biofuel policies? By answering the first research question, we show how the supply of a certain vegetable oil and land devoted to oilseed crops cultivation react to changes in prices of feedstocks adopted to produce biodiesel. We investigate cross-commodity linkages in vegetable oils market by analysing supply responsiveness to price changes. Cross-commodity linkages are synthesised by own-price and cross-price elasticities of vegetable oils quantity. Further, we examine the acreage response to changes in prices of vegetable oils to conclude on land use effects. By answering the second research question, we speculate on the environmental and policy implications due to different price elasticities and land use effects. Environmental implications are mostly due to different emissions associated with the production of feedstocks (Delta, 2011; Humalisto, 2015). We argue that, in order to efficiently plan biofuel policies, and prevent an excessive production of GHG emissions it is important to consider how supplies and land allocations react to price movements. For instance, interventions to reduce the available quantity of biodiesel from a low GHG saving feedstock, may not be environmental-friendly if the measures tend to incentivise the available quantity of biodiesel from another high ILUC feedstock and the share of land devoted to its cultivation. The environmental sustainability of a biofuel policy should be assessed not only based on a reduction in the dependency on fossil fuels, but also in terms of direct and indirect effects associated with the production of feedstocks.

The EU market is a case study of relevance, as a good example of a policy-driven biofuel market, influenced by interventions aimed at promoting fuel security and environmental goals (Peri and Baldi, 2013). The revised Renewable Energy Directive 2018/2001/EU (i.e. RED II), entered into force as part of the Clean energy for all Europeans package, targets reduction of emissions, as established in the Paris Agreement[2]. The REDII sets objective and non-discriminatory criteria to promote sustainability and reduce GHG emission in the biofuel markets[3]. All vegetable oils are treated equally, and the sustainability and GHG emission criteria neither single out any specific biofuel/feedstock nor limit the market access of imported biofuels to the EU[4]. This is true for palm

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[2] The Paris Agreement aims limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C.

[3] In this respect, the RED II is WTO compatible (European Union, 2019).

[4] Most of imported vegetable oils enters the EU with zero or low tariffs (European Union, 2019). A few exceptions are the anti-dumping and the countervailing duties against the US biodiesel in force since 2009 and extended until 2020. However the recent developments on the anti-dumping duties and market defence lead to the removal of the duties on Argentinean and Indonesian biodiesel exports (USDA FAS, 2019).

oil, for which the EU is a net importer[5]. Although scientific data show that palm oil is associated with high level of deforestation (European Commission, 2019a), palm oil is not identified as a "bad biofuel" per se[6]. However, only palm oil that is certified as low ILUC-risk is entitled to be subsidised[7]. The REDII sustainability and GHG emission criteria also identify sustainable biofuels that are eligible for public support; sustainability in biofuel market is a priority for the EU and within the Common Agricultural Policy 2014–2020 this priority creates also opportunities to access to aids for the adoption of sustainable and multifunctional agricultural practices (Schulte et al., 2019).

The empirical literature has predominantly focused on price elasticities of demand, evidences on cross-commodity responses of vegetable oils supplies are rather scant. A few exceptions are recent articles by Santeramo and Searle (2019, 2020) on supply price elasticities of soy and palm oils in the US. Other studies focus on crop supply responses (e.g. Guyomard et al., 1996; Britz and Hertel, 2011; Kim and Moschini, 2018). Against this background, the contribution of this article is to enrich the existing evidence by examining the price responsiveness of vegetable oils quantities and land devoted to oilseed crops cultivation in the EU. We study own- and cross-price elasticities for palm, rapeseed, soy, and sunflower oils, characterised by different levels of direct and indirect, via land use change, GHG emissions saving. The selected feedstocks accounted for 65% of total EU biodiesel production in 2018; the remaining part was covered by used cooking oils and animal fats and oils. Rapeseed oil is the main biodiesel feedstock in the EU followed by palm oil; they accounted, respectively, for 39% and 19% of total production in 2018. The soy-based biodiesel accounted for 8% of the EU supply, whereas sunflower oil is less than 1% of the total biodiesel

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[5] The EU imposed antidumping duties on Indonesian palm oil biofuel in 2013, but has withdrawn them in 2018 (ICCT, 2019). Currently, the EU has no import restrictions for palm oil (European Union, 2019). Similarly, there is no EU legislation on palm oil labelling, whereas few Palm Oil free campaigns are in place; the latters are expression of environmental concerns of consumers and manufacturers (European Commission, 2019b).

[6] During the negotiations for the RED II, the European Parliament phased out palm oil biofuel. The proposal sounded non-WTO compliant, so that the European Commission had to define high-risk ILUC biofuels and plan to phase them out by 2030. The list of high risk ILUC biofuels has been published in the Official Journal Delegated Regulation 2019/807; according to the document, palm oil is the only vegetable oil that can be defined as high-risk ILUC biofuel (USDA FAS, 2019).

[7] This is to meet the sustainability criteria set by the RED II. A few exceptions are palm oil planting on free lands, or palm oil from small holders (i.e. farm size smaller than 2 hectares), to ensure their tenure and independence over land (European Commission, 2019b). These measures are implemented to protect local communities, ecosystems and carbon stocks, in line with the Paris Agreement and Sustainable Development Goals 2030 (European Commission, 2019a).

feedstock in 2018 (USDA FAS, 2019). Rapeseed, palm, soy and sunflower oils are not only very important for the EU supply of biodiesel, but also associated with relevant emissions saving as compared to conventional diesel, and sunflower oil is the most GHG emission saving oil (Edwards et al., 2017). Estimates from a system of vegetable oils (palm oil, rapeseed oil, soy oil, and sunflower oil) inform on direct and indirect (via land use change) relationships linking the main inputs of the first-generation biodiesel and allow us to derive implications on the sustainability of future biofuel policies in the EU. Greater effort is still required to increase the share of renewables and sustainable alternative in the global energy mix, to meet the Sustainable Development Goals[8]. In order to ensure a long-term stability of the targets, the policies should be continuously adapted to the changing market conditions. Our analysis speaks in this direction.

The reminder of the article is organised as follows: the next section outlines contributions from previous studies on the linkages among vegetable oils; the third section describes the emergence and evolution of biofuel policies in the EU and the trends in the vegetable oils sector; the fourth section presents the empirical framework adopted to infer on cross-commodity linkages; the fifth section reports the empirical results, analysed on a comparative basis with previous findings; we conclude with environmental implications for future development of biofuel policies in the EU.

2. Evidence from previous studies

Biofuels have a relevant influence both on prices of processed products (e.g. vegetable oils) and on prices of agricultural commodities (e.g. oilseed crops) (Baier et al., 2009). It is well documented in literature that biofuel production has increased agricultural prices (e.g. Banse et al., 2008; Araujo Enciso et al., 2016). While Babcock (2012) suggests that biofuels contribute to increase pressure on agricultural commodity prices due to the growing demand for vegetable oils of the biofuel industry, Kocar and Civas (2013) argue that agricultural lands offer an alternative: changes in land use may

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[8] Sustainable Development Goals were adopted by all United Nations Member States in 2015 as an universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030.

accommodate the increased demand of energy crops driven by the biofuel industry. The upward pressure on commodity prices associated with the expansion of biofuel production explains the renewed interest in the supply and acreage responses (Kim and Moschini, 2018). However, evidences on cross-commodity responses of vegetable oils supplies are rather scant. Relevant empirical evidences on price responsiveness of supply are synthesised in table 1. A recent article by Santeramo and Searle (2019) on supply price elasticities of soy and palm oils in the US. They conclude on asymmetric reactions to price shocks; their findings suggest that if biofuel policies in the US underestimate substitution effects between soy and palm oils, climate benefits from soy-based biofuel may be overestimate. However, if it is true that first-generation biofuel markets are highly policy-dependant (Araujo Enciso et al., 2016), conclusions achieved for the US market of vegetable oils may not apply to the EU market. A major difference with the US market is that the EU is lead producer of biodiesel, with a production share of 36% mostly based on rapeseed oil (OECD-FAO, 2019).

A few studies focus on crop supply responses in the EU. Guyomard et al. (1996) analyse the EU Common Agricultural Policy reforms that reduced-price support levels: they find that the supply functions of rapeseed, soy, and sunflower are upward sloping in their own price and downward sloping in cross prices. Britz and Hertel (2011) develop an integrated assessment of the environmental impacts of EU biofuels mandates and derive compensated supply elasticities for the aggregate EU crops sector: the interaction between different commodities (i.e. rice, wheat, coarse grains, oilseed, sugar), competing for fixed resources, suggests that all but one crop (i.e. rice) are net substitutes in supply. However, cross-commodity responses of crops supplies may be not always comparable with supply responsiveness of vegetable oils, especially for net importer markets, such as the EU in the case of palm oil.

Table 1. Selected studies on price responsiveness of supply.

References	Country	Commodity	Palm price	Rapeseed price	Soy price	Sunflower price
Choi and Helmberger (1993)	US	Soy (yield)			0.13	
Guyomard et al. (1996)	EU	Rapeseed (supply)		0.42	-0.02	-0.09
	EU	Soy (supply)		-0.15	3.70	-0.40
	EU	Sunflower (supply)		-0.05	-0.02	0.22
Stout and Abler (2004)	US	Rapeseed (yield)		0.04		
	US	Soy (yield)			0.10	
	Canada	Rapeseed (yield)		0.05		
	Canada	Soy (yield)			0.07	
	Mexico	Rapeseed (yield)		0.02		
	Mexico	Soy (yield)			0.02	
Arnade and Kelch (2007)	US	Soy (supply)			0.31	
Santeramo and Searle (2019)	US	Soy (supply)	0.14		0.19	
	US	Palm (supply)			1.23	

Notes: Highlighted values are own-price elasticities.

Other Different studies provide evidence on crop supply response, but frequently the focus is on other markets, such as the US (e.g. Lee and Helmberger, 1985; Shideed and White, 1989; Chavas and Holt, 1990; Choi and Helmberger, 1993; Arnade and Kelch, 2007; Hendricks et al., 2014; Kim and Moschini, 2018) or Canada and Mexico (e.g. Stout and Abler, 2004). Only Guyomard et al. (1996) provide evidence for the EU market. Such studies take into account cross-price elasticities between different products and estimate crop acreage responses to price changes; they deal with the estimation of models to measure how prices affect farmers' production decisions (e.g. Bayramoglu and Chakir, 2016; Haile et al., 2016; Kim and Moschini, 2018). However, it is worth of mention the difficulty of comparing estimates from studies that differ in scope, data, and estimation methods. The table 2 reports empirical evidence from previous studies estimating both own- and cross-price elasticities of acres of rapeseed, soybeans, and sunflower seeds.

