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Do political economy factors matter in explaining the increase in the production of bioenergy?

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Abstract: In this paper, we analyse the impact of political economy factors on the production of bioenergy. We theoretically and empirically show that the quality of governance and environmental policy stringency instruments promote the development of bioenergy production. We also find that the factors that favour oil production and renewable energy negatively influence the development of bioenergy, whereas the conditions of production (cereal yield) and demand factors (gross domestic product, population density, and urbanization) tend to favour the production of bioenergy.

Keywords: bioenergy, ethanol, biodiesel, governance, oil, panel data modelling
JEL classification: Q42, Q56, C33, C34

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1 Introduction

The international political and economic context is characterized by a growing awareness of the need to fight against global warming (due largely to the increase in greenhouse gas emissions, according to the Intergovernmental Panel on Climate Change (IPCC 2014) and to find alternatives to fossil fuels. Indeed, the increase in temperature, the multiplication of natural disasters (storms, droughts, floods, etc.), and the volatility of oil prices are signals that should encourage states to act against global warming.

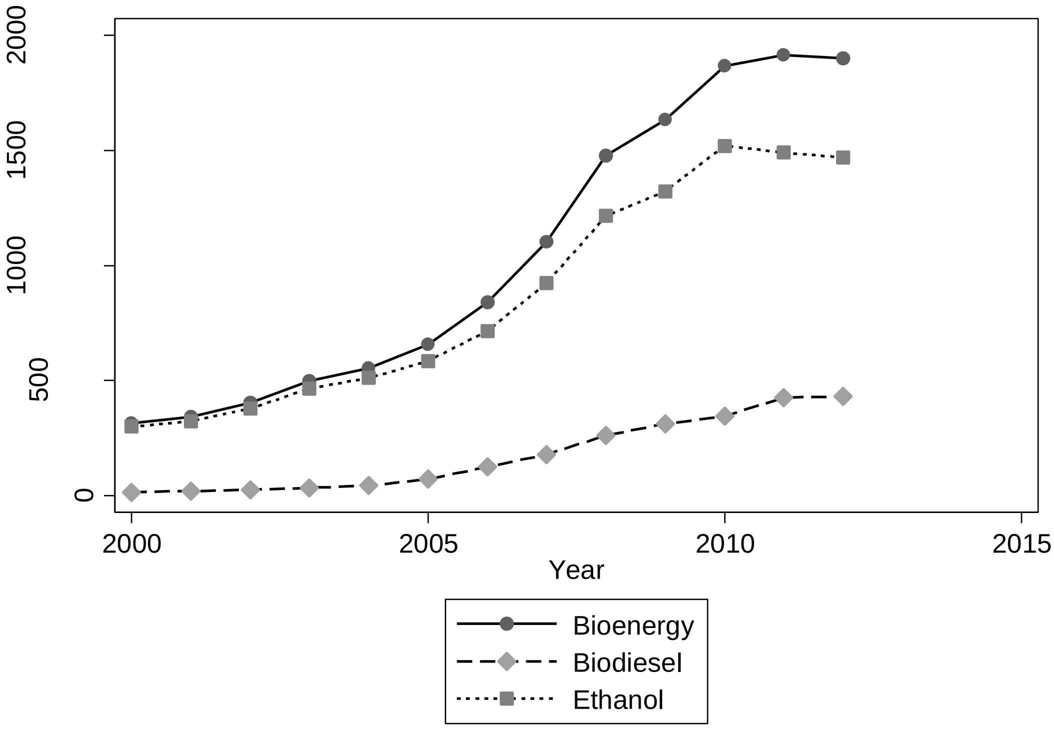
In such a context, the 'bioenergy with carbon capture and storage' (BECCS) technology appears as an alternative to fossil fuels. Indeed, these energies have a very favourable carbon footprint[1] because they are produced from agriculture and forestry biomass. They are mainly used to produce heat, biofuels, and electricity. For these reasons, many countries have chosen to respond to environmental and energy challenges through increased production of bioenergy. For example, the United States, with the Renewable Fuel Standard Program (RFS2) and the Energy Independence and Security Act of 2007, set the goal of incorporating a minimum of 36 billion gallons of biofuels into the fuel market by 2022 (EPA 2010). According to data from the United States Energy Information Administration (EIA 2015a), illustrated in Figures 1 and 2, world production of bioenergy (ethanol and biodiesel) has increased dramatically over the last decade. Global bioenergy production increased from 300,000 barrels per day (BPD) in 2000 to 1.9 million BPD in 2012. This increase was primarily due to strong growth in ethanol production: 1.47 million BPD in 2012 versus 299,000 BPD in 2000. Biodiesel production increased from 15,000 to 431,000 BPD between 2000 and 2012. At the same time, the number of bioenergy-producing countries quadrupled between 2000 and 2011, followed by a slight decline in 2012.[2] Despite this progress, the IPCC (2014: 82) recommends a fourfold increase in investments in BECCS in order to limit global warming to 2°C. Therefore, a better understanding of the determinants of bioenergy production is essential to promote the transition to clean energy.

