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European farmers' responses to higher commodity prices: cropland expansion or forestlands preservation?

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ABSTRACT

This paper analyses the impact of European farmers' responsiveness to changes in agri-commodities prices on their trade-off between agricultural expansion and forestland preservation. We investigate this issue by estimating a recursive model using a comprehensive dataset of European agricultural holdings over the period 2008-2017, covering 128 regions (26 countries). Our main finding is that there is indeed evidence of such a trade-off. An increase in commodity prices leads to higher cropland profitability, which in turn causes deforestation in the 128 European regions considered. Replicating the analysis on different subsamples confirms the robustness of these findings.

KEYWORDS

Agricultural commodity prices; Land-use change; Cropland; Woodland.

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1. Introduction

In Europe, since the 1990s, the evolution of agricultural and forest land has been identified as the main driver of land-use changes, with a strong heterogeneity between the different regions (Plieninger et al., 2016). Contrary to global level observations, reforestation and declining agricultural land are noticed in Western Europe (FAO, 2020, Mather, 2002). Existing studies identify several socio-economic explanations for these phenomena in Europe. Among others, a massive abandonment of agricultural land, agro-climatic conditions, urbanization, and low farm productivity have concurred with the ongoing reforestation and decrease in agricultural land observed across Europe (Kuemmerle et al., 2016; Oliveira et al., 2019; Ustaoglu and Collier, 2018).

While there is a consensus of an overall ongoing reforestation (see Appendix E), there is some evidence that, at the micro-level, changes in cropland still conflict with woodland managed by farmers in many regions in Europe (Petit et al., 2003; Blanco et al., 2020 among others). This pattern can be observed in Figure 1, which displays the joint evolution of woodland areas and utilized agricultural areas (UAA) of farming holdings surveyed over the period between 2004 and 2018. Consequently, the trade-off of farmers, who also are private forestland owners, between croplands and woodlands does not necessarily follow the European global patterns, implying macro and micro-level inconsistencies.

From a theoretical perspective, the optimal land-use theory, inspired by Von Thünen (1875), identifies changes in the land rent of different uses as the key factor explaining changes in land uses. In this approach, commodity prices play a crucial role in farmers' land allocation (between cropland expansion and forestland preservation), especially when privately owned. A rise in agricultural prices logically increases rents of agricultural land uses, and will result in forestland conversions into agricultural land (Byerlee et al., 2014; Garrett et al., 2018). Reciprocally, forests are to be conserved if they are more profitable than other possible uses (Ahrends et al., 2010; Indarto and Mutaqin, 2016). Against this background, our paper proposes to assess the interconnection between commodity prices, and land-use changes between agricultural and forest areas within European regions.

The contribution of our paper is twofold. Firstly, we build off the previous theoretical arguments and empirical evidence to assess the responsiveness of crop supply to agri-commodity prices simultaneously with European farmers' trade-off between agricultural intensification and forestland preservation. Secondly, we give a full picture of the interconnection between commodity prices, agricultural and forests land use within a unique framework, contrary to existing studies.[1] More specifically, we propose a recursive model that assesses the multiplicity of pathways from higher commodity prices to changes in land-use. We also attempt to account for the endogeneity problem generated by feedback effects across variables and control for the presence of geographical spillovers among woodland areas. The analysis uses panel data for 128 European regions, from 26 countries, over the period 2008-2017[2]

[1] We are essentially referring here to studies on price-responsiveness of crop yields or on the cropland deforestation and crop supply-deforestation nexuses, where both research questions are separately addressed.

[2] We choose the period 2007-2017 to include the maximum number of European regions.

that has been characterized by a steady increase of real agricultural prices (FAO and Unece, 2015; CEPF, 2020).

The empirical results from the baseline model provide evidence that an increase in agricultural prices has a statistically significant positive impact on crop yield, which in turn, leads to woodland losses. Despite the global reforestation process noted in Europe, we thus show that the intensification of crop supply conflicts with forestland at the farm-level (Jevons effect [3]) through increases in agricultural prices. Moreover, these findings are robust when considering only regions with significant forestlands and controlling for the level of farm income and environment protection expenditures.

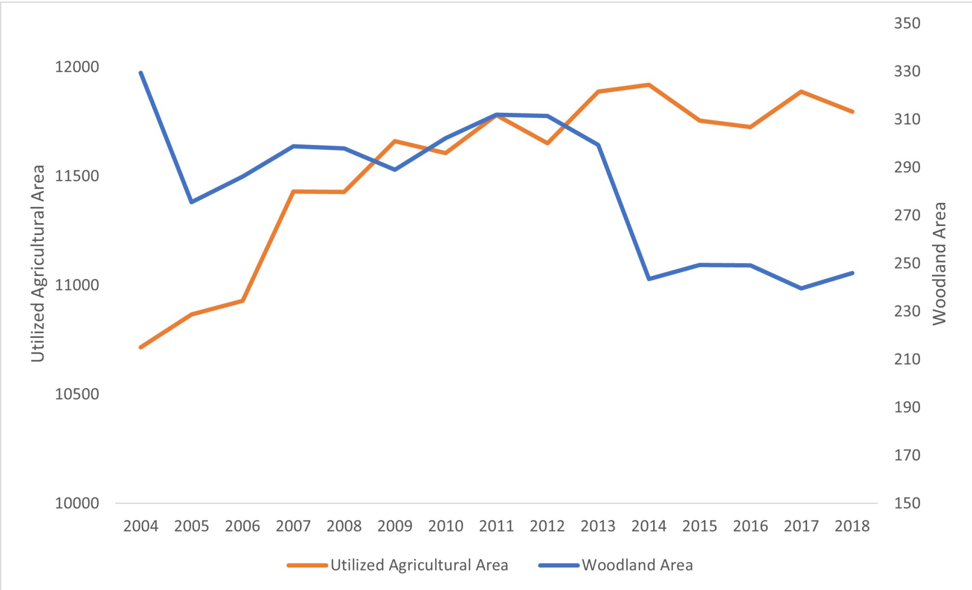

Figure 1. Evolution agricultural areas and woodland in 128 European regions

Note. The two variables are extracted from FADN databases and expressed in ha.

The remaining of this paper is organized as follows. Section 2 presents a brief review of the literature. Section 3 describes the empirical strategy and discusses the dataset constructed for this analysis. Section 4 presents the results of our empirical analysis. We check the robustness of our results in Section 5 and draw some concluding remarks in Section 6.

2. Literature review

The relations among agricultural expansion, deforestation, and agricultural commodity prices have been the subject of a large literature. However, all papers focus on two of these variables at a time, with no studies examining how all three factors interact.

[3]The Jevons or rebound effect in our context is a phenomenon by which increasing efficiency (crop supply per hectare) will lead to increases in cropland.

A large literature looks at the responsiveness of crop production to changes in price. The founding work by Nerlove (1958), Behrman (1966), Yotopoulos and Lau (1974), Houck and Gallagher (1976) and Choi and Helmberger (1993) point out the importance of commodities prices, as they determine the relative importance of crops, farm size, and resources available to the farmer. All other things being equal, in reaction to (expected) price changes, the crop mix is qualitatively and quantitatively adjusted to achieve higher incomes. Reviewing leading empirical studies on agricultural supply's and/or price-elasticity of the farmers' supply, Askari and Cummings (1977), Rao (1989), and Schiff and Montenegro (1997) argue that, though proxies for price expectations and non-price factors are problematic, the long-run elasticities range between 0.3 and 1.2. Recently, empirical contributions to the topic have also assessed output and input (fertilizers) prices elasticities of crop supply as a policy instrument (Berry and Schlenker, 2011; Miao et al., 2016). Since the ecological impacts of food production and land-use can be quantified through the price elasticities of crop supply and acreage, these elasticities' estimates are of fundamental importance (Scott, 2013; Williamson, 2011). Thereby, the study by Miller and Plantinga (1999) estimates a crop yield elasticity of about 0.95, while Lin and Dismukes (2007) and Barr et al. (2011) respectively report values between 0.17-0.35 and 0.01-0.03. Estimates of crop yield's price-elasticity largely depend on the sample, period, and empirical strategies (Scott, 2013).

A second strand of the literature looks at the trade-off between land-use for agriculture and woodland conservation. The optimal land-use theory assesses the sequence of possible land allocations and the farmer's trade-off between agricultural production and woodland. This theory, animated by Amsberg (1994, 1998), Angelsen (1999), Walker (2004) and Angelsen (2007), among others, analyses the farmer's decision to convert wilderness (unmanaged forests) or woodland into farmland. These studies highlight the role of market structure (rents and prices) in the farmer's optimal choice and identify factors such as land clearing for crops and pasture and illegal logging as directly linked to deforestation. Similar to rents, increasing prices promote the conversion of (un-) managed forest land into other uses. As the farmer's trade-off is based on profit maximization behaviour, this theory has recently led to conservation policies towards environmental subsidies or compensation, considering woodland preservation as forgone benefits of farming Ahrends et al., 2010; Indarto and Mutaqin, 2016).

There is also evidence that agricultural intensification can influence the cropland-woodland nexus at the farm-level. This has been the case, among others, in the works by Byerlee et al. (2014), Hertel (2012), and Richards et al. (2012). Through its Common Agricultural Policy (CAP), Europe has encouraged the intensification of agricultural practices, promoting homogeneity of the landscape, the reinforcement of the use of chemical inputs (pesticides and fertilizers), and the abandonment of the less productive land. Nevertheless, several works have highlighted the complex nature of the relationship between intensification and farmland-forestland nexus. On the one hand, increasing productivity seems an obvious answer to meet its challenges without agricultural expansion taking over forest areas (Borlaug, 2002). On the other hand, the increase in productivity, following intensive practices, will increase farmland profitability compared to other land uses and induce agricultural land expansion (Lambin et al., 2001). In the same vein, Byerlee et al. (2014) identify two main drivers of intensification: technological change and market opportunities, and conclude that market-driven agricultural intensification (crop yield per hectare) resolves into cropland expansion at the cost of woodlands, as predicted by the Jevons' Paradox. The latter posits that 'increases in agricultural productivity will be accompanied by an expansion in the land area' (Hertel, 2012). In this paradigm, several studies have empirically assessed agricultural intensification in European regions and find results indicating that agricultural expansion has contributed to the depletion of wooded areas managed by farmers. Works on individual case in France (Blanco et al., 2020) and Spain (Arnaiz-Schmitz et al., 2018) reach similar outcomes.

Furthermore, other individual factors may be involved in this trade-off. For instance, while trees can be blamed for competing with crops by hindering mechanized work (Blanco et al., 2019), parasites and wild mammals (sheltered by Woodlands) negatively affect crops and livestock (Ango et al., 2014; Dorresteijn et al., 2017). In conclusion, despite the global reforestation in Europe, micro-level analyses, as intended by this paper, provide evidence suggesting that agricultural intensification conflicts with woodlands managed by farmers.

Notwithstanding the insights provided by this literature, we lack solid evidence on agricultural prices as a major driver of these land-use changes. The following section aims to investigate this issue empirically.

3. Empirical strategy

3.1. Regression methodology

To assess the trade-off between land-use for agriculture and woodland conservation from changes in agri-commodities prices, we rely on a recursive system of two equations:

$$y_{it} = \beta_0 + \beta_1 x_{it} + CV_y'\delta_y + \varepsilon_{it}, \quad \text{with } \varepsilon_{it}|x_{it}, CV_y \sim iid(0, \sigma_\varepsilon^2) \tag{1}$$

$$z_{it} = \alpha_0 + \alpha_1 y_{it} + CV_z'\delta_z + \nu_{it}, \quad \text{with } \nu_{it}|y_{it}, CV_z \sim iid(0, \sigma_\nu^2) \tag{2}$$

where x, y and z respectively stand for commodity price, crops supply, and woodland area. ε_{it} and ν_{it} are the error terms. α, β and δ are the model's parameters. Equation 1 makes crop supply a direct function of agri-commodity prices, while in equation 2 woodland areas depend on crop supply. Additional variables control for other factors determining differences in crop supply (CV_y') and woodland areas (CV_z') across regions.