Table 2. Selected studies on price responsiveness of acreage.

References	Country	Commodity	Rapeseed price	Soy price	Sunflower price
Lee and Helmberger (1985)	US	Soy (acres)		0.35	
Shideed and White (1989)	US	Soy (acres)		0.41	
Chavas and Holt (1990)	US	Soy (acres)		0.06	
Guyomard et al. (1996)	EU	Rapeseed (acres)	0.23	-0.02	-0.10
	EU	Soy (acres)	-0.12	0.85	-0.33
	EU	Sunflower (acres)	-0.06	-0.03	0.20
Arnade and Kelch (2007)	US	Soy (acres)		0.05	
Hendricks et al. (2014)	US	Soy (acres)		0.36	
Kim and Moschini (2018)	US	Soy (acres)		0.38	

Notes: Highlighted values are own-price elasticities.

Looking at the effects of changes in prices of vegetable oils both on supply of vegetable oils and acreage intended for the cultivation of oilseed crops in the EU market, our analysis highlights different points of novelty. First, given the lack of evidence on price responsiveness of vegetable oils supply in the EU, our study provides a better understanding of inter-commodity dynamics in a policy relevant market for the biofuel sector. In fact, it is worth noting that the EU is a dominant economy in the biofuel sector (Oliveira et al., 2017). Second, looking at productive and trade dynamics in the vegetable oils supply due to changes in domestic and imported prices, we are able to derive effects in terms of ILUC both in the EU and at the international level. In fact, the substitution and displacement responses of vegetable oils supply to higher commodity prices may induce countries, not only in the EU but also in other region of the world, to change the production use of land to accommodate the increased demand of feedstocks for the biodiesel industry, with consequences on direct and indirect GHG emissions (Haile et al., 2016; Edwards et al., 2017). Third, our analysis deepens on the effects of price changes on the entire supply chain. Indeed, by evaluating how changes in prices of vegetable oils affect farmers' behaviour, who respond with consequent decisions in terms of land allocation, and strategies of producers and marketers of vegetable oils, who adjust their production and trade schedules accordingly, we provide insights on the integration of markets in the vegetable oils sector.

3. Biofuel and vegetable oils in the EU

3.1 The emergence of biofuels

As suggested in Peri and Bald (2013) the growing expansion of biofuel production in the EU is a direct consequence of the political framework implemented to achieve fuel security and environmental goals. The expansion of the biofuel market dates back to 1992, when the provisions of the Mac Sherry reform of the Common Agricultural Policy (i.e. set-aside payment scheme, producer support scheme) allowed for the cultivation of feedstock (in particular rapeseed) for the production of biofuel (Oliveira et al., 2017). As shown in table 3, the share of acreage of rapeseed with respect to the total Utilised Agricultural Area (UAA) in the EU shows a steady increase since the period 1992-1997. Decreasing until the period 2004-2009, the share of acreage of sunflower seeds is 0.86%; acreages of soybeans have been almost constant since the early Nineties. It is worth noting that the EU is not a producer of palm kernel.

Table 3. Acreage of oilseeds and share with respect to the total Utilised Agricultural Area in the European Union, average values in sub-periods between 1992 and 2016.

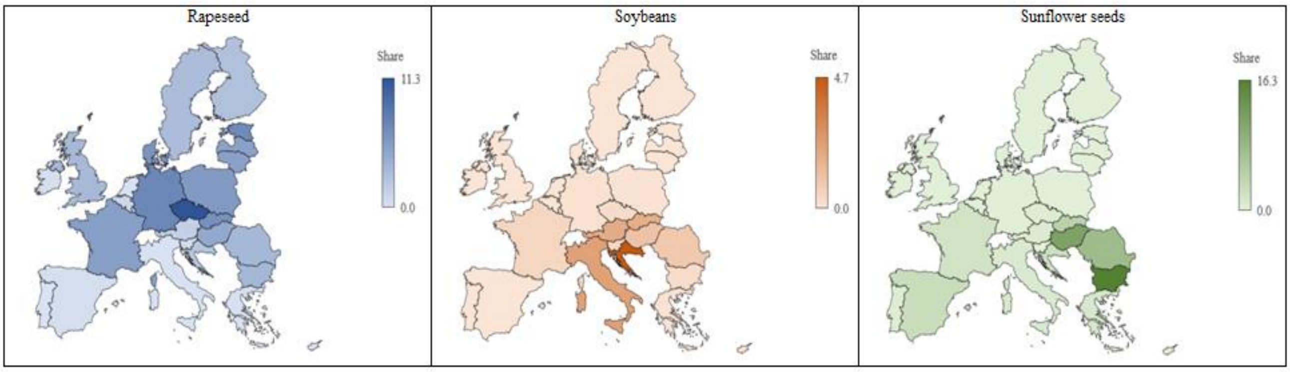
	1992-1997		1998-2003		2004-2009		2010-2016	
Oilseed	Area (1000 ha)	Share (%)	Area (1000 ha)	Share (%)	Area (1000 ha)	Share (%)	Area (1000 ha)	Share (%)
Palm kernel	0	0	0	0	0	0	0	0
Rapeseed	3,378	0.63	4,292	0.82	5,681	1.13	6,640	1.36
Soybeans	498	0.09	523	0.10	407	0.08	581	0.12
Sunflower seeds	4,422	0.82	3,923	0.75	3,725	0.74	4,218	0.86

Source: Elaboration on data from FAOSTAT.

Among countries of the EU, Germany and France have been pioneers of biofuel with their agricultural sector as a major driving force; currently, they dominate the EU's biodiesel market

(Oliveira et al., 2017). However, in 2016 while the largest share of rapeseed acreage is concentrated in countries of northern Europe (e.g. Czech Republic 11%, Germany, Estonia and Slovakia 7%, Denmark and Poland 6%, France 5%), the shares of soybeans and sunflower seeds acreages are higher respectively in southern (e.g. Croatia 5%, Italy and Slovakia 2%) and eastern (e.g. Bulgaria 16%, Hungary 11%, Romania 8%) countries of the EU.

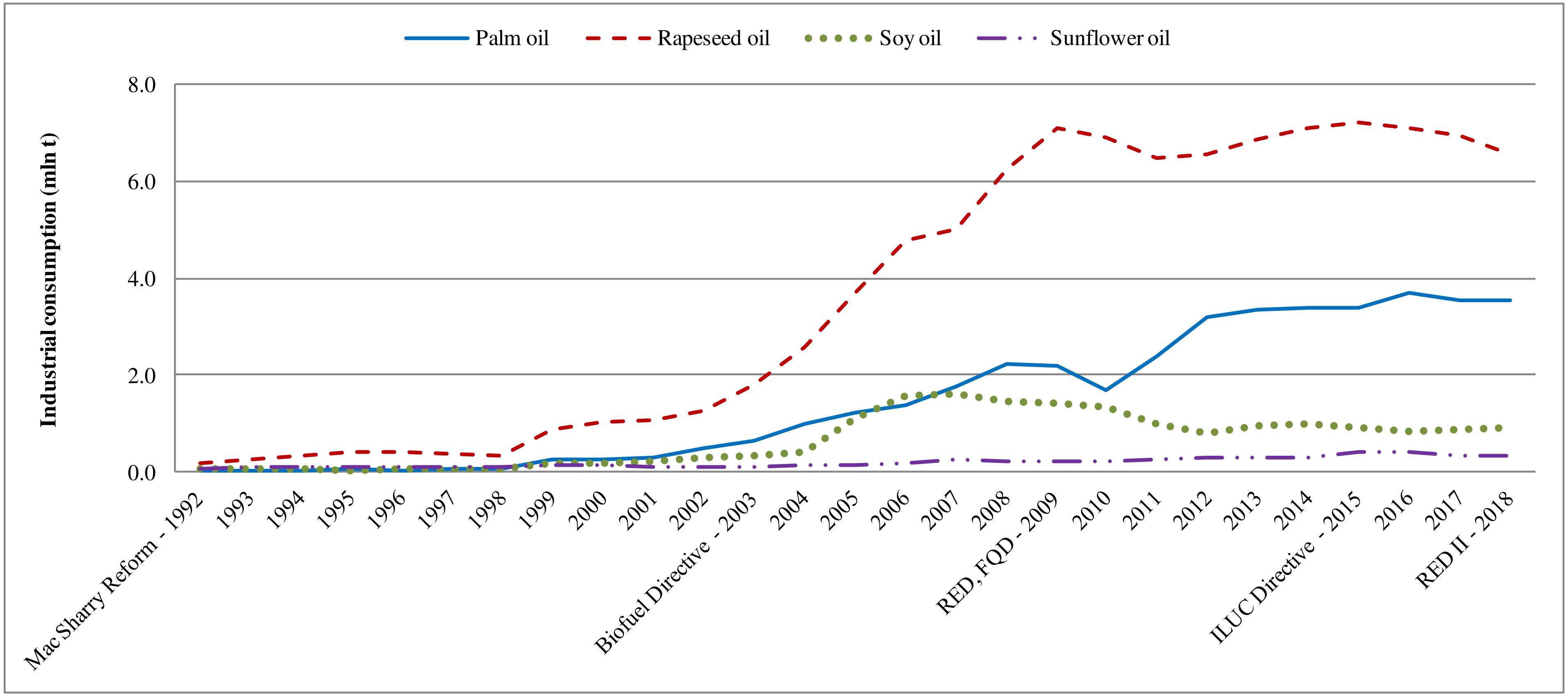
Figure 1. Share of area harvested of oilseeds with respect to the total Utilised Agricultural Area in the European countries, 2016.



Source: Elaboration on data from FAOSTAT.

Since the early 2000s, the increased production of feedstock expanded domestic consumptions of vegetable oils for industrial uses (figure 2) and called for regulations on the growing EU biofuel market.

Figure 2. Domestic consumption of vegetable oils for industrial uses (fuel and non-food industries) and relevant events for the biofuel sector in the European Union: 1992-2018.



Source: elaboration on data from USDA FAS PSDO.

Notes: Data until 1998 refer to the sum of industrial domestic consumption of single Member States. The acronyms are: Renewal Energy Directive (RED), Fuel Quality Directive (FQD), Indirect Land Use Change (ILUC).