To the best of our knowledge, only Gan and Smith (2011) have empirically analysed the macroeconomic determinants of bioenergy. In the OECD (Organization for Economic Cooperation and Development) countries, they showed that gross national product along with bioenergy market deployment policies have significant and positive impacts on the per capita supply of renewable energy and bioenergy. Surprisingly, the impact of political economy factors was ignored in their study, even though several papers have shown that the quality of political and economic governance influences economic activity (including bioenergy production) through its impact on investment and entrepreneurship (Acemoglu et al. 2001; Baum and Lake 2003; Christopoulos and Tsionas 2004; La Porta et al. 2008; Nelson and Singh 1998).

[1] If they do not generate indirect land use changes.

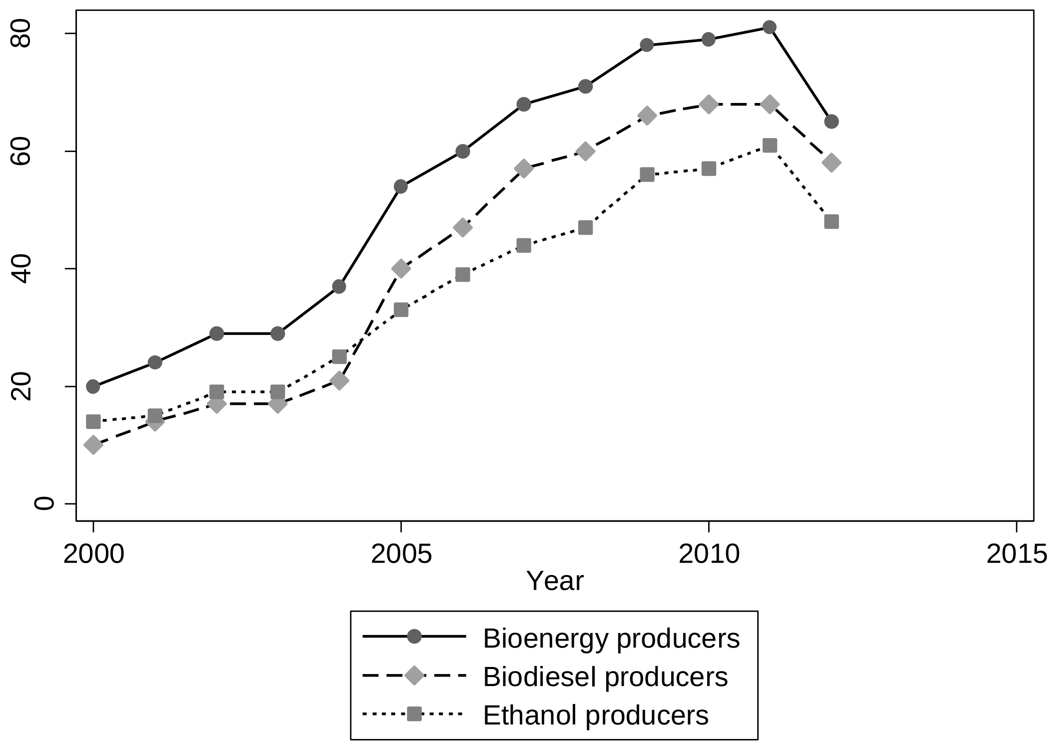
[2] Countries (Barbados, Trinidad and Tobago, Kazakhstan, Vietnam, Jamaica, Honduras, Nicaragua, El Salvador, Singapore, Hong Kong, Pakistan, Serbia, Costa Rica, Cambodia, Switzerland, Bosnia and Herzegovina, and Norway) that have stopped production of bioenergy between 2011 and 2012 account for only 0.4 per cent of production; hence the small effect on global production. This phenomenon can be explained by the increase in agricultural prices in 2012.