Due to ecological processes (that go beyond the administrative boundaries), the spatial aspects of woodland areas are quite obvious (Turner, 1989) and have been illustrated by recent studies on forest conservation (Honey-Rosés et al., 2011; Votsis, 2017). To consider potential spatial spillovers among forestlands privately owned by agricultural holdings, we incorporate spatial autocorrelation in equation (2) by regressing the woodland area for a given region to the woodland areas of its neighbouring regions.

$$z_{it} = \alpha_0 + \rho \sum_{j=1}^{n} w_{ij} z_{jt}' + \alpha_1 y_{it} + CV_z'\delta_z + \nu_{it}, \quad \text{with } \nu_{it}|y_{it}, CV_z \sim iid(0, \sigma_\nu^2) \tag{3}$$

where $\sum_{j=1}^{n} w_{ij} z'_{jt}$ is the spatial lag of woodland areas, which measures the average woodland in the neighbouring regions, and the parameter ρ captures the strength of geographical spillovers.[4]

Some sources of econometric endogeneity also arise from Equations 1 and 3. Eq. 1 specifies the responsiveness of crop supply to commodities price changes and amounts estimating a supply function. Though one can argue that agricultural holdings across European regions do not influence price fixation, economic theory suggests that prices are not neutral to (expected) output/supply, creating a reverse causality. Furthermore, as Scott (2013) observed, the supply function may suffer from other endogeneity sources (omitted variable, measurement errors). To address this, we rely on the instrumental variable method, using as an instrument for the current price, its yearly lags. A simple rationale justifies these instrumental variables (IV). Besides the high correlation between current and previous prices, the current price can be viewed as a combination of previous ones.[5] Eq 3 also highlights the existence of reverse causality in the forestlands and agricultural expansion nexus. If, as theory suggests, the farmer faces a trade-off between croplands (y_{it}) and forestlands (z_{it}) at any given period (Foley et al., 2005; Benhin, 2006; Ordway et al., 2017), then while agricultural expansion may lead to woodland losses, the reverse will also be true—agricultural expansion will also be affected by woodland patterns. In this case, croplands (y_{it}) and forestlands (z_{it}) are simultaneously determined. The reverse causality, which is an endogeneity issue, will thus alter our estimated parameters if not satisfactorily dealt with. To deal with this issue, we also rely on the instrumental variables technique. From a theoretical perspective, changes in agri-commodities prices and subsides directly relate to crop supply (responsiveness hypothesis, Askari and Cummings (1977) and Miao et al. (2016)). Therefore, we use agri-commodity prices, and environmental subsides as instrumental variables for crop supply when estimating model 3.

Given these methodological issues and to obtain consistent and unbiased estimates, we finally estimate the interconnection between woodlands preservation, agricultural expansion, and agri-commodities prices using the following recursive three stages regression model where an additional first-stage equation (Eq. 4) is introduced to solve endogeneity issues in the supply function specified by Eq. 1. Concretely, this equation links current prices (x_{it}) to their own lags.

$$x_{it} = a_0 + a_1 x_{it-1} + a_2 x_{it-2} + a_3 x_{it-3} + CV'_x \delta_x + \mu_{it}, \text{ with } \mu_{it} | x_{it-1,2,3}, CV_x \sim iid(0, \sigma^2_\mu) \tag{4}$$

$$y_{it} = \beta_0 + \beta_1 \hat{x}_{it} + CV'_y \delta_y + \varepsilon_{it}, \quad \text{with } \varepsilon_{it} | x_{it}, CV_y \sim iid(0, \sigma^2_\varepsilon) \tag{5}$$

$$z_{it} = \alpha_0 + \rho \sum_{j=1}^{n} w_{ij} z'_{jt} + \alpha_1 \hat{y}_{it} + CV'_z \delta_z + \nu_{it}, \quad \text{with } \nu_{it} | y_{it}, CV_z \sim iid(0, \sigma^2_\nu) \tag{6}$$

3.2. Data

We exploit data from the Farm Accountancy Data Network (FADN, 2020) on agricultural holdings in 128 European regions from 26 countries and observed over

[4]Weighting system is based on k-nearest neighbours principle, k being the average number of links.

[5]According to the literature, farmer's expectations can be described using futures prices or lagged prices as there is no strong evidence to suggest that one outperforms the other (Miao et al., 2016).

the period between 2008 and 2017.[6] Forestlands are areas covered by woodlands, forests, and poplar plantations hold by agricultural holdings (FADN, 2020). The farmers' forestlands can be considered as an environmental indicator since forest cover, whether it belongs to natural reserves or agricultural holdings, participates in natural habitat and provides ecosystem services. Data on forestlands are expressed in hectares (ha). As a proxy for agricultural land use, we exploit the total output of crops and crop products evaluated in euro per ha. Considering total output per ha, as proposed by the FADN (2020), appears to be an efficiency measure for agricultural holdings, in addition to being expressed in relative terms. As shown by the literature, it also represents the effect of farming decisions at extensive margin (e.g., acreage expansion).[7]

We also gather Eurostat (2020)'s data on yearly Agricultural Commodity Prices (ACP) indexes (2015=100). These price indexes provide information on producer prices for agricultural products and measure changes in farmers' prices for their products at different points in time.

Finally, we select, based on existing studies, other characteristics of agricultural holdings as control variables. Thereby, we consider three sets of control variables. The first set includes items of expenditure posts related to productivity. These are expenditures on fertilizers, machinery, rent paid, wages paid, and forestry-specific costs (Choi and Helmberger, 1993; Marenya and Barrett, 2009; Liu et al., 2020). The second set of indicators concerns the financial aspects. These are precisely gross farm income and other types of subsidies and grants (Kumbhakar and Lien, 2010; Dudu and Smeets Kristkova, 2017; Rizov et al., 2013). A third set contains variables that directly impact forest area, namely forestry wood processing and competing cultures such as grassland and energy crops. Finally, we also include weather changes (precipitation) taken from the Climate Change Knowledge Portal (CCKP, 2020). Tables A1 and A2 in the Appendix report descriptive statistics of each indicator involved in the empirical analysis and control variables' definition, respectively.

Figure 2 provides graphical illustrations of the regional distribution of woodlands and crop output across the 128 European regions. As can be seen, a non-uniform distribution of both phenomena is primarily noticeable across Europe, corroborating the indication in Table A1, where relatively high standard deviations appear for forestlands and crop supply. While the considered regions belong to a common 'Political and Economic Union' and apply a 'Common Agricultural Policy', there are still large regional heterogeneities due to different climatic and socio-economic conditions. Indeed, there seems to be a land use allocation favoring croplands associated with low woodland areas, particularly in regions located in France, Southern, and Eastern Europe. There are also areas where we notice the inverse distribution (Austria) and others in which significant agricultural and forest areas coexist (England, Germany).

[6] The FADN is an instrument for evaluating the income of agricultural holdings and the impacts of the Common Agricultural Policy. It consists of an annual survey carried out by the Member States of the European Union. Derived from national surveys, the FADN is the only source of microeconomic data that is harmonised. Holdings are selected to take part in the survey based on sampling plans established at the level of each region in the Union. (FADN (2020), accessed on July 20, 2020).

[7] The (FADN, 2020) defines total output as sales + farm use + farmhouse consumption + (closing valuation - opening valuation).

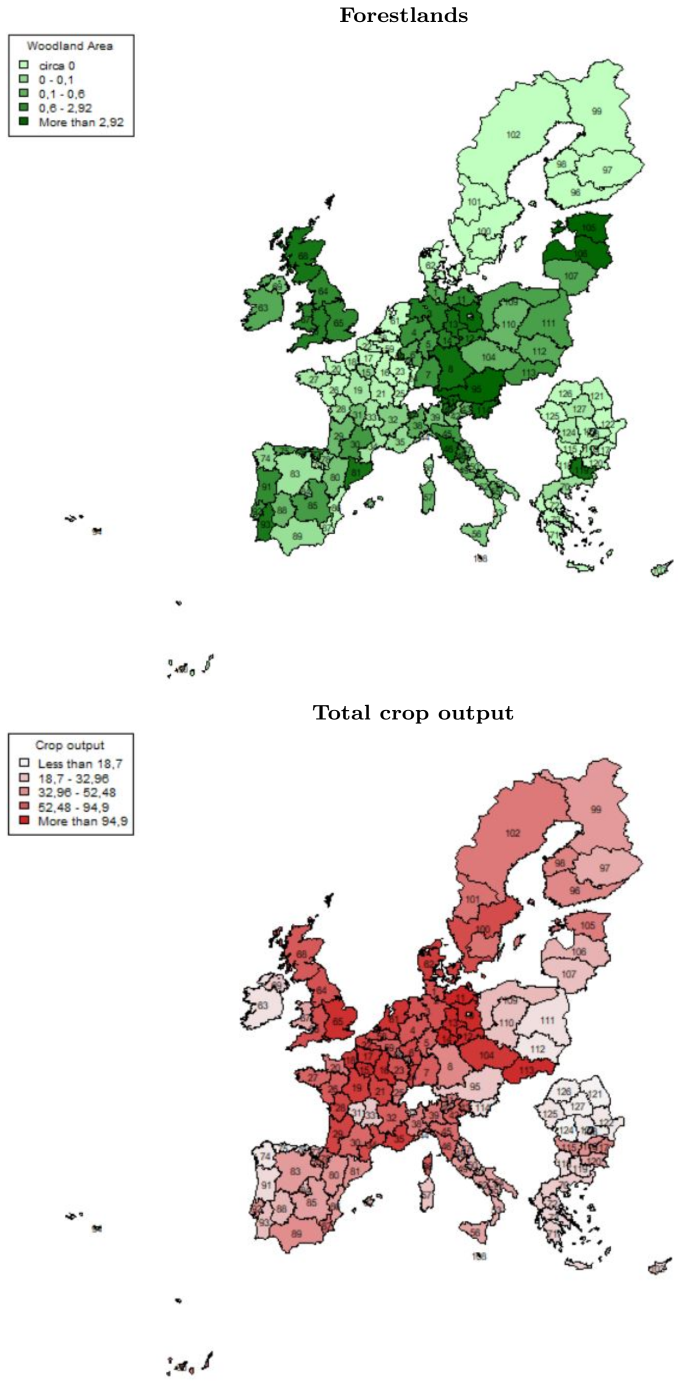

Figure 2. Geographical distribution of woodlands and crop output of agricultural holding across EU-Regions