The EU's decarbonisation strategy, through the Renewable Energy Directive (RED) (2009/28/EC) and the Fuel Quality Directive (FQD) (2009/30/EC), improved the previous Biofuel Directive (2003/30/EC) and established targets to be achieved by 2020. In particular, the RED targeted 10% as minimum blending level with vegetable oils for biofuels, and the FQD aimed at reducing GHG emissions by 6%. Since 2009, the demand of vegetable oils levelled off after its rapid growth beginning in 2000 (OECD-FAO, 2019). Both RED and FQD are responses to the criticisms on the role of biofuel in GHG emissions (Searchinger et al., 2008). A by-product of directives on blending levels for biofuels is due to the potential indirect effects they may induce in terms of land use change: biofuels consumption would have displacement effects on non-cropland (e.g. grassland, forests), increase the level of atmospheric CO_2 and reduce GHG saving effects. In order to address these concerns, the Indirect Land Use Change Directive, or ILUC Directive ((EU)2015/1513), amended RED and FQD, established a minimum requirement on GHG saving for biofuels. Under the EU regulations, it is of great importance the calculation of net GHG emissions for ILUC related to the production of biofuel (Efroymson et al., 2016). Following the rules set by the ILUC Directive, the European Commission's Joint Research Center (EC JRC) evaluated the GHG emissions associated with biofuels: as compared to diesel or heating oil, the emissions saving is 64% for sunflower oil, 61% for soy oil, 57% for rapeseed oil and, for palm oil, range between 36% of open effluent pond and 63% of methane collected from effluent (Edwards et al., 2017).

A recent change in biofuel policy has occurred in 2018, when the revised Renewable Energy Directive 2018/2001/EU (RED II) entered into force as part of the Clean energy of the Paris Agreement: the policy promotes emissions reduction. In the RED II, the EU targets to raise the use of renewable energy sources by 32% in 2030, and defines sustainability and GHG emission criteria that biofuels used in transport must comply with to be eligible for financial support by public authorities. Member States must require fuel suppliers to provide, by 2030, a minimum share (14%)

of renewable energy in road and rail transportation[9]. Under the RED II, sustainable aviation and maritime fuels can contribute to achieve the 14% transport target, given the compliance with the sustainability and GHG emission criteria. Bio-based aviation fuels may have lower GHG emissions as compared with traditional fossil fuels[10]. However, despite there have been several initiatives[11] to increase the market penetration, the EU consumption is lower than the potential production capacity, and accounts only for 4% of the EU demand for conventional fossil aviation fuels (European Union Aviation Safety Agency, 2019).

Biofuel policies in the EU contribute to land use change and land concentration within the EU but also in other regions of the world (Oliveira et al., 2017), such as Ukraine which is a leading exporters of rapeseed for EU biodiesel producers (Schaffartzik et al., 2014). The RED took into account feedstocks provided by extra-EU countries and related consequences in terms of land use change in those countries; similarly, the RED II also establishes rules to minimise the risk of ILUC associated with biofuel either locally produced or imported. However, in order to promote sustainability and reduce GHG emission in the biofuel markets, the REDII sets non-discriminatory criteria that make the it WTO compatible. According to non-discriminatory criteria, all vegetable oils are treated equally, and most of imported vegetable oils enters the EU with zero or low tariffs (European Union, 2019). A few exceptions are the anti-dumping and the countervailing duties against the US biodiesel in force since 2009 and extended until 2020. However the recent developments on the anti-dumping duties and market defence lead to the removal of the duties on Argentinean and Indonesian biodiesel exports (USDA FAS, 2019).

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[9] Transport is the end use with the lowest renewable energy share. Most of the renewable energy consumed in the transport sector is policy driven and comes from crop-based biodiesel blended with fossil fuels that are used for transport. Most renewable fuel consumption is currently in road vehicles, with minimal use in aviation and maritime transport. This is due to the low economic and technical viability of renewable fuels and to the less policy support for their use in these long-haul sectors (IEA, IREA, UNSD, WB, WHO, 2019).

[10] The EC JRC estimates the GHG emissions from the production of sustainable aviation fuel based on soy and sunflower oils at around 40 gCO2eq/MJ, and based on rapeseed oil at around 51 gCO2eq/MJ (European Union Aviation Safety Agency, 2019).

[11] For instance, the EU Emissions Trading System (EU ETS) incentivise aircraft operators to use sustainable aviation fuels in order to comply with the sustainability and GHG emission criteria, as defined in the RED II. In addition, the European Advanced Biofuels Flightpath has launched, in 2011, a partnership between the European Commission and the major European stakeholders in order to facilitate the introduction of sustainable aviation fuels (European Union Aviation Safety Agency, 2019).

3.2 The dynamics of vegetable oils markets

The EU is the first producers of biodiesel, with a production share of 36%; the main feedstock used to produce biodiesel is rapeseed oil (OECD-FAO, 2019). Palm, rapeseed, soy, and sunflower oils are the main vegetable oils, in terms of production and trade volumes, and satisfy 91% of domestic consumption. According to the USDA FAS PSDO data, in 2017 and 2018 rapeseed (39%), palm (25%), sunflower (18%), and soy oils (9%) have been the most supplied[12] vegetable oils.

The table 4 synthesise data on produced, imported and exported quantities of vegetable oils for fuel and non-food industries, whereas figure 3 reports the evolution of prices of vegetable oils.

Table 4. Production, imports, and exports of vegetable oils for industrial uses (fuel and non-food industries) in the European Union, average values in sub-periods between 1992 and 2016.

Vegetable oil	Unit	1992-1997			1998-2003			2004-2009			2010-2016		
		Prod.	Imp.	Exp.	Prod.	Imp.	Exp.	Prod.	Imp.	Exp.	Prod.	Imp.	Exp.
Palm oil	Tg	0.0	18.5	0.7	0.0	27.7	0.6	0.0	47.6	1.3	0.0	63.5	1.4
Rapeseed oil	Tg	28.3	0.2	7.6	42.1	0.1	3.9	72.5	3.8	1.1	96.9	3.4	3.2
Soy oil	Tg	25.5	0.2	6.6	28.6	0.5	8.4	25.3	7.1	3.6	24.9	3.9	8.4
Sunflower oil	Tg	20.7	1.4	2.4	22.9	4.3	2.0	22.9	11.0	1.5	29.2	10.1	3.0

Source: Elaboration on data from USDA FAS PSDO.

Notes: Tg stands for 10^{12} g.

Trends in terms of production and trade have steadily grown, exception made for rapeseed and soy oils, which showed increases in imports from 1998-2003 to 2004-2009 and a setback of exports in recent years (table 4). The EU market is quite integrated: the prices of rapeseed, soy, and sunflower oils tend to co-move in the long run, exception made for palm oil prices, with more erratic trends, and marked downward (in 1996) and upward (in 2001 and 2007) peaks (figure 3).

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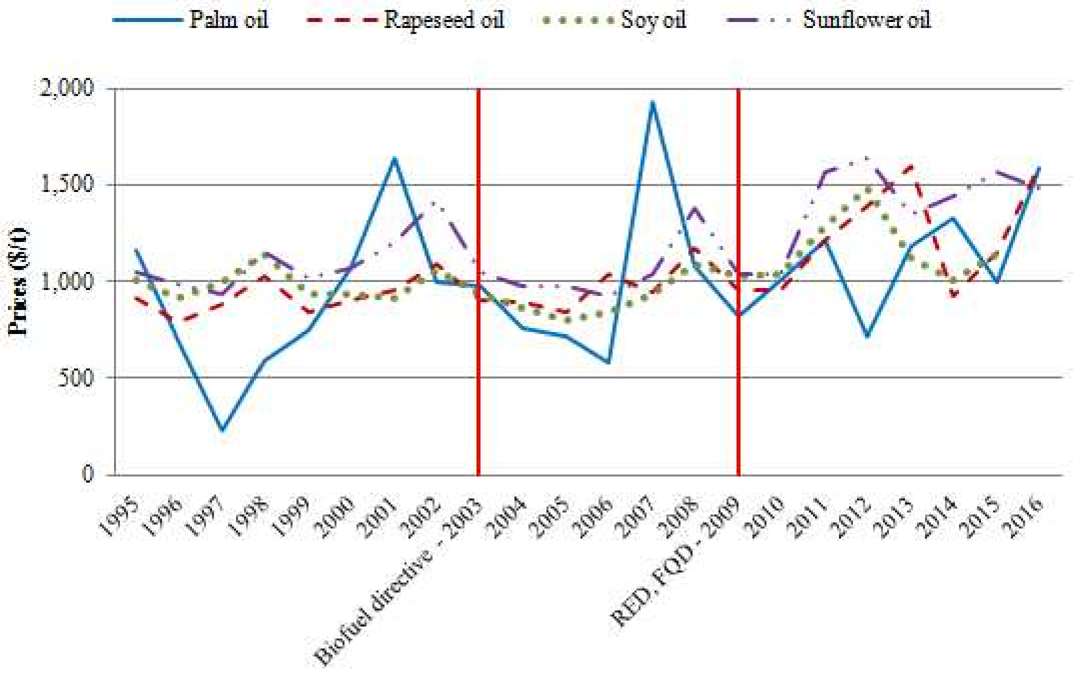
[12] Supplied quantities are obtained as the sum between produced and imported quantities, net of exported quantities.

The EU is a large producer of rapeseed oil (96.2 Tg produced in 2016), and a main importer of whole soybeans, crushed to produce and export soy oil: rapeseed and soy oils are the most supplied for fuel and non-food uses. The growing demand of rapeseed oil for industrial uses (see figure 2) helps explaining the progressive increase of produced and imported quantities, and the reduction of exports. We observe a remarkable increase of rapeseed oil supply during the 2004-2009 period (table 4), coupled with a sharp increase in domestic consumptions (figure 2). During the same time span the prices of rapeseed oil have been growing (figure 3). The rising biofuel production is likely a main driver of the agricultural price hike (Rajcaniova et al., 2013).

Figure 3. Prices of vegetable oils in the European Union, 1995-2012.



Source: Elaboration on data from Eurostat.

Notes: The acronyms are: Renewal Energy Directive (RED), Fuel Quality Directive (FQD).