Figure 1: Evolution of bioenergy production



Source: Author's calculations using data from EIA (2015a).

Figure 2: Number of bioenergy producers



Source: Author's calculations using data from EIA (2015a).

We classify political economy factors into two categories: governance quality and macroeconomic policies. Quality of governance reflects the quality of political and economic institutions, and can be captured by the following indicators: environmental policy stringency (EPS) instruments, bureaucracy quality, corruption, investment profile, democratic accountability, government stability, and law and order. Furthermore, according to La Porta et al., 'the historical origin of a country's laws is highly correlated with a broad range of its legal rules and regulations, as well as with economic outcomes' (2008: 285), and thus, indirectly, with the economic and political conditions in which bioenergy is produced. High-quality governance helps to create institutional and political dynamics, a transparent and predictable framework that encourages economic actors to invest in growth sectors of the future, including bioenergy. Macroeconomic policies (financial development, interest rates, trade openness, and oil scarcity) may also play an important role in increasing the production of bioenergy. Indeed, financial development facilitates the financing of future projects at low cost. It results in low interest rates and high credit volume. Open trade facilitates access to technology, increases competition, and provides new market opportunities for bioenergy, whereas the increasing scarcity of physical oil (high prices and low reserves) stimulates the transition to clean energy (Grafton et al. 2012; Heun and de Wit 2012). Finally, the amount of renewable energy produced is an important determinant of biofuels production. Energy transition can be achieved through specialization in the production of bioenergy and/or renewable energy based on the comparative advantages of each country.

This study tries to fill the gap in the literature on the macroeconomic drivers of bioenergy by examining the impact of political economy factors, oil production, renewable energies, and macroeconomic factors. First, we present a simple theoretical model in which oil, renewable energy, and bioenergy are produced simultaneously. This formalization allows us to highlight the theoretical connections between oil production, supply of bioenergy, and political economy factors. We show that the supply of bioenergy depends positively on governance quality, financial development, land yields, and market conditions (price, income). On the negative side, oil reserves and renewable energies tend to reduce bioenergy supply. Second, we empirically highlight the determinants of the supply of bioenergy using an unbalanced panel dataset of 112 countries for the period between 2000 and 2012. Motivated by the fact that 'zeros' represent a large fraction of the bioenergy data (40 per cent), we use a fixed effects tobit model (Honoré 1992) to address the censoring problem, as well as unobservable heterogeneity specific to each country. Third, we make separate estimates of the supply function of bioenergy for all the countries in our sample of developed and developing countries. This allows us to analyse and compare the effects of political economy factors on bioenergy production, depending on the level of development. Finally, given that most countries do not produce bioenergy, we analyse the determinants leading to the decision of whether or not to produce bioenergy by using a random effects probit model.[3] We show that political economy factors (governance quality and macroeconomic policies) are central in deciding whether or not to produce bioenergy, but their impact on production size is limited. Indeed, when the decision to produce is made, market size and production conditions have a greater influence on the amount of bioenergy. Using a long-term analysis, we find that the countries whose laws are of Germanic, Scandinavian, and French origin produce relatively more bioenergy, whereas those whose laws have a Socialist origin produce less than other countries.

[3] There are several countries that produce bioenergy throughout the period and others that do not produce anything. Using a discrete choice model with fixed effects removes these countries from the analysis. This is why we choose a random effects model.

The remainder of the paper is organized as follows. Section 2 outlines the theoretical model, the empirical strategy, and data. Section 3 discusses the results and their implications. The last section concludes by indicating how political economy factors can facilitate the transition to clean energy.