Note. 1-Schleswig-Holstein, Hamburg, 3 Niedersachsen, Nordrhein-Westfalen, 5 Hessen,Rheinland-Pfalz,7 Baden-Württemberg, Bayern, 9 Saarland, Brandenburg, 11 Mecklenburg-Vorpommern Sachsen, 13 Sachsen-Anhalt, Thueringen, 15-Ile de France, Champagne-Ardenne, 17 Picardie, Haute-Normandie, 19 Centre,Basse-Normandie, 21 Bourgogne,Nord-Pas-de-Calais, 23 Lorraine, Alsace, 25 Franche-Comte,Pays de la Loire, 27 Bretagne, Poitou-Charentes, 29 Aquitaine,Midi-P., 31 Limousin, Rhänes-Alpes, 33 Auvergne, Languedoc-Roussillon, 35 Provence-Alpes-C.Corse, 37 Valle d'Aoste, Piemonte, 39 Lombardia,Trentino, 41 Alto-Adige, Veneto, 43 Friuli-Venezia,Liguria, 45 Emilia-Romagna,Toscana, 47 Marche,Umbria,49 Lazio, Abruzzo, 51 Molise,Campania, 53 Calabria, Puglia, 55 Basilicata, Sicilia, 57 Sardegna, Vlaanderen, 59 Wallonie, Luxembourg, 61 The Netherlands, Denmark, 63 Ireland,England-North, 65 England-East,England-West, 67 Wales, Scotland, 69 Northern Ireland,Makedonia-Thraki, 71 Ipiros-Peloponissos-Nissi Ioniou Thessalia, 73 Sterea Ellas-Nissi Egaeou-Kriti, Galicia, 75 Asturias, Cantabria, 77 Pais Vasco, Navarra, 79 La Rioja, Ara., 81 Cataluna, Baleares, 83 Castilla-Le.,Madrid,85 Castilla-La Mancha, Comunidad Valenciana, 87 Murcia,Extremadura, 89 Andalucia,Canarias, 91 Norte e Centro,Ribatejo e Oeste, 93 Alentejo e do AlgarveA. e da Madeira, 95 Austria,Etela-Suomi, 97 Sisa-Suomi, Pohjanmaa, 99 Pohjois-Suomi, Slattbygdslan, 101 Skogs-och mellanbygdslan Lan i norra, 103 Cyprus,Czech Republic, 105 Estonia,Latvia, 107 Lithuania,Malta, 109 Pomorze-Muzurie, Wielkpolska-Slask, 111 Mazowsze-Podlasie,Malopolska-Pog. 113 Slovakia, Slovenia, 115 Severozapaden, Severen tsentralen, 117 Severoiztochten, Yugozapaden, 119 Yuzhen tsentralen,Yugoiztochen, 121 Nord-Est, Sud-Est, 123 Sud-Muntenia,Sud-Vest-Oltenia, 125 Vest, Nord-Vest, 127 Centru, 128-Bucuresti-llfov.

4. Estimation results

4.1. Specification tests

Before estimating the parameters of equations 4, 5, and 6, we run some specification tests. We first perform a Hausman test, comparing fixed effects (FE) to random effects (RE) specification for each regression model.[8] The results (Table 2) favour a RE specification for the first stage regression model (Eq. 4). For the supply function (Eq. 5) and croplands/forestlands trade-off function (Eq. 6), the results reject the null-hypothesis, implying that a FE specification matches better the data generating process.[9]

We also test for spatial dependence in the FADN reported woodlands areas (and in the model's residuals) using the robust LM-tests discussed by Baltagi et al. (2007) and Anselin (2013). Proceeding by yearly waves, we found results supporting the existence of spatial spillovers in each of the ten yearly waves of the dataset (Table 1).[10] These test results justify the specification adopted in Eq. 6, which accounts for spatial effects to assess the forestlands-croplands trade-off.

Finally, the relevancy of instruments is investigated by using F-test in the first-stage regression 4, in which the lags of commodities price as instrumental variables for current prices. Results (Table 2, column 2) show that the excluded instruments are statistically meaningful predictors of commodity prices. Moreover, the first-stage regression shows outstanding predictive power in addition to be overall significant. Following the standard IV procedure, we will use the commodities price's predicted values in estimating the second stage model: the responsiveness of crop output (per ha) to changes in prices (Eq. 5).

Table 1. Test for spatial dependence in forestlands considering yearly waves

	k=2		*k=3*		*k=4*	
Wave	Moran I	*p*-value	Moran I	*p*-value	Moran I	*p*-value
2008	4.871	0.000	5.564	0.000	5.452	0.000
2009	5.751	0.000	6.479	0.000	6.599	0.000
2010	5.181	0.000	5.827	0.000	5.715	0.000
2011	5.519	0.000	6.13	0.000	6.013	0.000
2012	5.445	0.000	6.039	0.000	5.678	0.000
2013	5.996	0.000	6.814	0.000	6.593	0.000
2014	6.340	0.000	6.985	0.000	7.117	0.000
2015	6.251	0.000	6.931	0.000	7.137	0.000
2016	5.953	0.000	6.802	0.000	7.062	0.000
2017	6.192	0.000	6.953	0.000	7.354	0.000

Note: Moran-I test under randomisation. Weighting system based on k-nearest neighbours principle, k being the average number of links. The null-hypothesis H_0 is no spatial dependence.

[8]The test null-hypothesis suggests that both FE and RE specifications are consistent (RE being more efficient), while the alternative hypothesis advocates for a FE.

[9]For Eq. 6, both standard and spatial Hausman tests reach the same conclusion.

[10]We use different connectivity matrices based on the k-nearest neighbour principle.

4.2. Benchmark results

4.2.1. Do changes in commodities price drive crop supply?

To estimate the second stage regression model (Eq. 5), we regress the total crop output (per ha) on the predicted price index and control variables, using a standard FE estimator. The results are reported in Table 2, column 3.

Regarding the responsiveness of crop supply (in log) to changes in commodity prices (in log), the results show a positive and statistically significant elasticity. The estimated value is around 0.572, indicating that a 1% increase in price induces a 0.57% increase in the total crop supply. Regarding the magnitude of the price elasticity, it is also homogeneous to values displayed by existing studies and lies between the estimations provided by Miller and Plantinga (1999) (circa 0.95) and Lin and Dismukes (2007) (circa 0.35). Hence, this result shows that European farmers intensify their crop supply to take advantage of relatively high prices and increase their earnings. Such a conclusion is also supported by results of several empirical studies that assess crop supply sensitivity to commodity price changes (Houck and Gallagher, 1976; Choi and Helmberger, 1993; Miao et al., 2016).

As expected, fertilizers and machinery show positive and significant effects on crop yields, indicating that a 1% increase of spending on fertilizers and machinery, respectively, enhances crop supply by 0.10% and 0.04%. These results are standard in agricultural economics, as investments in fertilizers and equipment allow the farmer to be more productive (Choi and Helmberger, 1993; Marenya and Barrett, 2009;Liu et al., 2020).

Rental charges show a negative effect on crop supply. Indeed, they imply higher costs of production, which logically reduce the economic value of crop produced. On the contrary, wages paid, which reflect labour used, positively drive crop yields of agricultural holdings. This result is explained by the fact that an increase in wages paid may indicate an increase in the labour force that accompanies the expansion induced by higher productivity. Concerning the gross farm income, a positive effect reflects that the larger agricultural holdings are (in terms of economic size), the larger their investments in agricultural inputs, and consequently, their crop supplies are.

Subsidies on crops negatively impact crop supply. This result is understandable since these payments can be viewed as a (financial) substitution for farm income loss by reducing the negative impacts of intense agricultural practices on the environment and soil quality (Enjolras et al., 2012). Finally, accounting for weather variations, our results show that the higher rainfalls during the month of October are, the lower is crop output.

In conclusion, a takeaway appears in our analysis. In the context of increased commodity prices, agricultural holdings become more productive (rise of output per ha). To assess the impact of crop yields on forestlands, we assess in what follows the third-stage regression linking crop supply to privately owned forestlands.

Table 2. Results of estimating the three stage regression model

	Dependent variable:		
	LogComP	LogTotalCropsOutputPerha	LogWoodlandArea
LogComP(-1)	0.499*** (0.029)	–	–
LogComP(-2)	-0.190*** (0.033)	–	–
LogComP(-3)	0.148*** (0.026)	–	–
$\widehat{LogComP}$	–	0.572*** (0.125)	–
$\widehat{LogTotalCropsOutputPerha}$	–	–	-0.570** (0.244)
LogEnvironmentalSubsidies	0.005*** (0.002)	-0.020*** (0.004)	–
LogFertilisers	-0.005 (0.009)	0.103*** (0.023)	0.062 (0.050)
LogMachinery	0.001 (0.007)	0.036** (0.018)	0.217*** (0.031)
LogRentpaid	-0.010 (0.007)	-0.081*** (0.020)	-0.068 (0.041)
LogWagesPaid	-0.017** (0.007)	0.161*** (0.019)	0.071 (0.047)
LogGrossFarmIncome	0.081*** (0.011)	0.436*** (0.027)	0.210* (0.120)
LogOtherRuralDevelopmentPayments	-0.001 (0.001)	-0.004* (0.002)	0.003 (0.003)
LogSubsidiesonagriculturalinvestments	-0.003*** (0.001)	0.002 (0.002)	0.0001 (0.003)
LogTotalsubsidiesoncrops	-0.006*** (0.001)	-0.005* (0.003)	-0.010** (0.005)
LogForestryspecificcosts	0.0002 (0.002)	0.009 (0.006)	0.011 (0.010)
LogForestryandWoodProcessing	-0.002 (0.002)	-0.004 (0.004)	-0.023*** (0.007)
LogPermanentGrassland	-0.001 (0.005)	-0.201*** (0.017)	-0.206*** (0.056)
LogEnergycrops	0.0005 (0.001)	0.002 (0.003)	-0.001 (0.004)
LogJan	0.020*** (0.007)	0.005 (0.016)	-0.001 (0.023)
LogFeb	-0.019*** (0.004)	-0.011 (0.010)	-0.008 (0.015)
LogMar	-0.017*** (0.004)	-0.011 (0.011)	-0.009 (0.016)
LogApr	0.026*** (0.004)	0.009 (0.011)	0.011 (0.016)
LogMay	0.020*** (0.004)	0.002 (0.010)	-0.013 (0.014)
LogJun	-0.012** (0.005)	-0.004 (0.011)	-0.031* (0.017)
LogJul	-0.007 (0.004)	-0.001 (0.010)	-0.020 (0.015)
LogAug	0.008** (0.004)	-0.005 (0.009)	-0.017 (0.013)
LogSep	0.017*** (0.005)	0.005 (0.011)	0.002 (0.015)
LogOct	0.013** (0.005)	-0.029** (0.012)	-0.011 (0.018)
LogNov	-0.027*** (0.003)	0.008 (0.007)	-0.004 (0.009)
LogDec	-0.025*** (0.003)	0.012 (0.008)	0.027** (0.012)
Constant	1.901*** (0.157)	–	–
λ	–	–	0.315*** (0.046)
ρ	–	–	-0.262*** (0.053)
	(Spatial) Hausman test		
χ^2	37.79 (0.102)	65.15*** (0.000)	316.06*** (0.000)
Observations	1280	1280	1280
Adjusted R^2	0.518	0.459	–
F-Statistic	1403.95***	47.57***	–
Loglikelihood	–	–	-1346.17
AIC	–	–	-2638.34

Note: *p<0.1; **p<0.05; ***p<0.01. Bootstrap standard errors in parenthesis. For the first stage, robust standard errors are considered. The model of woodlands (column 4) being a spatial model, we compute the corresponding impacts measure (see Table B3).

4.2.2. Woodland and crop production: Is there a trade-off?

Estimating the regression model parameters for forestlands (Eq. 6), we exploit the predicted crop output values (from Eq. 5). Moreover, we allow for spatial spillovers as suggested by the test results (Table 1) and use a maximum likelihood (ML) estimator for spatial panel FE (SARAR) models.

The results for the 128 European regions (Table 2 column 4) support the existence of positive spatial spillovers in forestlands owned by agricultural holdings, as previously suggested by test results. Thus, European regions show similar behaviours in their efforts of preserving and extending forests owned by farmers. More specifically, the latter result implies that when farmers from a given region maintain or increase their forestlands, they incite similar behaviour from their colleagues of neighbouring areas, leading to group dynamics in forest preservation or woodland extension.