After rapeseed oil, palm is the second most demanded oil for industrial uses (figure 2). The erratic trend in domestic prices of palm oil (figure 3) is likely due to the movements of import prices. Production, exports and domestic consumption of sunflower oil have been almost constant over time (table 4, figure 2). Figure 3 shows short term decline in prices of domestically produced vegetable oils (i.e. rapeseed, soy, and sunflower oils) just after changes in biofuel policies, in 2003 (Biofuel Directive) and 2009 (Renewable Energy Directive). In the following years the supplies of vegetable oils have been altered: palm oil supply increased by 71% in 2004-2009 and by 34% in 2 010-2016; rapeseed oil supply increased by 96% in 2004-2009 and by 29% in 2010-2016 (table 4). The own- and cross-price elasticities of supply would inform on the linkages across those markets.

4. Methodological framework

4.1 Supply response equation

In order to investigate linkages across vegetable oils in the EU, we examine how the supply of palm, rapeseed, soy, and sunflower oils reacts to changes in prices. We estimate own- and cross-price elasticities (PES) for all combinations among selected vegetable oils with a two-stage least square (2SLS) procedure, using instrumental variables (IVs). This procedure allows us to account for the identification problem inherent the estimation of PES (Santeramo, 2015). The application of 2SLS solves problems of heteroscedasticity, multicollinearity, autocorrelation, and endogeneity of price and quantity of goods (Chanthawong et al., 2016). We use weather-induced shocks (i.e. temperature and precipitation) and a time trend as IVs. The use of weather-induced shocks to instrument prices is common in the context of an aggregate global caloric supply (e.g. Hendricks et al., 2015). The rationale is that if, at the decision time, producers are partially aware of forthcoming supply shocks (determined by predictable weather shocks), their production and import decisions may change accordingly, affecting expected prices. The omission of predictable components from the estimating equation may generate endogeneity bias due to potential correlation between the price variable and the error term. The use of IVs allows us to mitigate potential problem of endogenous price. However, as suggested in Hendricks et al. (2014), potential endogeneity of prices is not a major concern in the estimation of supply equations if the analysis is focused on how the supply behaves at a country level (i.e. the EU). Similarly to Moschini and Kim (2018), we also assume price variations in the period under consideration triggered by exogenous demand shifts, including the development of policies in favour of biofuel.

In the first stage, we predict prices with respect to which the elasticity of available quantities will have to be estimated in the second stage. The price of the *i*-th vegetable oil at time *t* is modelled as follows:

$$\boldsymbol{p}_{it} = \boldsymbol{\alpha}_i + \boldsymbol{\beta}_i \boldsymbol{p}_{it-1} + \boldsymbol{\gamma}' \boldsymbol{x}_{t-1} + \boldsymbol{v}_{it} \tag{1}$$

where $\boldsymbol{p}_{it}$ is the 4 × 1 vector of prices, $\boldsymbol{\alpha}_i$ is the 4 × 1 vector of constants, $\boldsymbol{p}_{it-1}$ is the 4 × 1 vector of lagged own-prices and $\boldsymbol{\beta}_i$ is the vector of related coefficients, $\boldsymbol{x}_{t-1}$ is the 4 × 1 vector of past weather-induced shocks (i.e. a flexible form of temperature and precipitation) and time trends and $\boldsymbol{\gamma}'$ is the vector of related coefficients, $\boldsymbol{v}_{it}$ is the 4 × 1 vector of error terms.

In the second stage, we use the forecasted price to derive own-PES and cross-PES of supply of vegetable oils. Our specification is consistent with the profit-maximisation strategy of producers who condition production and imports decisions on expected prices. In line with the framework of rational expectations (Askari and Cummings, 1977), expected prices equal realised prices with one period lag. The supply for the *i*-th vegetable oil at time *t* is modelled as:

$$\boldsymbol{y}_{it} = \boldsymbol{\theta}_i + \mathbf{E}\widehat{\boldsymbol{p}}_{it-1} + \boldsymbol{\gamma}' \boldsymbol{x}_t + \boldsymbol{\nu}_{it} \tag{2}$$

where $\boldsymbol{y}_{it}$ is the 4 × 1 vector of quantities, $\boldsymbol{\theta}_i$ is the 4 × 1 vector of constants, $\widehat{\boldsymbol{p}}_{it-1}$ is the 4 × 1 vector of expected prices (i.e. prices realised with one period lag), predicted in the first stage, $\mathbf{E}$ is the (symmetric) 4 × 4 matrix of coefficients of interest, $\boldsymbol{x}_t$ is the 4 × 1 vector of current weather-induced shocks and time trend and $\boldsymbol{\gamma}'$ is the vector of related coefficients, $\boldsymbol{\nu}_{it}$ is the 4 × 1 vector of error terms.

The specification allows us to investigate whether, and to what extent, the supply of the i-th vegetable oil is influenced by the own expected price of i and by the expected prices of other J vegetable oils. The models in equations (1) and (2) are estimated in log form so to have coefficients easily interpretable as own- and cross-elasticities[13] and in a Seemingly Unrelated Regression Equations (SURE) fashion. A system of equations estimated by 2SLS is more efficient in capturing the interrelation between equations, as well as causal and feedback effects between the core variables of the system (Chanthawong et al., 2016). The 2SLS approach is preferred when data are limited: compared to other specification it provides more accurate estimates.

4.2 Acreage response equations

In order to estimate the indirect land use effect due to changes in prices of vegetable oils, we assume the total cropland (A) to be fixed and devoted to four alternative uses: rapeseed, soybeans, sunflower and all other uses[14]. This assumption is in line with standard theory of land use choice (e.g. Villoria and Liu, 2018). Following Kim and Moschini (2018), we posit that land allocation decisions depends on the choices of a profit-maximiser farmer, whose decision problem consists in choosing acreage shares, $s_i = A_i/A$ where is the acreage allocated to the i-th crop (i.e. rapeseed, soybeans, sunflower, all other uses). Given that acreage allocated to each crop is measured as a proportion of available arable land in each county, acreage shares should reflect the relative profitability of producing a certain crop in each county in comparison to other uses (Garrett et al., 2013). We assume that farmers' decisions of land allocation depend directly on changes in oilseed prices (i.e. agricultural prices) and indirectly on changes in vegetable oils prices (i.e. prices of processed products).

Assuming there are K EU countries observed over T periods, the acreage response equation for each i-th crop can be specified as follows:

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[13] The interpretation of price elasticies in the output response equation is in the Appendix A.1.

[14] We do not consider palm kernel in that the EU is not a producer.

$$\boldsymbol{s}_{ikt} = \boldsymbol{\lambda}_i + \boldsymbol{\lambda}_{it} + \boldsymbol{\lambda}_{ik} + \boldsymbol{\delta}_{ik}\boldsymbol{s}_{ikt-1} + \mathbf{E}\boldsymbol{p}_{it} + \boldsymbol{\mu}_{ikt} \tag{3}$$

where $\boldsymbol{s}_{ikt}$ is the 4 × 1 vector of shares, $\boldsymbol{\lambda}_i$ is the 4 × 1 vector of constants, $\boldsymbol{\lambda}_{it}$ is the 4 × 1 vector of time fixed effects controlling for structural changes (e.g. technological progress) or policy changes, $\boldsymbol{\lambda}_{ik}$ is the 4 × 1 vector of time-invariant country fixed effects accounting for heterogeneity across countries, $\boldsymbol{s}_{ikt-1}$ is the 4 × 1 vector of own-lagged shares[15] and $\boldsymbol{\delta}_{ik}$ is the vector of related coefficients, $\boldsymbol{p}_{it}$ is the 4 × 1 vector of vegetable oils prices (in logarithm) and **E** is the (symmetric) 4 × 4 matrix of coefficients of interest, $\boldsymbol{\mu}_{ikt}$ is the 4 × 1 vector of error terms.

It is worth noting that the model in equation (3) considers shares of acreage at the country level and EU prices instead of domestic prices. As in Haile et al. (2016), we assume that the aggregate acreage response estimated through equation (3) implicitly considers the imperfect transmission of EU prices to domestic producer prices.

The model in (3) is estimated as a system of equations through SURE in order to obtain efficient estimates of the acreage response to price changes (Chanthawong et al., 2016).

4.3 Data description

A four-vegetable oil model (palm oil, rapeseed oil, soy oil, sunflower oil) is specified for the EU over the period between 1992 and 2016, using annual data[16]. Information on produced, imported, and exported quantities of vegetable oils (in Tg) are collected from the USDA FAS PSDO database[17] and data are available for the EU at the aggregate level. The aggregate EU refers to EU-

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[15] In a sensitivity analysis we include own- and cross-lagged shares to maintain the land constraint $s_{rapeseed} + s_{soybeans} + s_{sunflower\ seeds} + s_{other} = 1$. The results are confirmed. For more details, see table A.1 in the Appendix A.2.

[16] See table A.2 in the Appendix A.3 for descriptive statistics of key variables.

[17] The USDA FAS PSDO database provides data on production, supply and distribution of agricultural commodities for key producing and consuming countries. The USDA FAS PSDO database contains official statistics and includes all attributes, countries and years pertaining to a particular commodity.

15[18] until 2003, to EU-25[19] since 2004 until 2006, to EU-27[20] since 2007-2012; starting from 2013, Production, Supply and Distribution numbers for the aggregate EU reflect the addition of Croatia to the former EU-27. Spot prices (in $/t) are obtained from the Eurostat database. In particular, prices are average prices in the EU-15 until 2003, average prices in the EU-25 since 2004 until 2006, average prices in the EU-27 since 2007-2012, and average prices in the EU-28[21] since 2013. Collected prices refer to “Crude palm oil and its fractions (excluding chemically modified)” for palm oil, “Crude rape; colza or mustard oil and their fractions (excluding chemically modified)” for rapeseed oil, “Crude soya-bean oil and its fractions (excluding chemically modified)” for soy oil, “Crude sunflower-seed and safflower oil and their fractions (excluding chemically modified)” for sunflower oil. We collected country-level data on the Utilised Agricultural Area (UAA) and area harvested for rapeseed, soybeans and sunflower seeds (in ha) from the FAOSTATA database[22]. We obtain acreage shares for rapeseed, soybeans and sunflower seeds as the ratio between the acreage allocated to each crop and the total of UAA of a certain EU country. Weather data are from the Center for Climatic Research at the University of Delaware (version 2.01). Annual data are computed by averaging monthly temperature and precipitation over the growing seasons.

5. Results and discussion

5.1 Price responsiveness of vegetable oils supplies

Table 5 presents the results of the first stage (model in equation 1), estimated in a SURE fashion. The system of equations controls for the effect of past weather shocks and time trends[23].. Two out

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[18] EU-15 includes: Belgium, Germany, France, Italy, Luxembourg, the Netherlands, Denmark, Ireland, United Kingdom, Greece, Spain, Portugal, Austria, Finland and Sweden.