2 Analytical framework

2.1 A simple theoretical model

To motivate the empirical analysis below, we develop a function of bioenergy supply taking into account the governance quality, macroeconomic policies, energy demand, and supply of oil and renewable energy. First, we assume that bioenergy, oil, and renewable energy are perfect substitutes in producing energy. The total energy demand D_E is decreasing with the price of energy P and increasing with national income Y: $D_E = (P,Y)$. Based on the Hotelling (1931) rule, we define the function of oil supply S_O as an increasing function of price P, interest rates r, and oil reserves R: $S_O = (P,r,R)$. If the country is not an oil producer, oil supply will be provided by imports and will depend on world oil reserves and international prices. Significant global reserves of oil and low international prices will make imports cheaper. However, a non-oil-producer is more likely to promote the development of bioenergy for reasons of energy sovereignty. Second, we suppose that for each unit of bioenergy sold, the producer receives $P_B = P + \tau$, where $\tau \geq 0$, a premium price for bioenergy. This prime can be the willingness of consumers to pay more for, or a state to subsidize, bioenergy. Finally, we assume that bioenergy is produced by a representative firm whose profit function is:

$$\Pi = (P + \tau)\ BioE - CT(BioE, L, Gov, MP), \tag{1}$$

where $BioE$ represents the quantity of bioenergy supplied, L the productivity of the land, Gov the indicator of the quality of governance, MP the macroeconomic policies, and $CT(BioE,L,Gov,MP)$ the total cost of production. We assume that the marginal cost is positive ($CT_{BioE} > 0$) and decreases with the quantity produced ($CT_{BioE,BioE} < 0$). In addition, the marginal cost of production decreases with productivity of land ($CT_L < 0$), governance quality ($CT_{Gov} < 0$), and macroeconomic policies ($CT_{MP} < 0$). Indeed, the better the governance and macroeconomic policies, the more conducive the conditions for the development of economic activities, including the production of bioenergy. In addition, good governance and macroeconomic policies can lead a country to invest more in the energy transition.

Let $D_E(P,Y)$ represent the demand of energy and $Renew$ the amount of renewable energy produced. At equilibrium, demand equals supply: $D_E(P,Y) = S_O(P,r,R) + Renew + BioE$. This means that $BioE = D_E(P,Y) - S_O(P,r,R) - Renew$. As a result, the demand for bioenergy can be defined as the difference between the total energy demand and the supply of oil:

$$D_{BioE}(P, Y, r, R) = D_E(P, Y) - S_o(P, r, R) - Renew. \tag{2}$$

By inserting the inverse demand for bioenergy, $P(BioE,Renew,Y,r,R) = P(D_{BioE})$, in the profit equation 1 we get:

$$\max_{BioE} \Pi = [P(BioE, Renew, Y, r, R) + \tau]BioE - CT(BioE, L, Gov, MP). \tag{3}$$

On the basis of the first-order conditions of this maximization programme, we have:

$$[(\partial P(BioE, Renew, Y, r, R))/\partial BioE]BioE + P(BioE, Renew, Y, r, R) + \tau = \mathrm{Cm}(BioE, L, Gov, MP). \tag{4}$$

At the optimum, the marginal benefit of an additional unit of bioenergy is equal to the marginal cost of the unit. The optimal bioenergy supply can be expressed as:

$$BioE^* = BioE(P, Renew, Y, r, R, \tau, L, Gov, MP). \tag{5}$$

Using simple linear functions, a comparative static analysis allows us to better understand the insights of this result.

Let $S_O(P,r,R) = \delta_1 P + \delta_2 R + \delta_3 r$, $D_E(P,Y) = \gamma_1 Y - \gamma_2 P$, $CT(BioE,L,Gov,MP) = (v_1 - v_2 L - v_3 Gov + v_4 MP)BioE$. Therefore, the demand for bioenergy equals $D_{BioE}(P,Y,r,R) = \gamma_1 Y - \gamma_2 P - \delta_1 P - \delta_2 R - \delta_3 r - n_1 Renew$ and the optimal bioenergy supply can be expressed as follows:

$$BioE^* = \frac{1}{2}(\gamma_1 Y - n_1 Renew - \delta_2 R - \delta_3 r + (\gamma_2 + \delta_1)\,(\tau - v_1 + v_2 L + v_3 Gov + v_4 MP)). \tag{6}$$