To examine whether there is a trade-off between forestland and cropland, we focus on the estimated parameter of the total crop output per ha. As suggested by the literature on agriculture and deforestation (Foley et al., 2005; Fairhead and Leach, 2003; Zak), our estimate shows a negative elasticity, indicating that the more productive farmers are, the larger forestlands they convert. More precisely, a 1% increase in crop output per ha induces a 0.57% decrease in farmers' regional woodland area. Thus, high productivities represent a form of incentive to agricultural holdings to expand agricultural land against forest areas to take advantage of increased crop yields per ha.

Our regression analysis includes control variables, and their estimated parameters also deserve a discussion. Thereby, while the effect of machinery and farms' economic size (farm gross income) is positive, the impact of subsidies on crops, permanent grassland, and forest wood processing is negative. The positive effect of machinery and farms' income, previously observed in the supply function (Eq. 5), suggests that independently of crop supply and price, the larger the economic size of farms is, the more actively they seem to participate in forests preservation. Unfortunately, our results so far do not permit us to claim that the latter is uniform across farm income levels. While it is not surprising to note that increasing forestry products harms forests, the estimated negative externalities of subsidies on crops supply and forest areas question the effectiveness of direct and compensatory payments in preserving privately owned forests. Although not the aim of our paper, we note some contrasting effects regarding farm income levels and subsidies on crops, which remains open to further discussions.

Our empirical analysis of the crop supply responsiveness to commodity prices, together with farmers' land-use decisions, has provided some clear teachings so far. Primarily, commodities price increases positively drive crop supply in the 128 European regions where the FADN surveyed agricultural holding between 2008 and 2017. Moreover, it appears that crop output and, consequently, agricultural expansion threaten forest areas owned by agricultural holdings. Overall, all other things being equal, increased commodity prices tend to create incentives for European farmers to convert forestlands into croplands to increase the acreage devoted to crops.

5. Sensitivity analysis

To ensure that our results are robust, we undertake several additional checks, accounting for the heterogeneity of forestlands' importance, farm income groups, and government expenditures in environmental protection.

5.1. Considering only regions with significant forestlands

For some European regions, the FADN data report no forestlands owned by agricultural holding, implying that some farmers do not face a trade-off between croplands and forestlands following a rise in agricultural prices. Checking our results, we resample the data, considering only regions where the FADN surveys report positive forestlands, that is, 81 regions.

Considering this subsample, we use the same econometric procedure as above. The first stage regression (Table 3, column 1) delivers results very similar to those obtained previously. Concerning the responsiveness of crop supply to prices, the estimates (Table 3, column 3) indicate that an increase in agricultural prices drives crop supply. The estimated parameter of prices (0.250) is positive and statistically significant. As noticed in existing literature, crop supply's price-elasticity is positive but varies greatly depending on price indicators, sample, and crops (Keeney and Hertel, 2009; Scott, 2013). Thus, though its magnitude differs from that obtained in Table 2), the price-elasticity remains positive and statistically significant, supporting our initial results. The estimated coefficients of the control variables suggest no significant changes in the conclusions.

Finally, similar results are obtained estimating the third stage regression. Farmers with a more reactive crop supply per ha to price changes tend to expand croplands at the expense of forest. The results also confirm the existence of spatial spillovers in forestlands owned by agricultural holding, previously suggested by the spatial dependency test (Table 1) and our initial estimates (Table 2). Globally, we thus still find robust evidence that owing to increased prices, the more productive farmers are, the less they prioritize forestlands preservation.

Table 3. Results considering regions with significant forestlands

	Dependent variable:		
	LogComP	LogTotalCropsOutputPerha	LogWoodlandArea
LogComP(-1)	0.472*** (0.039)	–	–
LogComP(-2)	-0.263*** (0.047)	–	–
LogComP(-3)	0.204*** (0.038)	–	–
$\widehat{LogComP}$	–	.250* (0.145)	–
$LogTotal\widehat{CropsOutput}Perha$	–	–	-1.748* (0.912)
LogEnvironmentalSubsidies	0.006** (0.002)	-0.009 (0.007)	–
LogFertilisers	0.029*** (0.011)	.131*** (0.043)	0.316** (0.151)
LogMachinery	-0.004 (0.009)	.017 (0.02)	.254*** (0.052)
LogRentpaid	-0.025** (0.010)	-0.110*** (0.031)	-0.241** (0.121)
LogWagesPaid	-0.019** (0.009)	.132*** (0.038)	0.235** (0.119)
LogGrossFarmIncome	0.093*** (0.016)	.558*** (0.047)	0.973* (0.526)
LogOtherRuralDevelopmentPayments	-0.002 (0.001)	.001 (0.002)	.009 (0.005)
LogSubsidiesonagriculturalinvestments	-0.001 (0.001)	-0.002 (0.001)	-0.004 (0.004)
LogTotalsubsidiesoncrops	-0.006*** (0.001)	-0.001 (0.003)	-0.006 (0.006)
LogForestryspecificcosts	-0.001 (0.003)	.005 (0.005)	0.012 (0.013)
LogForestryandWoodProcessing	-0.001 (0.002)	-0.002 (0.003)	-0.018 ** (0.009)
LogPermanentGrassland	0.004 (0.008)	-0.267*** (0.024)	-0.569** (0.246)
LogEnergycrops	0.002 (0.002)	-0.004 (0.002)	-0.008 (0.007)
LogJan	0.017** (0.008)	.041*** (0.014)	0.073 (0.055)
LogFeb	-0.011** (0.005)	-0.027*** (0.009)	-0.053 (0.033)
LogMar	-0.015*** (0.005)	-0.021* (0.010)	-0.029 (0.033)
LogApr	0.028*** (0.006)	.001 (0.010)	.005 (0.021)
LogMay	0.020*** (0.005)	.009 (0.011)	.006 (0.023)
LogJun	-0.005 (0.006)	-0.033*** (0.012)	-0.073* (0.041)
LogJul	-0.015** (0.006)	.016 (0.011)	.017 (0.024)
LogAug	0.004 (0.005)	-0.008 (0.008)	-0.027 (0.022)
LogSep	0.026*** (0.007)	-0.007 (0.011)	-0.003 (0.023)
LogOct	0.022*** (0.007)	-0.014 (0.013)	-0.015 (0.024)
LogNov	-0.021*** (0.004)	-0.001 (0.005)	-0.007 (0.014)
LogDec	-0.017*** (0.004)	-0.003 (0.009)	.004 (0.018)
Constant	1.705*** (0.242)	–	–
λ	–	–	0.472*** (0.062)
ρ	–	–	-0.476*** (0.071)
	Spatial Hausman test		
χ^2	27.25 (0.504)	43.41** (0.017)	176.37 (0.000)
Observations	810	810	810
R^2	0.506	0.591	–
Adjusted R^2	0.488	0.529	–
F Statistic	80.565***	39.082***	–
Loglikelihood	–	–	-868.12
AIC	–	–	-1682.24

Note: *p<0.1; **p<0.05; ***p<0.01. Bootstrap standard errors in parenthesis. For the first stage, robust standard errors are considered.

5.2. The role of gross farm income

Our empirical analysis indicates that the more productive agricultural regions are across Europe, the more farmers convert forestlands into croplands to take advantage of increasing agricultural prices. Reciprocally, farm gross income' is positively linked to both crop output and forestland, suggesting that economic size matters not only in the farmers' responsiveness to increasing price but also in farmers' efforts of forestland preservation. Based on the latter observation, one would expect farms with higher gross income to adopt more environmental-friendly practices. To assess the role of farm income level, we dissociate regions with low-income from those with high-income using the median gross farm income. We then run regressions over the two subsamples (of equal size) to check our results' robustness to the heterogeneity of farm income level. Table 4 reports the estimation results.

The findings show that regions with low farm incomes have a statistically significant price-elasticity of crop supply of circa 0.308 (Table 4, column 3). Thus, similar to the basic pattern highlighted for the full sample, commodities price increases are positively associated with improved crop output per ha. Moreover, our results show that increasing crop supply reduces forestlands privately owned by farmers. Globally, our conjecture stating that the more sensitive crop supply is to commodities price, the more farmers convert forestland into cropland also holds when considering regions with relatively low farm incomes.

Similar results are obtained for higher-farm income regions. Higher commodities prices lead to increasing crop supply, which traduces into forestland reduction. For this second category of regions, one finds a higher price-elasticity of crop supply of about 0.712 (Table 4, column 6). Moreover, the relationship between agricultural profitability and deforestation is still positive and significant.

Accounting for the heterogeneity only yields a different picture of control variables between the two farm income sub-samples. For instance, fertilizer use boots crop supply and threatens forestland only in high farm income regions, while they are insignificant in low farm regions. Similarly, subsidies on agricultural investments positively drive crop supply and forestland only in high farm income regions. Finally, dissociating low and high-farm income samples reveals that forestry and wood processing significantly threaten forestland in low farm income areas, contrary to high farm income regions. Table D4 (in the Appendix) proposes a comparison between the results obtained using the full sample and those given by sub-sample analyses.

In conclusion, despite these heterogeneous results, our findings support the conclusion that agricultural profitability is driven by agricultural prices changes and affects in turn land use at the expanse of forest.