[19] EU-25 includes also Czech Republic, Estonia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Slovenia and Slovakia which enlarged the EU-15 in 2004.

[20] EU-27 includes also Bulgaria and Romania which enlarged the EU-25 in 2007.

[21] EU-28 includes also Croatia which enlarged the EU-27 in 2013.

[22] The FAOSTAT database provides crops statistics expressed in terms of area harvested, production quantity and yield.

[23] Past temperatures and their squares are significant only for palm and soy oils: the relationship linking palm and soy oils prices and temperatures is non linear. Past precipitations are detrimental for current prices of vegetable oils, but up to a certain threshold. In fact, for each vegetable oils, coefficients estimated are negative for past precipitations, but positive for the square of past precipitations. The coefficients estimated for the time trend are not statistically significant at any conventional level. Coefficients estimated for control factors, omitted for brevity, are available upon request.

of four coefficients are statistically significant at the 5% significance level. The price of rapeseed oil is negatively related to its own lagged price; the opposite is true for soy oil price. Vice-versa, prices of palm and sunflower oils seem to not react to their past prices, reflecting their constant trend overtime net to the effect of unexpected upward or downward peaks (see figure 3). The high R-squared and the low Root Mean Square Error (RMSE) (respectively, 0.800 and 0.067 for soy oil equation, 0.711 and 0.245 for palm oil equation, 0.610 and 0.090 for rapeseed oil equation, 0.559 and 0.116 for sunflower oil equation) speak for the quality of estimates.

Table 5. Seemingly Unrelated Regression Equation (SURE) estimation of the I stage (equation 1).

	Dependent variable: current prices							
Explanatory variable: past prices	Palm oil		Rapeseed oil		Soy oil		Sunflower oil	
Own lagged price	0.135		-0.298	**	0.253	**	-0.002	
	(0.110)		(0.126)		(0.117)		(0.135)	
RMSE	0.245		0.090		0.067		0.116	
R-squared	(0.711)		(0.610)		(0.800)		(0.559)	

Notes: The system of equations includes control factors (i.e. past weather shocks and time trends). Standard errors are in parentheses. ** indicates statistical significance at 5%.

The second stage of the system of equations (model in equation 2), reported in table 6, provides own- and cross-price elasticities (PES) among palm, rapeseed, soy, and sunflower oils. The SURE model controls for weather shocks and time trend[24]. R-squared greater than 0.85 for each equation and low values of RMSE (ranging between 0.036 and 0.056) indicate the good fit of the model.

The diagonal in table 6 reports the own-PES: all but one coefficient are statistically significant at the 1% significance level. The statistically significant coefficients of the own-PES have the expected sign: the own price elasticity is positive for palm, soy, and sunflower oils; differently, the

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[24] Higher temperatures are beneficial for supplies of rapeseed and sunflower oils. However, the relationship between temperatures and supply of sunflower oil is non-linear (i.e. the coefficient estimated for temperatures-squared is negative). A non-linear relationships also link precipitations and supplies of soy and sunflower oils. The coefficients estimated for the time trend are statistically significant. Coefficients estimated for control factors, omitted for brevity, are available upon request.

supply of rapeseed oil does not react to changes in its own price (the estimated coefficient is not statistically different from zero). In line with the expectations, our results suggest that quantities of palm, soy, and sunflower oils positively responds to increase in their own prices.

Table 6. Seemingly Unrelated Regression Equation (SURE) estimation of the II stage (equation 2).

	Dependent variable: quantities							
Explanatory variables: estimated price	Palm oil		Rapeseed oil		Soy oil		Sunflower oil	
Palm oil	0.203	*	-0.513	***	0.458	***	-0.504	***
	(0.112)		(0.136)		(0.087)		(0.119)	
Rapeseed oil	0.729	**	-0.331		0.008		-1.778	***
	(0.368)		(0.446)		(0.284)		(0.392)	
Soy oil	1.094	**	-2.181	***	1.260	***	-1.028	**
	(0.473)		(0.572)		(0.364)		(0.503)	
Sunflower oil	-1.816	***	2.322	***	-1.195	***	2.858	***
	(0.591)		(0.716)		(0.456)		(0.630)	
RMSE	0.046		0.056		0.036		0.049	
R-squared	0.986		0.981		0.859		0.848	

Notes: The system of equations includes control factors (i.e. current weather shocks and time trend). Standard errors are in parentheses. ***, **, and * indicate statistical significance at 1%, 5%, and 10%.

A 1% change in palm oil prices induces a supply expansion of 0.2%; differently, soy and sunflower oils supplies expand, respectively, by 1.3% and 2.9%, after a 1% change in their own prices. Soy and sunflower oils have a more elastic response to changes in their own prices, whereas palm oil reacts less than proportionally to domestic price changes (i.e. it is price inelastic), plausibly because the EU is a net importer of palm oil.

The markets of vegetable oils are more reactive in the EU than in other countries. While we find the supply of palm oil having a limited reaction to changes in domestic price of palm oil (+0.2), Santeramo and Searle (2019) find no response of palm oil imports to changes in price of palm oil in the US. Similarly, soy oil is elastic in the EU, and inelastic in the US. Our estimated own-PES is in line with the findings of Guyomard et al. (1996) for the EU. These evidences are not surprising if one considers the composition of supply of vegetable oils in the EU and in the US (see figure A.2 in the appendix A.5). While both the US and the EU are not producers of palm oil, the US produces larger quantities of soy oil than the EU. The latter imports and crushes large quantities of whole soybeans to produce soy oil and meet domestic demand. Indeed, the share of area harvested of soybeans in the EU is the lowest as compared to those of other oilseeds (see figure 1). The evidence supporting the greater responsiveness of vegetable oils in the EU than in the US is in line with the argument of Rajcaniova et al. (2013) who state that, compared to other leading promoters of biofuel (e.g. the US, Brazil), the EU is price-maker in the vegetable oils markets for biofuel.

Due to the high price responsiveness of sunflower and soy oils, EU policy measures intended to increase the use (thus the demand) of first-generation biodiesel would benefit the most domestic producers of sunflower and soy oils. The benefits would be also in environmental terms: soy and sunflower oils have the highest GHG saving, both direct and indirect, via land use changes (Edwards et al., 2017). In this context, in order to ensure a sustainable biofuel market, biofuel policies should consider the possibility to incentivise energy crop cultivation by promoting conservation agricultural practices: this would promote a sustainable biofuel production, making the EU supply chains independent and self-sufficient over time.

Relative to the own-PES, the cross-PES of palm and rapeseed oils are large in absolute value, indicating that the expansion of the market for palm oil or rapeseed oil largely comes at the expense of other vegetable oils, and vice-versa. Differently, the cross-PES of soy and sunflower oils are lower than their own-PES in absolute value, showing their low reactivity to changes in markets of related vegetable oils.

We find palm and soy oils to be closely related: the market for palm oil tends to expand with upward prices in soy oil market, and vice-versa. However, the reaction of palm oil to changes in price of soy oil is more moderate with respect to that of soy oil to changes in price of palm oil. In fact, the cross-PES of palm oil to soy oil price is elastic (+1.1), whereas the cross-PES of soy oil to palm oil prices is inelastic (+0.5)[25]. The lower responsiveness of soy oil is likely to be due to the competition with end uses of soybean: in fact, the market value of soybean is biased in favour of soy-based meal, whereas soy oil accounts for a lower percentage (USDA FAS, 2019). Our estimated cross-PES between palm and soy oils are in line with Santeramo and Searle (2019), who find similar evidence for the US market, with few differences: the supply of soy oil is more sensitive in the EU (+0.5) than in the US (+0.1) to changes in price of palm oil; vice-versa, imports of palm oil are less reactive in the EU (+1.1) than in the US (+1.2) to changes in price of soy oil.

Differently from palm and soy oils, palm and sunflower oils as well as soy and sunflower oils tend to substitute each other. In fact, both palm and soy oils suffer a contraction after an increase in prices of sunflower oil, and vice-versa. In absolute value, rapeseed oil reacts to changes in price of soy (-2.2) and sunflower oils (+2.3) more than in price of palm oil (-0.5) (table 6): the most produced vegetable oil in the EU (rapeseed oil) appears to be more affected by the competition of the domestically produced commodities (soy and sunflower oils), rather than of the imported commodity (palm oil). Similar conclusions may be drawn for sunflower oil, whose supply reduces more than proportionally following an increase in price of rapeseed (-1.8) and soy oils (-1.0), but less than proportionally after a surge in palm oil price (-0.5) (table 6). The supply of palm oil and price of rapeseed oil are positively correlated; similar conclusions are derived for the supply of rapeseed oil and price of sunflower oil.

The estimated response of vegetable oils supplies to prices of related products in the EU market has been somewhat controversial. Guyomard et al. (1996) find that the supply functions of rapeseed, soy, and sunflower are inelastic (exception made for soy), upward sloping in their own price and downward sloping in cross prices. Our results agree with those of Guyomard et al. (1996), exception made for the elasticities of soy to prices of rapeseed (as we find a null effect), and for rapeseed and sunflower which move in the same direction. The differences in results are likely to

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[25] In order to convey the implications of our findings we show, in figure A.1 in the Appendix A.4, how the available output of soy oil tends to react to changes in palm oil price.

reflect the different focus of the studies: our analysis is intended to investigate the linkages among vegetable oils; Guyomard et al. (1996) examine the supply response of crops to changes in prices. We investigate the price relationships among supplies of major inputs of first-generation biodiesel. Overall, we find that domestically produced vegetable oils tend to be net substitutes in supply: an increase in prices of one vegetable oil reduces the availability of other vegetable oils. An exception is the complementarity relationships between sunflower price and rapeseed quantity. The imported palm oil tends to move together with domestically produced vegetable oils, exception made for sunflower oil, that tend to be complement with palm oil. Price elasticities are informative in terms of environmental implications of policy interventions. The emissions associated with ILUC and the emissions saving from biofuel vary on a case-by-case basis: the net effect of GHG saving depends on the feedstock whose production is expanding. The empirical results reveal that increases in price of one oil may reduce the supply of other domestically produced vegetable oils (e.g. rapeseed, soy, and sunflower oils) that are low GHG saving feedstocks, and increase imports of palm oil, which is responsible of high ILUC (Edwards et al., 2017). Investigating the supply responsiveness of vegetable oils to price changes allows the EU government to better design the EU biofuel policies. In addition, we speculate on how the supply responsiveness to price changes may be informative to plan sustainable biofuel policies. Our results suggest that EU policies incentivising the use of first-generation biodiesel may foster competition among domestically produced feedstocks, and benefit imported feedstock (i.e. palm oil). Such a conclusion may be explained by the ability of the biofuel industry to substitute feedstocks that are competing for similar end uses. A side-effect of such hypothesised policies would be the expansion of oil palm plantations that may induce important impacts in terms of ILUC emissions. The environmental and socioeconomic problems entailed by large-scale production of feedstock for biofuel should discourage policies that favour imports of feedstocks to reach the domestic target in the use of renewable energy. Our analysis offers several insights to help planning biofuel policies and preventing excessive GHG emissions.

5.2 Price responsiveness of oilseeds acreages

Table 7 present the SURE estimates of the acreage response equation. The system of equations controls for time and country fixed effects to account for structural or policy changes and heterogeneity across countries, respectively[26]. The high R-squared (never lower than 0.95) and the low RMSE (never higher than 0.005) indicate the goodness of the model. As expected, the lagged dependent variables are positive as well as statistically and economically significant in all acreage response model.

We fail to find a significant acreage-price relationship for sunflower seeds. As for soybeans, the acreage response to own price is positive and statistically significant at the 1% significance level, which is consistent with economic theory. The results suggest that a higher price of soy oil induces producers to increase acreage devoted to soybeans. This result is consistent with previous studies that find positive effects of price change on soybean acreage. For instance, Haile et al. (2016) found that changes in international price of soybeans increase by 0.15 acreages devoted to soybeans cultivation. As for country-level studies, a positive response of soybean acreages to changes in own-price is found by Lee and Helmberger (1985) (+0.35), Shideed and White (1989) (+0.41), Chavas and Holt (1990) (+0.06), Arnade and Kelch (2007) (+0.05), Hendrick et al. (2014) (+0.36), Kim and Moschini (2018) (+0.38). The focus of these studies is on the US market. Our results suggest a lower responsiveness of the EU market to changes in price of soy oil (+0.009).

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[26] In a sensitivity analysis we estimate the model in equation (3) without country fixed effects. For more details, see table A.3 in the Appendix A.6.

Table 7. Seemingly Unrelated Regression Equation (SURE) estimation of the model in equation (3).

	Dependent variables: Share of acreage		
Variables	Rapeseed	Soybeans	Sunflower seeds
Lagged dependent variable	0.850***	0.742***	0.741***
	(0.025)	(0.026)	(0.033)
Palm oil (log)	0.013**	0.001	0.001
	(0.007)	(0.002)	(0.006)
Rapeseed oil (log)	0.044	-0.008	0.001
	(0.030)	(0.009)	(0.027)
Soy oil (log)	0.018	0.009***	-0.004
	(0.011)	(0.003)	(0.010)
Sunflower oil (log)	-0.057**	-0.001	0.006
	(0.026)	(0.008)	(0.023)
RMSE	0.005	0.001	0.005
R-squared	0.959	0.954	0.974

Notes: The system of equations includes time and country fixed effects. Standard errors are in parentheses. ***, **, and * indicate statistical significance at 1%, 5%, and 10%.

The results also show that rapeseed has the largest acreage response to cross-oil prices. Its acreage share increases with a surge in the price of imported palm oil, and decreases when the price of sunflower oil increases. For instance, a change in the average imported price of palm oil from 903 \$/t to 993 \$/t (a 10% increase) induces farmers to increase their land allocation to rapeseed cultivation by 8,632 ha (a 0.013% increase, considering an average acreage of 6,640 thousands of ha during the period between 2010-2016, see table 3). Differently, a 10% rise in sunflower oil price (say from 1,137 \$/t to 1,251 \$/t) determines a reduction in land allocation to rapeseed cultivation by 0.057% (say from 6,640 thousands of ha to 6,636 thousands of ha during the period between 2010-2016, see table 3). Our results are consistent with Guyomard et al. (1996) who find that the acreage response of rapeseed to changes in price of sunflower is -0.10.

In order to test if acreage of oilseeds has a different responsiveness to changes in prices of vegetable oils pre- and post-biofuel era, we perform a sensitivity analysis. In particular, we evaluate price responsiveness of oilseeds acreage in the post-biofuel era, i.e. since 2003, the year of entry into force of the first Biofuel Directive (2003/30/EC)[27]. We find that effects observed on the whole period (table 6) are driven by effects observed in the pre-biofuel era, with effects found on the whole period confirmed on the sample of year post-biofuel era. Further, we find that acreage devoted to the cultivation of rapeseed also respond to changes in price of soy oil. in line with Hamulczuk et al. (2019), we may argue that the demand driven expansion in the vegetable oils market, due to an increasing request from the biofuel industry, has tightened the linkages across markets.

Our findings have implications in terms of land use effects. An increase in price of sunflower oil decreases the use of land for rapeseed. The results are coherent with the effects we found for prices responsiveness of rapeseed oil supply: a complementary relationship links sunflower oil price and rapeseed oil quantity. An increase in sunflower oil price augments the domestic production of both rapeseed and sunflower oils (see table 6). At the domestic level, this puts land allocation to rapeseed cultivation and sunflower cultivation in competition with each other due to land constraint. This effects explains the negative acreage response of rapeseed to a surge in sunflower oil price.

Differently, an increase in the price of imported palm oil, for instance due to palm oil imports restrictions for food safety (e.g. Palm Oil free campaigns) or environmental (e.g. displacement effects on non-cropland, reduction in GHG saving effects) concerns, results in a major use of land for rapeseed. Both the land use effects would be more relevant in northern EU countries, where the production of rapeseed is the most intense (see figure 1). In fact, the acreage response to changes in prices of vegetable oils presents some differences between countries that tend to be net producers of rapeseed or of soy and sunflower oils. In a sensitivity analysis, we divide the sample of countries in net produces of rapeseed (i.e. Belgium, Czechia, Denmark, Estonia, Finland, France, Germany,

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[27] The results of the sensitivity analysis are reported in the Appendix A.6.

Ireland, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Slovakia, Slovenia, Sweden, United Kingdom) and net producers of soybeans and sunflower seeds (i.e. Austria, Bulgaria, Croatia, Cyprus, Greece, Hungary, Italy, Malta, Portugal, Romania, Spain)[28]. Findings suggest that the share of acreage intended to the cultivation of rapeseed is sensitive to changes in prices of all vegetable oils for countries that tend to be net producers of rapeseed. In detail, the acreage share of rapeseed grows with an increase in prices of imported palm oil and of domestically produced rapeseed and soy oils, whereas it reduces when prices of sunflower oil increases. The results are confirmed also for the sample of net producers of rapeseed observed in the post-biofuel era (i.e. since 2003). Differently, the share of acreage intended to the cultivation of oilseeds in countries that tend to be net producers of soybeans and sunflower seeds do not respond to changes in prices of vegetable oils. The only exception is the positive relationship linking soybeans acreage and price of soy oil. Similar results are also found for the sample of net producers of soybeans and sunflower seeds observed in the post-biofuel era (i.e. since 2003).

Overall, we may conclude that the effects found on the sample of all countries are mostly driven by price responsiveness of acreage in net producers of rapeseed. For instance, if hypothetic restrictions in the EU imports of palm oil, due to food safety or environmental concerns, determine a surge in imported price, more land is likely to be devoted to rapeseed cultivation in countries that tend to be net producers of rapeseed (e.g. Czech, Germany, Estonia, Slovakia). Differently, an increase in price of sunflower oil decreases the use of land for rapeseed in those countries.. Findings also reveal that biofuel policies in the EU tend to be tailor-made on rapeseed oil which is domestically produced and consumed; in fact, the ratio between trade (imports and exports) and production constantly reduces overtime (it moves from 0.28 in 1992-1997 to 0.10 in 1998-2003, to 0.07 in 2004-2009 and 2010-2016, see table 4). Differently, for soy and sunflower oils trade dynamics are more relevant than productive dynamics.

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[28] The results of the sensitivity analyses are reported in the Appendix A.6.

6. Concluding and policy implications

The demand driven expansion in the vegetable oils market, due to an increasing request from the biofuel industry, has tightened the linkages across markets. This phenomenon has interested also the EU, where the growing expansion of biofuel production is mostly due to a political framework implemented to achieve fuel security and environmental goals (Peri and Baldi, 2013). On top of this, the prominent role that vegetable oils play in the new biofuel era and the constant attention to the raising levels of GHG emissions, both direct and indirect (via land use changes), highlight the importance of understanding cross-commodity linkages in the vegetable oils market. We investigated the relationships among main sources of biodiesel in the EU, by examining how quantities of palm, rapeseed, soy, and sunflower oils react to changes in own prices and in prices of related feedstocks. We also examined the acreage response of domestically produced feedstocks to changes in prices of vegetable oils. The main scope was to understand the relationships among the major inputs of first-generation biodiesel, in order to derive implications in terms of land use and on the sustainability of biofuel policies in the EU.

The results highlighted a high competition among domestically produced vegetable oils, to the benefits of imported palm oil. Our findings are in line with the acreage response of rapeseed to changes in price of sunflower estimated by Guyomard et al. (1996) for the EU market. Our estimates are also comparable with evidence from other cases study, such as the US market (e.g. Arnade and Kelch, 2007; Hendrick et al., 2014; Kim and Moschini, 2018). In terms of land use effects, we found that an increase in the price of imported palm oil results in a displacement effect in land allocation to rapeseed cultivation. Such a displacement effects across vegetable oils are likely to be induced by policies incentivising biofuel demand (Hamulczuk et al., 2019).

The price responsiveness found for vegetable oils allowed us to provide insights on the future development of biofuel policies. A policy measure in the EU, incentivising the production of renewable and environmental-friendly fuel from sustainable feedstocks, may determine an expansion of biodiesel demand and a consequent increase in prices of feedstocks. The altered equilibrium prices would increase the domestic production of soy and sunflower oils, as a result of the high responsiveness of their supplies to own-prices. However, higher prices of domestically produced oils, such as soy and rapeseed oils, would increase imports of palm oil. From an environmental perspective, the hypothesised policy would be positive for the domestic market to the extent that it stimulates the production of vegetable oils (soy and sunflower oils) with the highest direct and indirect GHG saving (Edwards et al., 2017). However, the side-effects of such a policy would be the expansion of oil palm plantations in extra-EU producing countries, with important impacts in terms of indirect land use change emissions, and the increase in direct emissions due to the transports of greater imported quantities of palm oil. These side-effects would deprive the hypothesised policy of its twofold role: increase efficiency in the use of resources, while preventing the production emissions.