Table 4. Robustness analysis: Dissociating low and high farm income levels

	Sample with low farm gross income			Sample with high farm gross income		
	LogComP	LogTotalCropsOutputPerha	LogWoodlandArea	LogComP	LogTotalCropsOutputPerha	LogWoodlandArea
LogComP(-1)	0.548*** (0.040)	–	–	0.518*** (0.042)	–	–
LogComP(-2)	-0.082* (0.045)	–	–	-0.354*** (0.049)	–	–
LogComP(-3)	0.010 (0.036)	–	–	0.330*** (0.043)	–	–
$\widehat{LogComP}$	–	0.308 ** (0.134)	–	–	0.712 *** (0.172)	–
$LogTotalCr\widehat{opsO}utputPerha$	–	–	-0.359 *** (0.117)	–	–	-0.238 *** (0.044)
LogEnvironmentalSubsidies	0.005*** (0.002)	-0.020 *** (0.005)	–	0.001 (0.002)	-0.016 (0.010)	–
LogFertilisers	0.010 (0.009)	0.062 (0.042)	0.070 (0.082)	0.006 (0.016)	0.095 ** (0.046)	-0.121 *** (0.046)
LogMachinery	0.011 (0.007)	0.052 *** (0.02)	0.274 *** (0.045)	0.023* (0.014)	-0.071 (0.046)	0.232 *** (0.032)
LogRentpaid	0.001 (0.007)	-0.066 *** (0.024)	-0.092 ** (0.042)	-0.055*** (0.017)	-0.117 (0.074)	-0.053 (0.037)
LogWagesPaid	-0.004 (0.008)	0.108 *** (0.031)	0.012 (0.045)	-0.050*** (0.013)	0.334 *** (0.051)	0.128 *** (0.034)
LogGrossFarmIncome	0.020 (0.013)	0.437 *** (0.063)	0.119 * (0.065)	0.217*** (0.019)	0.384 *** (0.057)	-0.011 (0.044)
LogOtherRuralDevelopmentPayments	-0.002 (0.001)	-0.004 (0.003)	0.012 * (0.007)	0.0004 (0.001)	-0.005 (0.003)	0.003 (0.002)
LogSubsidiesonagriculturalinvestments	0.001 (0.001)	0.002 (0.002)	-0.007 (0.006)	-0.006*** (0.001)	0.007 ** (0.003)	0.005 ** (0.002)
LogTotalsubsidiesoncrops	-0.008*** (0.002)	-0.013 *** (0.004)	0.010 (0.007)	-0.002 (0.001)	-0.003 (0.003)	-0.011 *** (0.002)
LogForestryspecificcosts	-0.002 (0.003)	-0.005 (0.006)	0.008 (0.034)	-0.003 (0.003)	0.010 (0.007)	0.019 *** (0.006)
LogForestryandWoodProcessing	-0.001 (0.002)	-0.002 (0.004)	-0.044 *** (0.013)	-0.003 (0.002)	-0.003 (0.003)	0.010 ** (0.004)
LogPermanentGrassland	-0.004 (0.006)	-0.286 *** (0.023)	-0.197 *** (0.065)	0.029*** (0.010)	-0.132 * (0.069)	-0.095 *** (0.023)
LogEnergycrops	-0.004* (0.002)	-0.005 (0.004)	-0.004 (0.008)	-0.001 (0.001)	0.001 (0.003)	0.002 (0.002)
LogJan	-0.038*** (0.010)	0.047 *** (0.018)	-0.029 (0.041)	0.061*** (0.009)	-0.021 (0.021)	0.008 (0.013)
LogFeb	0.005 (0.006)	-0.02 * (0.01)	-0.007 (0.03)	-0.019*** (0.006)	-0.011 (0.012)	-0.006 (0.01)
LogMar	-0.005 (0.006)	-0.029 *** (0.011)	0.003 (0.025)	-0.017** (0.007)	0.010 (0.015)	0.013 (0.013)
LogApr	0.050*** (0.006)	0.043 *** (0.014)	0.004 (0.024)	0.015** (0.007)	0.003 (0.012)	0.018 (0.012)
LogMay	0.022*** (0.005)	0.022 * (0.011)	-0.041 * (0.022)	0.020*** (0.007)	-0.039 *** (0.015)	-0.011 (0.013)
LogJun	-0.007 (0.006)	-0.009 (0.011)	-0.054 (0.034)	-0.015 (0.010)	-0.021 (0.023)	-0.034 * (0.02)
LogJul	-0.002 (0.005)	0.014 (0.009)	-0.003 (0.022)	-0.013 (0.008)	-0.035 ** (0.016)	-0.043 *** (0.011)
LogAug	0.003 (0.004)	-0.014 (0.008)	-0.013 (0.021)	0.018** (0.007)	-0.022 (0.015)	-0.020 (0.014)
LogSep	0.0005 (0.006)	-0.022 * (0.011)	-0.034 (0.02)	0.032*** (0.009)	0.053 *** (0.021)	0.040 *** (0.015)
LogOct	-0.005 (0.007)	0.004 (0.014)	0.027 (0.027)	0.036*** (0.009)	-0.038 (0.023)	-0.014 (0.014)
LogNov	-0.027*** (0.004)	0.001 (0.007)	0.012 (0.018)	-0.009* (0.005)	0.014 (0.009)	-0.008 (0.005)
LogDec	-0.022*** (0.004)	-0.029 *** (0.008)	0.032 * (0.017)	-0.023*** (0.006)	0.055 *** (0.016)	0.078 *** (0.015)
Constant	2.183*** (0.210)	0.307 (0.664)	-0.120 (0.975)	0.093 (0.286)	-2.165 *** (0.639)	0.255 (0.583)
Observations	640	640	640	640	640	640
R^2	0.584	0.572	0.179	0.645	0.561	0.322
Adjusted R^2	0.565	0.553	0.145	0.629	0.543	0.295
F Statistic	857.652***	817.669***	133.681***	1,111.792***	784.206***	292.192***

Note: *p<0.1; **p<0.05; ***p<0.01. Bootstrap standard errors in parenthesis. For the first stage, robust standard errors are considered.

5.3. The role of environment protection expenditures

As a final check, we account for the macroeconomic specificity of our sample. Though European countries are part of the EU's CAP, they implement and reinforce conservation policies differently. Logically, one can assume that the more a country is involved in ecosystem protection (through higher spending), the more farmers are encouraged to adopt environmentally friendly practices and preserve private forest areas. Hence, we consider countries' involvement in ecosystem conversation, using 'public expenditure on biodiversity and landscape protection' as a criterion to dissociate the full sample into two sub-samples.[11]

We reassess the farmers' responsiveness to commodities price together with the trade-off between agricultural expansion and forestlands preservation. If ecosystem conservation efforts help mitigate the forest impact of crop supply, we should observe magnified effects in regions exhibiting low landscape protection expenditures.

Table 5 reports the regression results of this sensitivity analysis. Firstly, the results remain unchanged, regardless of the level of environmental conservation expenditure. Increases in agri-commodity prices generate a trade-off, with a positive effect on crop production per acre but at the same time decreasing private forest areas. Moreover, our results show significantly higher price-elasticities of crop supply in regions located in countries with low environmental conservation expenditure. Another important finding is that a higher forest impact of crop supply is observed in regions with lower conservation efforts.

Some heterogeneities are still noticeable between the two subsamples of countries. In particular, fertilizer induces higher crop supply levels only in regions located in countries with high environmental conservation expenditures. However, as previously, this heterogeneity does not question the main results of our empirical analysis on the interconnection between agri-commodities prices, crop supply, and forestlands across European regions. Thus, we can reasonably conclude that by expanding agricultural supply in response to increases in agri-commodities prices, European farmers progressively convert privately owned forestlands into croplands. This conclusion is robust to the inclusion of control variables and across different sub-samples.

[11] The countries data about public 'expenditure on biodiversity and landscape protection' are from Eurostat (2020). For the 28 countries of the sample, we consider the median value to build the sub-samples of regions.

Table 5. Robustness analysis: Dissociating low and high environment protection expenditures In progress

	Sample with low government expenditures			Sample with high government expenditures		
	LogComP	LogTotalCropsOutputPerha	LogWoodlandArea	LogComP	LogTotalCropsOutputPerha	LogWoodlandArea
LogComP(-1)	0.499*** (0.055)	–	–	0.473*** (0.037)	–	–
LogComP(-2)	-0.118* (0.061)	–	–	-0.316*** (0.043)	–	–
LogComP(-3)	0.014 (0.046)	–	–	0.239*** (0.037)	–	–
LogComP	–	1.117 *** (0.241)	–	–	0.391 *** (0.139)	–
LogTotalCropsOutputPerha1	–		-0.429 *** (0.174)	–	–	-0.221 *** (0.055)
LogFertilisers	-0.056** (0.023)	0.088 (0.059)	0.020 (0.073)	0.024** (0.011)	0.098 *** (0.040)	0.017 (0.064)
LogMachinery	0.016 (0.016)	0.022 (0.044)	-0.006 (0.057)	0.022** (0.009)	0.023 (0.022)	0.325 *** (0.035)
LogRentpaid	0.020 (0.017)	-0.054 (0.057)	0.004 (0.066)	0.010 (0.010)	-0.085 *** (0.027)	-0.073 * (0.038)
LogWagesPaid	-0.018 (0.016)	0.116 *** (0.042)	-0.024 (0.053)	-0.015 (0.009)	0.162 *** (0.035)	0.029 (0.044)
LogGrossFarmIncome	0.049** (0.021)	0.265 *** (0.097)	0.058 (0.121)	0.132*** (0.014)	0.549 *** (0.042)	0.106 * (0.055)
LogEnvironmentalSubsidies	0.002 (0.003)	-0.011 (0.007)	–	0.009*** (0.002)	-0.024 *** (0.006)	–
LogOtherRuralDevelopmentPayments	0.001 (0.002)	-0.018 *** (0.004)	0.002 (0.010)	-0.001 (0.001)	0.000 (0.002)	0.011 *** (0.004)
LogSubsidiesonagriculturalinvestments	-0.006*** (0.002)	0.005 (0.004)	-0.005 (0.007)	-0.001 (0.001)	-0.003 (0.002)	-0.004 (0.003)
LogTotalsubsidiesoncrops	-0.006*** (0.002)	-0.003 (0.005)	-0.001 (0.008)	-0.005*** (0.001)	-0.003 (0.003)	-0.005 (0.005)
LogForestryspecificcosts	-0.007 (0.005)	0.031 *** (0.011)	0.047 (0.075)	0.003 (0.003)	-0.004 (0.005)	-0.005 (0.010)
LogForestryandWoodProcessing	0.003 (0.005)	0.002 (0.010)	0.053 (0.036)	-0.004** (0.002)	0.001 (0.003)	-0.014 ** (0.006)
LogPermanentGrassland	0.035*** (0.012)	-0.065 (0.044)	0.035 (0.041)	-0.001 (0.009)	-0.297 *** (0.027)	-0.187 *** (0.049)
LogEnergycrops	-0.005* (0.003)	-0.007 (0.007)	0.002 (0.011)	0.001 (0.001)	0.000 (0.002)	-0.005 (0.004)
LogJan	0.024* (0.013)	-0.059 (0.041)	-0.037 (0.037)	0.031*** (0.008)	0.026 (0.016)	-0.011 (0.021)
LogFeb	-0.038*** (0.008)	0.043 * (0.025)	0.058 (0.036)	-0.025*** (0.005)	-0.022 ** (0.009)	-0.018 (0.015)
LogMar	-0.033*** (0.010)	0.029 (0.022)	-0.013 (0.032)	0.003 (0.005)	-0.013 (0.008)	0.028 (0.019)
LogApr	0.060*** (0.008)	0.017 (0.022)	0.025 (0.030)	0.004 (0.006)	-0.002 (0.010)	-0.001 (0.017)
LogMay	0.010 (0.008)	-0.013 (0.023)	0.042 (0.031)	0.024*** (0.005)	0.003 (0.010)	-0.052 *** (0.015)
LogJun	-0.026*** (0.010)	0.045 * (0.025)	-0.028 (0.039)	0.001 (0.006)	-0.022 * (0.012)	-0.032 (0.020)
LogJul	-0.002 (0.007)	-0.023 (0.018)	-0.005 (0.020)	-0.005 (0.006)	0.018 (0.011)	-0.031 (0.018)
LogAug	0.018*** (0.006)	-0.035 ** (0.017)	0.005 (0.032)	0.008 (0.005)	0.001 (0.008)	-0.026 * (0.015)
LogSep	-0.008 (0.008)	0.013 (0.025)	0.001 (0.023)	0.036*** (0.006)	0.007 (0.011)	-0.007 (0.019)
LogOct	0.006 (0.009)	-0.009 (0.020)	0.028 (0.032)	0.043*** (0.007)	-0.021 (0.013)	-0.002 (0.020)
LogNov	-0.017*** (0.006)	-0.001 (0.012)	-0.030 (0.022)	-0.018*** (0.004)	0.007 (0.006)	0.018 * (0.009)
LogDec	-0.043*** (0.006)	0.051 *** (0.018)	0.003 (0.022)	-0.017*** (0.004)	-0.004 (0.010)	0.053 *** (0.018)
Constant	2.720*** (0.321)	-2.515 ** (1.248)	2.436 * (1.274)	–	–	-1.523 *** (0.588)
Observations	310	310	310	970	970	970
R^2	0.675	0.472	0.102	0.577	0.617	0.244
Adjusted R^2	0.643	0.423	0.023	0.515	0.562	0.224
F Statistic	583.367***	252.972***	32.365	41.239***	52.440***	304.145***

Note: *p<0.1; **p<0.05; ***p<0.01. Bootstrap standard errors in parenthesis. For the first stage, robust standard errors are considered.

6. Concluding remarks

Existing studies in optimal land-use theory argue that farmers face a trade-off between forestlands preservation and cropland expansion in times of higher agricultural prices. However, empirical studies overlook the interconnection between agri-commodities prices, agricultural expansion, and private forestland conversion. The present paper proposes to fill in that gap, shedding light on the role of commodities prices in farmers' trade-off between agricultural expansion and privately-owned forestlands.

To this end, we exploit the FADN database about agricultural holdings in 128 European regions observed from 2008 to 2017 and data on agri-commodities prices from the European price monitoring tool covering the same period. Furthermore, we exploit a recursive system of equations which accounts for spatial spillovers and addresses regressor endogeneity.

Globally, the outcomes of our regression analysis support our conjecture. More specifically, our results primarily show a positive price-elasticity of crop supply, indicating that increasing commodity prices induce higher crop production profitability. Moreover, the estimated elasticity of forestlands to crop output per ha is negative and statistically significant throughout our different specifications, confirming the existence of conflicts between forestland owned by agricultural holdings and agricultural expansion. Altogether, our analysis suggests that by expanding agricultural supply in response to increases in agri-commodities prices, European farmers progressively convert privately owned forestlands into croplands. Our paper indicates that all other things being equal, notwithstanding conservation efforts, agricultural policies (CAP), and greening measures of the European Union, higher agricultural prices are a major cause of cropland expansion and deforestation at the local level.

The evidence of forest conversion into cropland across European regions definitely has some environmental and policy implications. In the same vein as studies pointing to croplands expansion among the drivers of forest degradation (Trisurat et al., 2019; Foley et al., 2005; FAO, 2020), our analysis provides evidence showing that in reaction to increasing commodities prices, agricultural expansion conflicts with forestlands in the EU. In the European context, where more than 50% of forests are privately owned (CEPF, 2020), our results show that forests privately owned by agricultural holdings suffer from the intensification of crop supply and forestry wood processing activities. Though our paper only assesses the case of forests privately owned by farmers, the expected environmental consequences of private forest degradation could not differ from those mentioned in existing studies. Forestlands conversion that follows crop supply intensification leads to ecosystem depletion and habitat disturbance in European regions, as noted in recent studies by Koh and Ghazoul (2010), Pereira et al. (2014), and Chaudhary et al. (2015). Therefore, our analysis encourages conservation practitioners to further efforts towards forests preservation, specifically forests privately owned by agricultural holdings.

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Appendices

A. Data

Table A1. Descriptive statistics

Statistic	N	Mean	St. Dev.	Min	Max	Unit
LogTotalCropsOutputPerha	1280	6.993	.926	3.631	11.787	in €/ha.
LogWoodlandArea	1280	.564	.749	.000	3.004	in ha.
LogEnvironmentalSubsidies	1280	6.516	2.182	.000	10.293	in €.
LogFertilisers	1280	8.392	1.204	4.344	11.642	in €.
LogEnergycrops	1280	1.451	2.626	0.000	9.462	
LogMachinery	1280	10.512	1.089	7.403	13.261	in €.
LogWagesPaid	1280	8.681	1.304	4.605	12.503	in €.
LogGrossFarmIncome	1280	10.785	.928	8.295	13.357	in €.
LogComP	1280	4.597	.089	4.338	4.934	
LogOtherRuralDevelopmentPayments	1280	3.617	2.325	.000	8.741	in €.
LogRentpaid	1280	8.001	1.527	4.407	11.445	
LogSubsidiesonagriculturalinvestments	1280	1.791	2.971	0	10	in €.
LogTotalsubsidiesoncrops	1280	4.460	2.686	.000	10.150	in €.
LogForestryspecificcosts	1280	.956	1.768	.000	7.510	in €.
LogPermanentGrassland	1280	2.265	1.346	.000	5.687	in €.
LogForestryandWoodProcessing	1280	2.062	2.641	.000	8.981	in €.
LogJan	1280	74.625	34.582	16.758	229.738	mm.
LogFeb	1280	59.762	32.807	5.518	255.278	mm.
LogMar	1280	57.102	28.806	5.589	251.109	mm.
LogApr	1280	57.690	25.600	5.174	159.756	mm.
LogMay	1280	69.711	30.921	1.557	187.711	mm.
LogJun	1280	67.821	30.700	.038	207.423	mm.
LogJul	1280	61.502	36.297	.011	204.112	mm.
LogAug	1280	55.585	34.407	.051	199.932	mm.
LogSep	1280	58.118	25.518	.174	256.862	mm.
LogOct	1280	76.536	30.795	9.743	272.753	mm.
LogNov	1280	80.340	40.067	.751	259.109	mm.
LogDec	1280	68.212	44.303	2.857	282.793	mm.

Note: Balanced panel data of EU 128 regions observed over 10 years, 2008-2017. Variables from Jan to Dec represent monthly rainfalls at country level.

Table A2. Definition of control variables

Variable	Definition
– Buildings	Buildings and fixed equipment belonging to the holder.
– Fertilisers	The quantity used of fertilizers, in €
– Energy crops	Areas sown under energy crops, in ha.
– Machinery	Machines, tractors, cars and lorries, irrigation equipment (except when of little value or used only during one year).
– Environmental subsidies	Environmental subsidies received, in €
– Wages paid	Wages and social security charges (and insurance) of wage earners. Amounts received by workers considered as unpaid workers are excluded.
– Gross farm income	Output and balance current subsidies & taxes minus intermediate consumption.
– Farm use	Value of crop products produced and used on the holding to obtain other final agricultural products.
– Other rural dev. payments	Support to help farmers to adapt to standards, to use farm advisory services to improve the quality of agricultural products, afforestation and stability of forests
– Forestry specific costs	Fertilisers, protective materials, miscellaneous specific costs.
– Forestry and wood processing	Covers the sales of felled and standing timber, of forestry products other than timber (cork, pine resin, etc.) and of processed wood during the accounting year.
– Rent paid	Rent paid for farm land and buildings and rental charges.
– Subsidies on agri. investments	Subsidies on agriculture-ortiented investments.
– Total subsidies on crops	All farm subsidies on crops, including compensatory payments/area payments and set-aside premiums.
– Permanent grassland	refers to the total number of hectares of permanent grassland (including both environmentally sensitive and non-sensitive)
– Rainfalls	Monthly rainfalls at country level in mm.

B. Additional results

Table B3. Computed impact measures (corresponding to Table 2 column 4)

	Direct	Indirect	Total
$\widehat{LogTotalCropsOutputPerha}$	-2.749* (1.538)	1.917 (1.271)	-0.832** (0.33)
LogFertilisers	0.299 (0.229)	-0.21 (0.178)	0.090 (0.057)
LogMachinery	1.044** (0.477)	-0.729* (0.425)	0.315*** (0.063)
LogRentpaid	-0.329 (0.229)	0.228 (0.183)	-0.1* (0.054)
LogWagesPaid	0.344 (0.27)	-0.241 (0.211)	0.104 (0.065)
LogGrossFarmIncome	1.011 (0.654)	-0.706 (0.524)	0.305** (0.155)
LogOtherRuralDevelopmentPayments	0.016 (0.019)	-0.012 (0.015)	0.004 (0.004)
LogSubsidiesonagriculturalinvestments	0.000 (0.015)	-0.001 (0.011)	0.000 (0.004)
LogTotalsubsidiesoncrops	-0.049* (0.029)	0.033 (0.023)	-0.015** (0.006)
LogForestryspecificcosts	0.05 (0.05)	-0.036 (0.038)	0.015 (0.013)
LogForestryandWoodProcessing	-0.113* (0.063)	0.078 (0.054)	-0.034*** (0.011)
LogPermanentGrassland	-0.993** (0.474)	0.692* (0.412)	-0.301*** (0.081)
LogEnergycrops	-0.005 (0.021)	0.002 (0.016)	-0.002 (0.006)
LogJan	-0.004 (0.13)	0.002 (0.097)	-0.002 (0.034)
LogFeb	-0.041 (0.089)	0.028 (0.067)	-0.013 (0.023)
LogMar	-0.045 (0.081)	0.03 (0.059)	-0.014 (0.022)
LogApr	0.052 (0.089)	-0.037 (0.068)	0.016 (0.022)
LogMay	-0.063 (0.083)	0.043 (0.063)	-0.02 (0.021)
LogJun	-0.149 (0.1)	0.103 (0.08)	-0.045* (0.023)
LogJul	-0.096 (0.088)	0.066 (0.068)	-0.029 (0.022)
LogAug	-0.083 (0.076)	0.057 (0.057)	-0.026 (0.02)
LogSep	0.01 (0.087)	-0.008 (0.064)	0.003 (0.023)
LogOct	-0.052 (0.098)	0.035 (0.074)	-0.016 (0.025)
LogNov	-0.019 (0.049)	0.012 (0.037)	-0.006 (0.013)
LogDec	0.130 (0.087)	-0.092 (0.073)	0.039** (0.017)

Note: *p<0.1; **p<0.05; ***p<0.01

Table B4. Results of preliminary estimations (using different specifications)

	First stage *(Dependent variable: LogComP)*				
	(1)	(2)	(3)	(4)	(5)
LogComP(-1)	0.600*** (0.029)	0.552*** (0.031)	0.576*** (0.030)	0.558*** (0.029)	0.499*** (0.029)
LogComP(-2)	−0.297*** (0.033)	−0.291*** (0.033)	−0.285*** (0.032)	−0.283*** (0.031)	−0.190*** (0.033)
LogComP(-3)	0.216*** (0.024)	0.203*** (0.024)	0.174*** (0.024)	0.162*** (0.026)	0.148*** (0.026)
LogEnvironmentalSubsidies	0.009*** (0.002)	0.007*** (0.002)	0.004** (0.002)	0.005*** (0.002)	0.005*** (0.002)
LogFertilisers		0.042*** (0.010)	0.008 (0.011)	0.018 (0.011)	−0.005 (0.009)
LogMachinery		0.014* (0.008)	0.011 (0.008)	0.009 (0.008)	0.001 (0.007)
LogRentpaid			−0.002 (0.010)	0.003 (0.010)	−0.010 (0.007)
LogWagesPaid			−0.025*** (0.009)	−0.027*** (0.009)	−0.017** (0.007)
LogGrossFarmIncome			0.122*** (0.013)	0.123*** (0.013)	0.081*** (0.011)
LogOtherRuralDevelopmentPayments				−0.001 (0.001)	−0.001 (0.001)
LogSubsidiesonagriculturalinvestments				−0.003*** (0.001)	−0.003*** (0.001)
LogTotalsubsidiesoncrops				−0.009*** (0.001)	−0.006*** (0.001)
LogForestryspecificcosts					0.0002 (0.002)
LogForestryandWoodProcessing					−0.002 (0.002)
LogPermanentGrassland					−0.001 (0.005)
LogEnergycrops					0.0005 (0.001)
Constant					1.901*** (0.157)
			Hausman test		
χ^2	65.896*** (.000)	24.108*** (.000)	42.997*** (.000)	48.255*** (.000)	37.792 (.102)
Observations	1,280	1,280	1,280	1,280	1,280
Adjusted R^2	0.272	0.286	0.337	0.370	0.518
F Statistic	152.121***	107.675***	87.501***	74.231***	1,403.956***
	Second stage *(Dependent variable: LogTotalCropsOutputPerha)*				
	(1)	(2)	(3)	(4)	(5)
$\widehat{LogComP}$	0.924*** (0.113)	0.398*** (0.126)	0.532*** (0.105)	0.477*** (0.113)	0.572*** (0.125)
LogEnvironmentalSubsidies	−0.012** (0.005)	−0.021*** (0.005)	−0.028*** (0.004)	−0.027*** (0.004)	−0.020*** (0.004)
LogFertilisers		0.238*** (0.027)	0.094*** (0.024)	0.106*** (0.025)	0.103*** (0.023)
LogMachinery		0.111*** (0.021)	0.071*** (0.018)	0.069*** (0.018)	0.036** (0.018)
LogRentpaid			−0.138*** (0.020)	−0.143*** (0.021)	−0.081*** (0.020)
LogWagesPaid			0.142*** (0.019)	0.136*** (0.020)	0.161*** (0.019)
LogGrossFarmIncome			0.428*** (0.030)	0.437*** (0.030)	0.436*** (0.027)
LogOtherRuralDevelopmentPayments				−0.003 (0.002)	−0.004* (0.002)
LogSubsidiesonagriculturalinvestments				0.0001 (0.002)	0.002 (0.002)
LogTotalsubsidiesoncrops				−0.006** (0.003)	−0.005* (0.003)
LogForestryspecificcosts					0.009 (0.006)
LogForestryandWoodProcessing					−0.004 (0.004)
LogPermanentGrassland					−0.201*** (0.017)
LogEnergycrops					0.002 (0.003)
			Hausman test		
χ^2	9.781*** (.007)	24.898*** (.000)	44.901*** (.000)	48.520*** (.000)	65.151 (.000)
Observations	1,280	1,280	1,280	1,280	1,280
Adjusted R^2	−0.051	0.085	0.360	0.369	0.459
F Statistic	33.330***	62.313***	122.103***	88.367***	47.571***
	Third stage: *(Dependent variable: LogWoodlandArea)*				
	(1)	(2)	(3)	(4)	(5)
$\widehat{LogTotalCropsOutputPerha}$	−0.628*** (0.174)	−0.104* (0.059)	−0.191*** (0.059)	−0.174*** (0.060)	−0.681** (0.278)
LogFertilisers		−0.163*** (0.030)	−0.036 (0.037)	−0.034 (0.038)	0.067 (0.055)
LogMachinery		0.328*** (0.028)	0.344*** (0.028)	0.339*** (0.028)	0.273*** (0.033)
LogRentpaid			−0.171*** (0.033)	−0.150*** (0.035)	−0.089** (0.045)
LogWagesPaid			0.026 (0.033)	0.025 (0.033)	0.078 (0.053)
LogGrossFarmIncome			0.039 (0.054)	0.024 (0.054)	0.264* (0.136)
LogOtherRuralDevelopmentPayments				0.010*** (0.004)	0.006 (0.004)
LogSubsidiesonagriculturalinvestments				−0.006** (0.003)	−0.0002 (0.004)
LogTotalsubsidiesoncrops				−0.007* (0.004)	−0.011** (0.005)
LogForestryspecificcosts					0.009 (0.011)
LogForestryandWoodProcessing					−0.026*** (0.007)
LogPermanentGrassland					−0.255*** (0.065)
LogEnergycrops					−0.003 (0.005)
Constant		−0.787* (0.418)	−0.693* (0.410)	−0.767* (0.415)	
			Hausman test		
χ^2	7.151*** (.007)	.743 (.863)	10.784* (.095)	15.921* (.068)	55.086*** (.000)
Observations	1,280	1,280	1,280	1,280	1,280
Adjusted R^2	−0.099	0.095	0.120	0.126	0.063
F Statistic	13.020***	137.816***	179.772***	192.599***	9.504***