Although attractive, the policy expectations for biofuel in the EU (e.g. GHG emissions reduction, domestic energy security, agro-industrial development) are difficult to achieve together in particular if vague or narrowly defined in regulations, as suggested by Hunsberger et al. (2017). Indeed, as shown in the empirical results, the efficacy and efficiency of environmental-friendly biofuel policies may depend on the interactions among biofuel feedstock markets. A policy framework for biofuel in the EU that considers interdependencies among resources and among policy sectors, accounting for path dependencies, are recommended to achieve a sustainability in the biofuel market.

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Appendix

A.1 Interpretation of price elasticies in the supply response equation

The models in equations (1) and (2) are estimated in log form so to have coefficients easily interpretable as elasticities. The elements of the matrix of coefficients of interest (**E**) in equation (2) represent the own-PES (ε_{ii}) and the cross-PES (ε_{ij}) of supply. The own-PES quantifies how quantities react to changes in its own price ($\frac{\partial y_i}{\partial p_i}\frac{p_i}{y_i}$); the cross-PES quantifies how quantities react to a change in price of a different commodity ($\frac{\partial y_i}{\partial p_j}\frac{p_j}{y_i}$). In line with the economic theory, the own-PES is expected to be non-negative, whereas the cross-PES is positive if the supply of i and j tend to move together, and negative if the opposite is true. As for the magnitude of the coefficients, own-PES or cross-PES greater than one in absolute value ($|\varepsilon| > 1$) characterise the supply as price elastic, while own-PES or cross-PES lower than one in absolute value ($|\varepsilon| < 1$) are typical of price inelastic supply. As suggested in Britz and Hertel (2011), the magnitude of own-PES or cross-PES depends on the relative importance of the vegetable oil, the flexibility of the supply, and the substitutability of vegetable oils.

A.2 Acreage response equations: controlling for the land constraint

In a sensitivity analysis we estimate the model in equation (3) including own- and cross-lagged shares to maintain the land constraint $s_{rapeseed} + s_{soybeans} + s_{sunflower\ seeds} + s_{other} = 1$. The results, reported in table A.2, confirm main findings.

Table A.1. The share of rapeseed acreage increases (decreases) with a palm (sunflower) oil price increase.

	Dependent variables: Share of acreage		
Explanatory variables	Rapeseed	Soybeans	Sunflower seeds
Lagged rapeseed share	0.842***	0.005	0.017
	(0.025)	(0.007)	(0.022)
Lagged soybeans share	-0.108	0.727***	-0.062
	(0.0895)	(0.026)	(0.079)
Lagged sunflower seeds share	0.0645*	0.026**	0.749***
	(0.039)	(0.011)	(0.034)
Palm oil (log)	0.014**	0.001	0.001
	(0.007)	(0.002)	(0.006)
Rapeseed oil (log)	0.046	-0.007	0.002
	(0.030)	(0.009)	(0.027)
Soy oil (log)	0.017	0.008***	-0.004
	(0.011)	(0.003)	(0.010)
Sunflower oil (log)	-0.058**	-0.001	0.005
	(0.026)	(0.008)	(0.023)
RMSE	0.005	0.002	0.005
R-squared	0.960	0.954	0.975

Notes: Seemingly Unrelated Regression Equation (SURE) estimation of the model in equation (3). Shares for other uses are the baseline. The system of equations includes time and country fixed effects. Standard errors are in parentheses. ***, **, and * indicate statistical significance at 1%, 5%, and 10%.

A.3 Descriptive statistics

The table A.2 provides descriptive statistics of key variables.

Table A.2. Descriptive statistics for key variables.

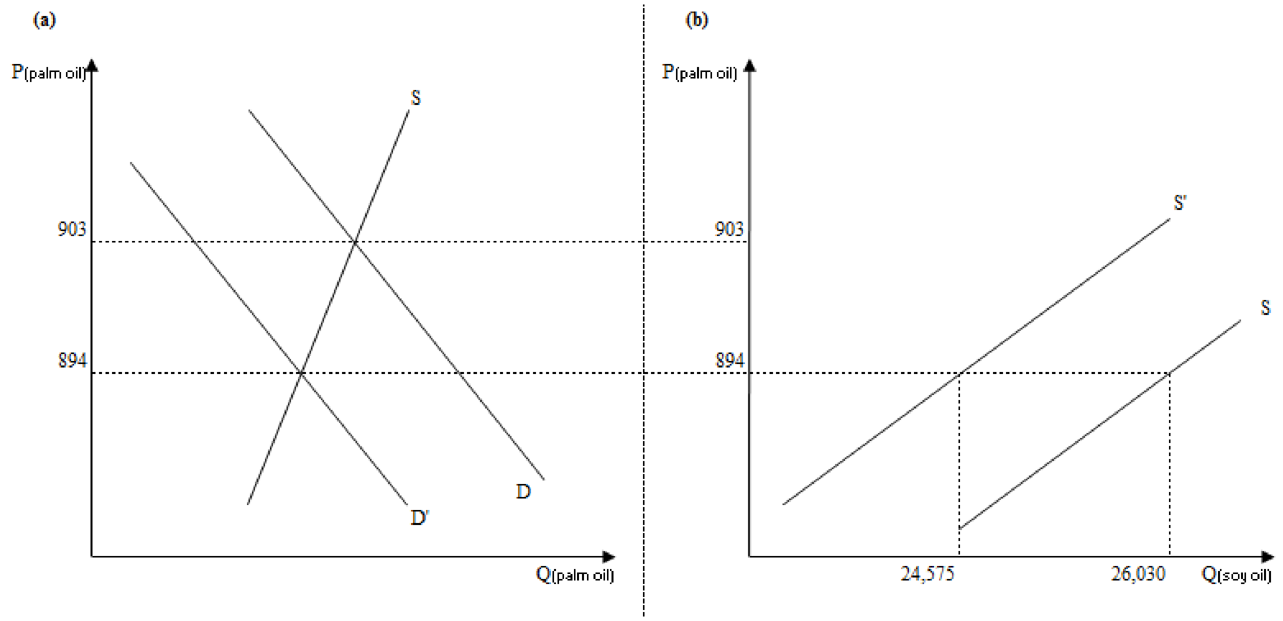
Variable	μ_x $(\pm\sigma_x)$ $[\underline{x};\ \overline{x}]$				
	Production (Tg)	Imports (Tg)	Exports (Tg)	Acreage (share)	Price ($/t)
Palm oil	00.00 (±00.00)	40.30 (±18.52)	1.01 (±0.42)	0.00 (±0.00)	902.93 (±437.06)
	[00.00; 00.00]	[15.30; 69.69]	[0.46; 2.00]	[0.00; 0.00]	[229.64; 1,929.77]
Rapeseed oil	61.46 (±28.22)	1.93 (±2.14)	3.92 (±2.76)	0.02 (±0.03)	983.42 (±147.43)
	[23.11; 106.03]	[0.03; 7.28]	[0.52; 9.44]	[0.00; 0.10]	[786.72; 1,389.50]
Soy oil	26.03 (±2.34)	2.97 (±3.30)	6.84 (±2.61)	0.002 (±0.01)	1,010.43 (±160.40)
	[22.20; 32.45]	[0.04; 10.38]	[2.44; 10.52]	[0.00; 0.05]	[800.77; 1,483.36]
Sunflower oil	24.16 (±4.05)	6.85 (±4.25)	2.24 (±1.02)	0.01 (±0.03)	1,137.11 (±211.83)
	[18.08; 32.32]	[1.08; 13.00]	[0.87; 4.58]	[0.00; 0.15]	[926.79; 1,637.08]

Notes: Descriptive statistics are mean (μ_x), standard deviation (σ_x), minimum ($\underline{x}$), and maximum ($\overline{x}$) of variables (x). Tg stands for 10^{12} g.

A.4 Comparing supplies of vegetable oils in the EU and the US

Our results show (see table 5) that palm and soy oils to be closely related: the market for palm oil tends to expand with upward prices in soy oil market, and vice-versa. In particular, the cross-PES of palm oil to soy oil price is elastic (+1.1), whereas the cross-PES of soy oil to palm oil prices is inelastic (+0.5). In order to convey the implications of our findings we show, in figure A.1, how the supply of soy oil tends to react to changes in palm oil price: for instance, the contraction of palm oil demand in the EU (i.e. a leftward demand shift from D to D', shown in panel (a)), possibly due to concerns risks related to the consumption of palm oil, would contract the supply of soy oil (i.e. a leftward demand shift from S to S', shown in panel (b)). Panel (a) shows an inelastic supply for palm oil (the own-PES equals 0.2, as from table 3), and price changes from 903 $/t to 894 $/t (one percent reduction). The cross-PES between soy and palm oils (0.5, as from table 3) implies that a price reduction for palm oil determines a (less than proportional) reduction in the available quantity of soy oil (i.e. a leftward shift from S to S’, as shown in panel (b)).