Note: *p<.1; **p<.05; ***p<.01. For space considerations, we have omitted the rainfall variables included only in the last specification (column 5).

C. Countries and regions included in the study

Table C1. List of regions and countries

Region	Country	Region	Country	Region	Country	Region	Country
Schleswig-Holstein	Germany	Valle d'Aoste	Italy	Ile de France	France	Norte e Centro	Portugal
Hamburg	Germany	Piemonte	Italy	Champagne-Ardenne	France	Ribatejo e Oeste	Portugal
Niedersachsen	Germany	Lombardia	Italy	Picardie	France	Alentejo e do Algarve	Portugal
Nordrhein-Westfalen	Germany	Trentino	Italy	Haute-Normandie	France	Açores e da Madeira	Portugal
Hessen	Germany	Alto-Adige	Italy	Centre	France	Austria	Austria
Rheinland-Pfalz	Germany	Veneto	Italy	Basse-Normandie	France	Etela-Suomi	Finland
Baden-Württemberg	Germany	Friuli-Venezia	Italy	Bourgogne	France	Sisa-Suomi	Finland
Bayern	Germany	Liguria	Italy	Nord-Pas-de-Calais	France	Pohjanmaa	Finland
Saarland	Germany	Emilia-Romagna	Italy	Lorraine	France	Pohjois-Suomi	Finland
Brandenburg	Germany	Toscana	Italy	Alsace	France	Slattbygdslan	Sweden
Mecklenburg-Vorpommern	Germany	Marche	Italy	Franche-Comté	France	Skogs-och mellanbygdslan	Sweden
Sachsen	Germany	Umbria	Italy	Pays de la Loire	France	Lan i norra	Sweden
Sachsen-Anhalt	Germany	Lazio	Italy	Bretagne	France	Nord-Est	Romania
Thueringen	Germany	Abruzzo	Italy	Poitou-Charentes	France	Sud-Est	Romania
Galicia	Spain	Molise	Italy	Aquitaine	France	Sud-Muntenia	Romania
Asturias	Spain	Campania	Italy	Midi-Pyrénées	France	Sud-Vest-Oltenia	Romania
Cantabria	Spain	Calabria	Italy	Limousin	France	Vest	Romania
Pais Vasco	Spain	Puglia	Italy	Rhônes-Alpes	France	Nord-Vest	Romania
Navarra	Spain	Basilicata	Italy	Auvergne	France	Centru	Romania
La Rioja	Spain	Sicilia	Italy	Languedoc-Roussillon	France	Bucuresti-llfov	Romania
Aragón	Spain	Sardegna	Italy	Provence-Alpes-Côte	France	Vlaanderen	Belgium
Cataluna	Spain	Pomorze-Muzurie	Poland	Corse	France	Wallonie	Belgium
Baleares	Spain	Wielkpolska-Slask	Poland	England-North	United Kingdom	Denmark	Denmark
Castilla-León	Spain	Mazowsze-Podlasie	Poland	England-East	United Kingdom	Ireland	Ireland
Madrid	Spain	Malopolska-Pogúrze	Poland	England-West	United Kingdom	Cyprus	Cyprus
Castilla-La Mancha	Spain	Severozapaden	Bulgaria	Wales	United Kingdom	Czech Republic	Czech Republic
Comunidad Valenciana	Spain	Severen tsentralen	Bulgaria	Scotland	United Kingdom	Estonia	Estonia
Murcia	Spain	Severoiztochten	Bulgaria	Northern Ireland	United Kingdom	Latvia	Latvia
Extremadura	Spain	Yugozapaden	Bulgaria	Makedonia-Thraki	Greece	Lithuania	Lithuania
Andalucia	Spain	Yuzhen tsentralen	Bulgaria	Ipiros-Peloponissos-Nissi Ioniou	Greece	Malta	Malta
Canarias	Spain	Yugoiztochen	Bulgaria	Thessalia	Greece	Slovakia	Slovakia
Luxembourg	Luxembourg	Netherlands	Netherlands	Sterea Ellas-Nissi Egaeou-Kriti	Greece	Slovenia	Slovenia

D. Summary tables

Table D2. Synopsis of the model specification presented in Table 2

	Eq. 4	Eq. 5	Eq. 6
Response variables	LogComP	LogTotalCropsOutputPerha	LogWoodlandArea
	LogComP(-1)	LogComP	
Excluded instrument	LogComP(-2)	LogEnvironmentalSubsidies	
	LogComP(-3)		
	LogEnvironmentalSubsidies	LogEnvironmentalSubsidies	–
	LogFertilisers	LogFertilisers	LogFertilisers
	LogMachinery	LogMachinery	LogMachinery
	LogRentpaid	LogRentpaid	LogRentpaid
	LogWagesPaid	LogWagesPaid	LogWagesPaid
	LogGrossFarmIncome	LogGrossFarmIncome	LogGrossFarmIncome
Included instrument	LogOtherRuralDevelopmentPayments	LogOtherRuralDevelopmentPayments	LogOtherRuralDevelopmentPayments
	LogSubsidiesonagriculturalinvestments	LogSubsidiesonagriculturalinvestments	LogSubsidiesonagriculturalinvestments
	LogTotalsubsidiesoncrops	LogTotalsubsidiesoncrops	LogTotalsubsidiesoncrops
	LogForestryspecificcosts	LogForestryspecificcosts	LogForestryspecificcosts
	LogForestryandWoodProcessing	LogForestryandWoodProcessing	LogForestryandWoodProcessing
	LogPermanentGrassland	LogPermanentGrassland	LogPermanentGrassland
	LogEnergycrops	LogEnergycrops	LogEnergycrops
	Rainfalls (Jan. – Dec.)	Rainfalls (Jan. – Dec.)	Rainfalls (Jan. – Dec.)

Table D3. Correlation matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)
LogTotalCropsOutputPerha	1	-.096	-.268	-.052	-.015	-.039	.251	.118	-.014	-.028	-.017	.005	-.132	-.045	-.019	.167	-.101	-.509	.009	.146	.118	.096	.061	.044	-.061	-.138	-.099	.128	.111	.170	.039
LogWoodlandArea	-.096	1	.316	.104	.127	.208	.111	.126	.105	.067	.067	.059	.136	.047	-.035	-.139	.512	.316	.626	.140	.086	.098	.108	.090	.036	.186	.187	.174	.178	.198	.171
LogEnvironmentalSubsidies	-.268	.316	1	.549	.242	.656	.497	.581	.248	.227	.233	.191	.235	.563	.166	.017	.338	.625	.376	.030	-.004	-.071	-.130	.008	.171	.350	.437	.171	-.030	.072	.011
LogFertilisers	-.052	.104	.549	1	.417	.840	.783	.876	.260	.262	.228	.187	.113	.888	.183	.135	.247	.597	.324	.051	-.049	-.100	-.089	.077	.166	.327	.388	.057	-.128	.047	.026
LogEnergycrops	-.015	.127	.242	.417	1	.435	.264	.386	-.015	-.107	-.263	-.348	-.114	.378	-.377	.250	.216	.265	.221	-.170	-.273	-.059	-.102	.033	.189	.304	.268	.163	.009	.004	.300
LogMachinery	-.039	.208	.656	.840	.435	1	.702	.849	.241	.226	.202	.159	.145	.821	.166	.003	.294	.581	.374	.030	-.072	-.107	-.153	.079	.242	.426	.501	.181	-.091	.071	.110
LogWagesPaid	.251	.111	.497	.783	.264	.702	1	.863	.193	.194	.208	.188	.088	.751	.170	.145	.225	.440	.286	.082	.028	-.058	-.060	.057	.118	.227	.295	.051	-.116	.088	.004
LogGrossFarmIncome	.118	.126	.581	.876	.386	.849	.863	1	.214	.181	.189	.180	.069	.886	.164	.073	.232	.592	.313	.115	.037	-.039	-.041	.130	.190	.299	.383	.121	-.082	.140	.047
LogComP	-.014	.105	.248	.260	-.015	.241	.193	.214	1	.579	.327	.292	.043	.204	.192	-.243	.179	.203	.220	.033	-.095	-.202	.020	.170	.129	.136	.179	-.018	.014	-.163	-.173
LogComP11	-.028	.067	.227	.262	-.107	.226	.194	.181	.579	1	.647	.380	.101	.215	.340	-.187	.165	.193	.221	.206	.033	-.137	.008	.151	.056	.117	.109	-.028	-.004	.004	-.185
LogComP22	-.017	.067	.233	.228	-.263	.202	.208	.189	.327	.647	1	.709	.113	.222	.541	-.214	.195	.187	.246	.170	.225	.008	-.152	.170	.070	-.008	.180	.036	-.055	.040	-.354
LogComP33	.005	.059	.191	.187	-.348	.159	.188	.180	.292	.380	.709	1	.108	.202	.596	-.217	.197	.168	.227	.089	.223	-.021	-.192	.082	.064	.0005	.154	-.114	-.192	-.050	-.358
LogOtherRuralDevelopmentPayments	-.132	.136	.235	.113	-.114	.145	.088	.069	.043	.101	.113	.108	1	.103	.197	.037	.068	.094	.015	.164	.149	-.006	-.020	-.013	.021	.048	.088	.001	-.011	-.018	-.017
LogRentpaid	-.045	.047	.563	.888	.378	.821	.751	.886	.204	.215	.222	.202	.103	1	.229	.110	.230	.612	.267	.086	-.003	-.061	-.066	.106	.187	.247	.310	.034	-.137	.037	-.007
LogSubsidiesonagriculturalinvestments	-.019	-.035	.166	.183	-.377	.166	.170	.164	.192	.340	.541	.596	.197	.229	1	-.092	.066	.164	.062	.168	.184	-.024	-.030	.025	.002	-.050	.031	-.158	-.168	-.020	-.460
LogTotalsubsidiesoncrops	.167	-.139	.017	.135	.250	.003	.145	.073	-.243	-.187	-.214	-.217	.037	.110	-.092	1	-.098	-.136	-.071	-.084	-.044	.064	.056	-.095	-.176	-.208	-.173	-.031	.064	.044	.062
LogForestryspecificcosts	-.101	.512	.338	.247	.216	.294	.225	.232	.179	.165	.195	.197	.068	.230	.066	-.098	1	.308	.651	-.102	-.107	-.174	-.174	.007	.124	.248	.212	-.009	-.075	-.168	-.044
LogPermanentGrassland	-.509	.316	.625	.597	.265	.581	.440	.592	.203	.193	.187	.168	.094	.612	.164	-.136	.308	1	.318	.111	.043	-.009	.006	.087	.108	.254	.291	.027	-.063	.090	.041
LogForestryandWoodProcessing	.009	.626	.376	.324	.221	.374	.286	.313	.220	.221	.246	.227	.015	.267	.062	-.071	.651	.318	1	.048	.042	-.042	-.075	.128	.207	.319	.333	.157	.043	.036	-.002
LogJan	.146	.140	.030	.051	-.170	.030	.082	.115	.033	.206	.170	.089	.164	.086	.168	-.084	-.102	.111	.048	1	.699	.538	.388	.183	-.015	-.174	-.068	.140	.294	.492	.134
LogFeb	.118	.086	-.004	-.049	-.273	-.072	.028	.037	-.095	.033	.225	.223	.149	-.003	.184	-.044	-.107	.043	.042	.699	1	.499	.195	.195	.013	-.200	-.090	.014	.248	.471	-.026
LogMar	.096	.098	-.071	-.100	-.059	-.107	-.058	-.039	-.202	-.137	.008	-.021	-.006	-.061	-.024	.064	-.174	-.009	-.042	.538	.499	1	.310	.172	.038	-.200	-.096	.214	.353	.391	-.008
LogApr	.061	.108	-.130	-.089	-.102	-.153	-.060	-.041	.020	.008	-.152	-.192	-.020	-.066	-.030	.056	-.174	.006	-.075	.388	.195	.310	1	.314	-.005	-.177	-.246	.141	.369	.406	.136
LogMay	.044	.090	.008	.077	.033	.079	.057	.130	.170	.151	.170	.082	-.013	.106	.025	-.095	.007	.087	.128	.183	.195	.172	.314	1	.270	.127	.151	.224	.247	.298	-.031
LogJun	-.061	.036	.171	.166	.189	.242	.118	.190	.129	.056	.070	.064	.021	.187	.002	-.176	.124	.108	.207	-.015	.013	.038	-.005	.270	1	.511	.359	.245	.080	-.073	-.081
LogJul	-.138	.186	.350	.327	.304	.426	.227	.299	.136	.117	-.008	.0005	.048	.247	-.050	-.208	.248	.254	.319	-.174	-.200	-.200	-.177	.127	.511	1	.695	.253	-.016	-.066	.194
LogAug	-.099	.187	.437	.388	.268	.501	.295	.383	.179	.109	.180	.154	.088	.310	.031	-.173	.212	.291	.333	-.068	-.090	-.096	-.246	.151	.359	.695	1	.474	.046	.010	.075
LogSep	.128	.174	.171	.057	.163	.181	.051	.121	-.018	-.028	.036	-.114	.001	.034	-.158	-.031	-.009	.027	.157	.140	.014	.214	.141	.224	.245	.253	.474	1	.372	.337	.162
LogOct	.111	.178	-.030	-.128	.009	-.091	-.116	-.082	.014	-.004	-.055	-.192	-.011	-.137	-.168	.064	-.075	-.063	.043	.294	.248	.353	.369	.247	.080	-.016	.046	.372	1	.364	.217
LogNov	.170	.198	.072	.047	.004	.071	.088	.140	-.163	.004	.040	-.050	-.018	.037	-.020	.044	-.168	.090	.036	.492	.471	.391	.406	.298	-.073	-.066	.010	.337	.364	1	.205
LogDec	.039	.171	.011	.026	.300	.110	.004	.047	-.173	-.185	-.354	-.358	-.017	-.007	-.460	.062	-.044	.041	-.002	.134	-.026	-.008	.136	-.031	-.081	.194	.075	.162	.217	.205	1

Note: (1)=LogTotalCropsOutputPerha, (2)=LogWoodlandArea, (3)=LogEnvironmentalSubsidies, (4)=LogFertilisers, (5)=LogEnergycrops, (6)= LogMachinery, (7)=LogWagesPaid, (8)= LogGrossFarmIncome, (9)=LogComP, (10)=LogComP11, (11)= LogComP22, (12)=LogComP33, (13)=LogOtherRuralDevelopmentPayments, (14)=LogRentpaid, (15)=LogSubsidiesonagriculturalinvestments, (16)=LogTotalsubsidiesoncrops, (17)=LogForestryspecificcosts, (18)=LogPermanentGrassland, (19)=LogForestryandWoodProcessing, (20)=LogJan, (21)=LogFeb, (22)=LogMar, (23)=LogApr, (24)=LogMay, (25)=LogJun, (26)=Logjul, (27)=LogAug, (28)=LogSep, (29)=LogOct, (30)=LogNov, (31)=LogDec

Table D4. Comparing results of the robustness analysis

	Full sample (primary results)			**low farm gross income**			**high farm gross income**			**low conservation efforts**			**high conservation efforts**		
	Price	Crops output	Forestland	Price	Crops output	Forestland	Price	Crops output	Forestland	Price	Crops output	Forestland	Price	Crops output	Forestland
LogComP(-1)	+			+			+			+			+		
LogComP(-2)	+			−			−			−			−		
LogComP(-3)	+						+			+			+		
LogComP		+			+			+			+			+	
LogTotalCropsOutputPerha1			−			−			−			−			−
LogEnvironmentalSubsidies	+	−		+	−								+	−	
LogFertilisers		+						+	−	−			+	+	
LogMachinery		+	+		+	+	+		+				+		+
LogRentpaid		−			−	−	−							−	−
LogWagesPaid	−	+			+		−	+	+		+			+	
LogGrossFarmIncome	+	+	+		+	+	+	+		+	+		+	+	+
LogOtherRuralDevelopmentPayments		−				+									+
LogSubsidiesonagriculturalinvestments	−						−	+		−	−				
LogTotalsubsidiesoncrops		−	−	−					−	−			−		
LogForestryspecificcosts					−				+		+				
LogForestryandWoodProcessing			−			−			+				−		−
LogPermanentGrassland		−	−		−	−	−	−	−	+				−	−
LogEnergycrops				−						−					

E. The dynamics of forestlands and agricultural lands

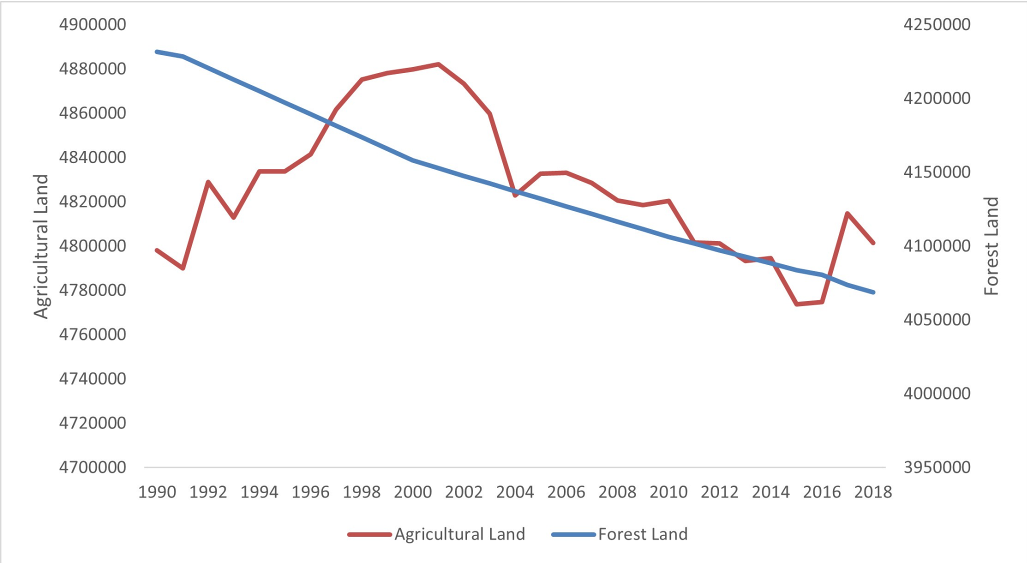

Figure D1. Forestlands and agricultural lands: A global perspective (FAO-Stat)

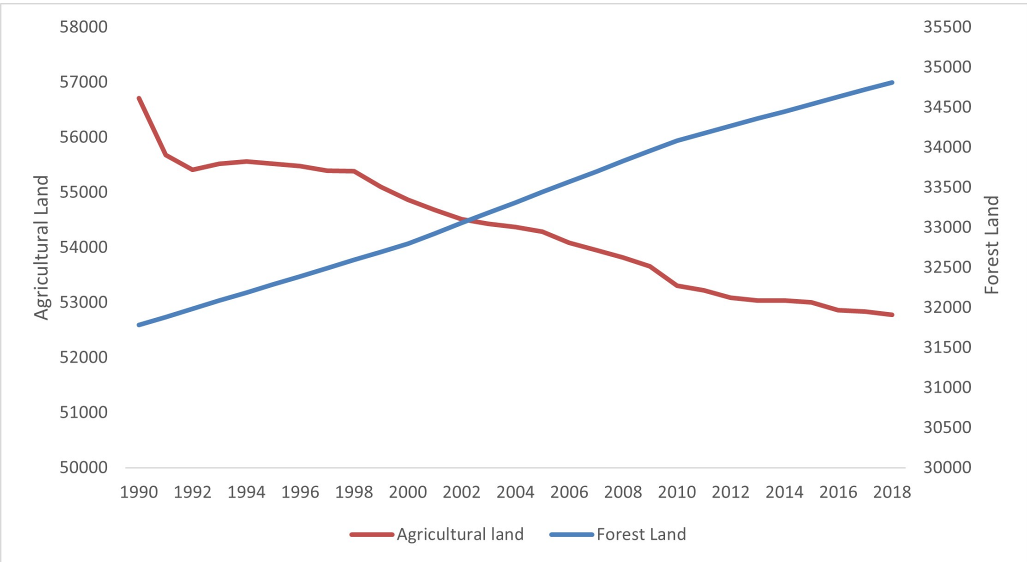

Figure D2. Global evolution of forestland and agricultural land in Western Europe (FAO-Stat)