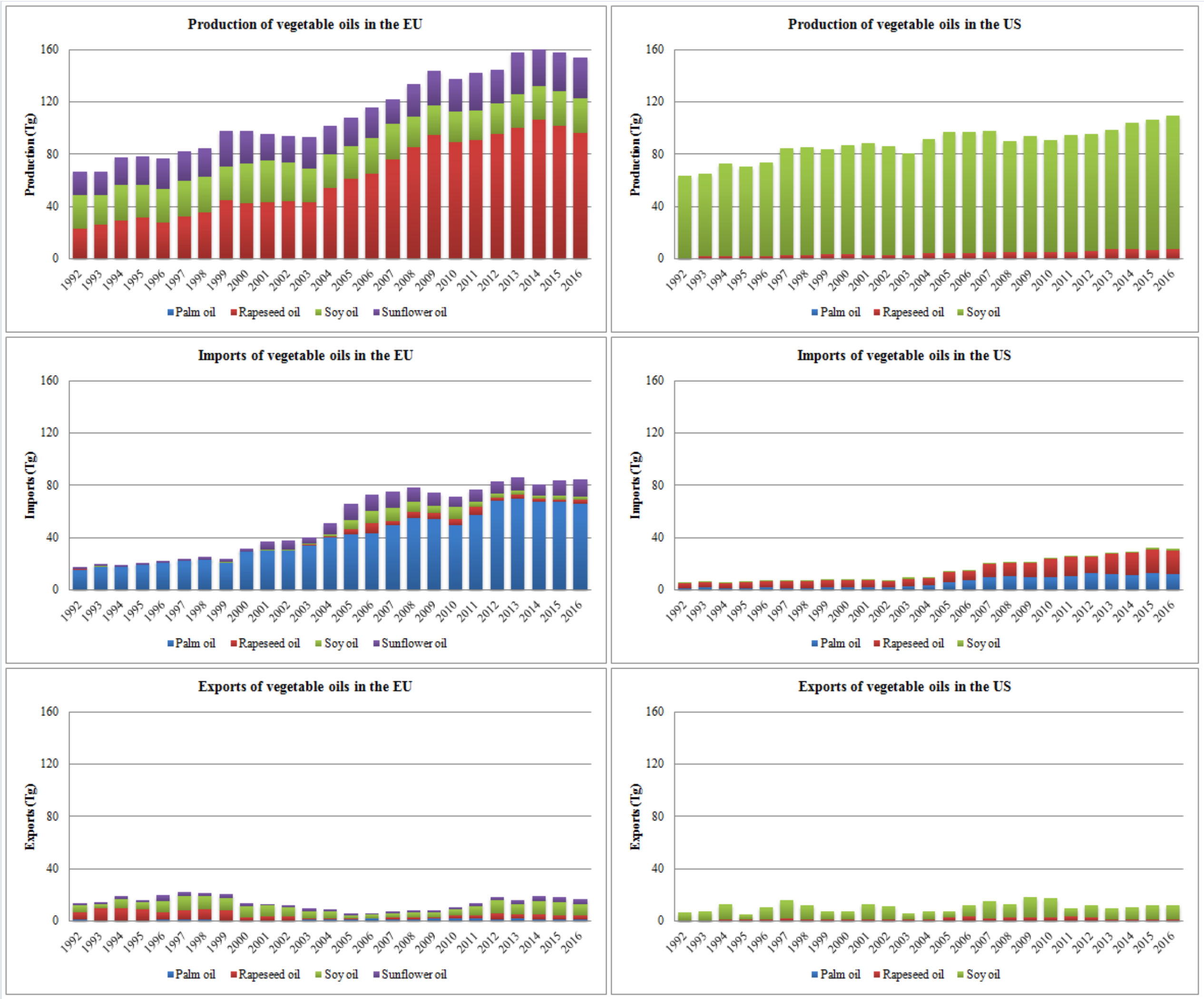
Figure A.1. Linkages between palm and soy oils markets.



A.5 Comparing supplies of vegetable oils in the EU and the US

The figure A.1 shows the composition of supply of vegetable oils in the EU and in the US.

Figure A.2. Production, imports, and exports of vegetable oils in the European Union (EU) and in the United States (US), 1992-2016.



Source: Elaboration on data from USDA FAS PSDO. Tg stands for 10^{12} g.

As regards palm oil, both the US and the EU are not producers: imports cover all domestic consumption. The US produces larger quantities of soy oil than the EU. In particular, the EU imports and crushes large quantities of whole soybeans in order to produce soy oil: domestic consumption is mainly due to domestic production. Rapeseed oil (canola oil in the US) has different profiles in the two markets: the EU is a great producer, while the US domestic consumption is essentially based on imports. The EU widely consumes sunflower oil, and imports compensate an insufficient domestic production.

A.6 Acreage response equations: sensitivity analyses

We estimate the model in equation (3) without country fixed effects.

Table A.3. The share of rapeseed acreage increases (decreases) with a palm (sunflower) oil price increase.

	Dependent variable s: Share of acreage		
Explanatory variables	Rapeseed	Soybeans	Sunflower seeds
Lagged dependent variable	1.003***	1.005***	1.014***
	(0.011)	(0.012)	(0.008)
Palm oil (log)	0.0121*	0.0004	0.002
	(0.007)	(0.002)	(0.006)
Rapeseed oil (log)	0.048	-0.010	0.004
	(0.033)	(0.010)	(0.029)
Soy oil (log)	0.013	0.008**	-0.009
	(0.012)	(0.004)	(0.010)
Sunflower oil (log)	-0.058**	0.001	0.006
	(0.028)	(0.009)	(0.024)
RMSE	0.006	0.002	0.005
R-squared	0.953	0.940	0.970

Notes: Seemingly Unrelated Regression Equation (SURE) estimation of the model in equation (3). The system of equations includes time fixed effects. Standard errors are in parentheses. ***, **, and * indicate statistical significance at 1%, 5%, and 10%.

We evaluated price responsiveness of oilseeds acreage in the post-biofuel era (since 2003, the year of entry into force of the first Biofuel Directive – 2003/30/EC). The aim of this analysis is to test if acreage of oilseeds has a different responsiveness to changes in prices of vegetable oils pre- and post-biofuel era. Results are reported in table A.4.

Table A.4. Seemingly Unrelated Regression Equation (SURE) estimation of the model in equation (3); sample of years post-biofuel era (since 2003).

	Dependent variables: Share of acreage		
Variables	Rapeseed	Soybeans	Sunflower seeds
Lagged dependent variable	0.699***	0.359***	0.320***
	(0.041)	(0.057)	(0.049)
Palm oil (log)	0.015**	0.002	0.001
	(0.007)	(0.002)	(0.005)
Rapeseed oil (log)	0.041	-0.004	-0.004
	(0.031)	(0.008)	(0.022)
Soy oil (log)	0.022**	0.011***	0.003
	(0.011)	(0.003)	(0.008)
Sunflower oil (log)	-0.056**	-0.004	0.005
	(0.027)	(0.007)	(0.018)
R-squared	0.964	0.969	0.986

Notes: The system of equations includes time and country fixed effects. Standard errors are in parentheses. *** and ** indicate statistical significance at 1% and 5%.

We divide the sample of countries in net produces of rapeseed (i.e. Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Ireland, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Slovakia, Slovenia, Sweden, United Kingdom) and net producers of soybeans and sunflower seeds (i.e. Austria, Bulgaria, Croatia, Cyprus, Greece, Hungary, Italy, Malta, Portugal, Romania, Spain). Note that a country is a net producer of rapeseed if the average share of acreage intended to the cultivation of rapeseed is greater than the average share of acreage cultivated with soybeans and sunflower seeds; the opposite is true for net producers of soybeans and sunflower seeds. The results for the entire period and for the period post-biofuels are reported in tables A.5 and A.6 for the sample of net producers of rapeseed and in tables A.7 and A.8 for the sample of net producers of soybeans and sunflower seeds.

Table A.5. Seemingly Unrelated Regression Equation (SURE) estimation of the model in equation (3); sample of net producers of rapeseed.

	Dependent variables: Share of acreage		
Variables	Rapeseed	Soybeans	Sunflower seeds
Lagged dependent variable	0.860***	0.969***	0.576***
	(0.031)	(0.028)	(0.042)
Palm oil (log)	0.020**	0.00004	-0.001
	(0.009)	(0.001)	(0.004)
Rapeseed oil (log)	0.076*	-0.003	-0.009
	(0.042)	(0.003)	(0.017)
Soy oil (log)	0.040***	0.002**	-0.002
	(0.015)	(0.001)	(0.006)
Sunflower oil (log)	-0.097***	0.001	0.008
	(0.036)	(0.002)	(0.014)
R-squared	0.955	0.940	0.955

Notes: The system of equations includes time and country fixed effects. Standard errors are in parentheses. ***, **, and * indicate statistical significance at 1%, 5%, and 10%.

Table A.6. Seemingly Unrelated Regression Equation (SURE) estimation of the model in equation (3); sample of net producers of rapeseed in post-biofuel era (since 2003).

	Dependent variables: Share of acreage		
Variables	Rapeseed	Soybeans	Sunflower seeds
Lagged dependent variable	0.662***	0.977***	-0.103*
	(0.053)	(0.057)	(0.056)
Palm oil (log)	0.022**	0.00003	-0.0002
	(0.009)	(0.001)	(0.003)
Rapeseed oil (log)	0.072*	-0.003	-0.008
	(0.044)	(0.003)	(0.013)
Soy oil (log)	0.045***	0.002*	0.005
	(0.016)	(0.001)	(0.005)
Sunflower oil (log)	-0.094**	0.001	0.003
	(0.037)	(0.002)	(0.011)
R-squared	0.956	0.942	0.979

Notes: The system of equations includes time and country fixed effects. Standard errors are in parentheses. ***, **, and * indicate statistical significance at 1%, 5%, and 10%.

Table A.7. Seemingly Unrelated Regression Equation (SURE) estimation of the model in equation (3); sample of net producers of soybeans and sunflower seeds.

	Dependent variables: Share of acreage		
Variables	Rapeseed	Soybeans	Sunflower seeds
Lagged dependent variable	0.767***	0.745***	0.759***
	(0.043)	(0.040)	(0.050)
Palm oil (log)	0.004	0.002	0.007
	(0.007)	(0.005)	(0.013)
Rapeseed oil (log)	-0.006	-0.016	0.017
	(0.033)	(0.021)	(0.059)
Soy oil (log)	-0.014	0.019**	-0.006
	(0.012)	(0.008)	(0.021)
Sunflower oil (log)	0.004	-0.003	0.001
	(0.028)	(0.018)	(0.050)
R-squared	0.895	0.951	0.973

Notes: The system of equations includes time and country fixed effects. Standard errors are in parentheses. *** and ** indicate statistical significance at 1% and 5%.

Table A.8. Seemingly Unrelated Regression Equation (SURE) estimation of the model in equation (3); sample of net producers of soybeans and sunflower seeds in post-biofuel era (since 2003).

	Dependent variables: Share of acreage		
Variables	Rapeseed	Soybeans	Sunflower seeds
Lagged dependent variable	0.766***	0.330***	0.407***
	(0.060)	(0.089)	(0.075)
Palm oil (log)	0.004	0.004	0.004
	(0.008)	(0.004)	(0.010)
Rapeseed oil (log)	-0.006	-0.008	0.005
	(0.037)	(0.018)	(0.047)
Soy oil (log)	-0.014	0.022***	0.004
	(0.013)	(0.007)	(0.017)
Sunflower oil (log)	0.004	-0.008	0.003
	(0.031)	(0.016)	(0.039)
R-squared	0.902	0.969	0.987

Notes: The system of equations includes time and country fixed effects. Standard errors are in parentheses. *** indicates statistical significance at 1%.