A comparative static analysis can be conducted by differentiation of Equation 6 with respect to each of the explanatory variables. Differentiation yields:

$$\frac{\partial BioE^*}{\partial Renew} = -\frac{n_1}{2} < 0$$
$$\frac{\partial BioE^*}{\partial Gov} = \frac{(\gamma_2 + \delta_1)v_3}{2} > 0$$
$$\frac{\partial BioE^*}{\partial \tau} = \frac{(\gamma_2 + \delta_1)}{2} > 0$$
$$\frac{\partial BioE^*}{\partial MP} = \frac{(\gamma_2 + \delta_1)v_4}{2} > 0$$
$$\frac{\partial BioE^*}{\partial Y} = \frac{\gamma_1}{2} > 0$$
$$\frac{\partial BioE^*}{\partial R} = -\frac{\delta_2}{2} > 0$$
$$\frac{\partial BioE^*}{\partial r} = -\frac{\delta_3}{2} > 0$$
$$\frac{\partial BioE^*}{\partial L} = \frac{(\gamma_2 + \delta_1)v_2}{2} > 0$$

The political economy factors (governance quality and macroeconomic policies) have a positive impact on bioenergy supply. These factors will promote the establishment of the necessary conditions for investment in growth sectors of the future, including bioenergy. The premium price for bioenergy favours the production of bioenergy. Indeed, the higher the premium price, the higher the country internalizes the environmental and social benefits of bioenergy. It also appears that biofuels and renewable energy are substitutable. Oil reserves have a negative effect on the supply of bioenergy. In addition, the interest rate has a negative effect on the production of bioenergy. According to the Hotelling (1931) rule, a high interest rate increases the incentive to exploit the oil reserves, investing the income from the sale of oil in a more profitable alternative. In addition, a higher interest rate discourages new investments. In the long term, however, the extraction of fossil fuels may cause oil scarcity. Then prices will rise making profitable renewable energy as in the case of low interest rates. The supply of bioenergy also depends positively on income. According to the environmental Kuznets curve, income growth leads to higher preferences for environmental goods. Finally, agricultural productivity has a positive effect on the production of bioenergy.

2.2 Econometric model

The aim of this article is to estimate the supply equation of bioenergy obtained in the theoretical model (Equation 5). However, there are some challenges, particularly regarding censoring of the dependent variable and how the unobserved heterogeneity is taken into account. Bioenergy production (*$BioE_{it}$*) is a latent variable because it is observable only if production is positive. If the optimal production is negative, the country does not produce. The dependent variable is limited by a positivity constraint. In this study sample, only 11 per cent of all countries were producing bioenergy in 2001 and 48 per cent in 2012. Censoring is important and must be taken into account. It may therefore be argued that a tobit model is the preferred estimator (Greene 2002; Wooldridge 2010). The model to be estimated can be written as follows:

$$BioE_{it} = \beta X_{it} + \alpha_i + \varepsilon_{it}, \tag{7}$$

whereas the observed value of the bioenergy variable, $BioE_{it}$, is given by:

$$BioE_{it} = \begin{cases} BioE_{it}^{*} & if\ BioE_{it}^{*} > 0 \\ 0 & if\ BioE_{it}^{*} \leq 0' \end{cases} \tag{8}$$

where the $BioE_{it}$ variable is greater than zero only when the latent $\boldsymbol{BioE_{it}^{*}}$ variable exceeds zero (which represents cases where a country's willingness to produce bioenergy is positive), X represents the matrix of explanatory variables, β the vector of the coefficients associated with X, α_i country fixed effects, and ε_{it} the term error, which is independently and identically distributed.

Equation 8 can be estimated using a tobit model with random effects, if the country-specific effects are not correlated with the explanatory variables. Otherwise, a fixed effects model must be used. In this case study, fixed effects are essential to control for unobserved heterogeneity specific to each country that does not vary over time (at least in the short term), such as institutional framework or preferences for bioenergy. The introduction of fixed effects allows us to take these factors into account in our regressions. To avoid the 'incidental parameters problem', we use the fixed effects tobit model suggested by Honoré (1992). This method is based on the work of Powell (1984, 1986), on least absolute deviations estimation for the censored regression model and symmetrically trimmed least squares estimation for tobit models.[4] To determine whether the fixed effects or random effects model is appropriate, we use a Hausman specification test. For all specifications, the test statistic χ^2 allows us to reject the null hypothesis of independence between errors and explanatory variables, and accordingly opt for a fixed effects model.

2.3 Data description

This study examines the drivers of per capita supply of bioenergy (see Appendix Tables A1–A3 for a description and summary of the data.). Owing to the availability of data,[5] we use ethanol,

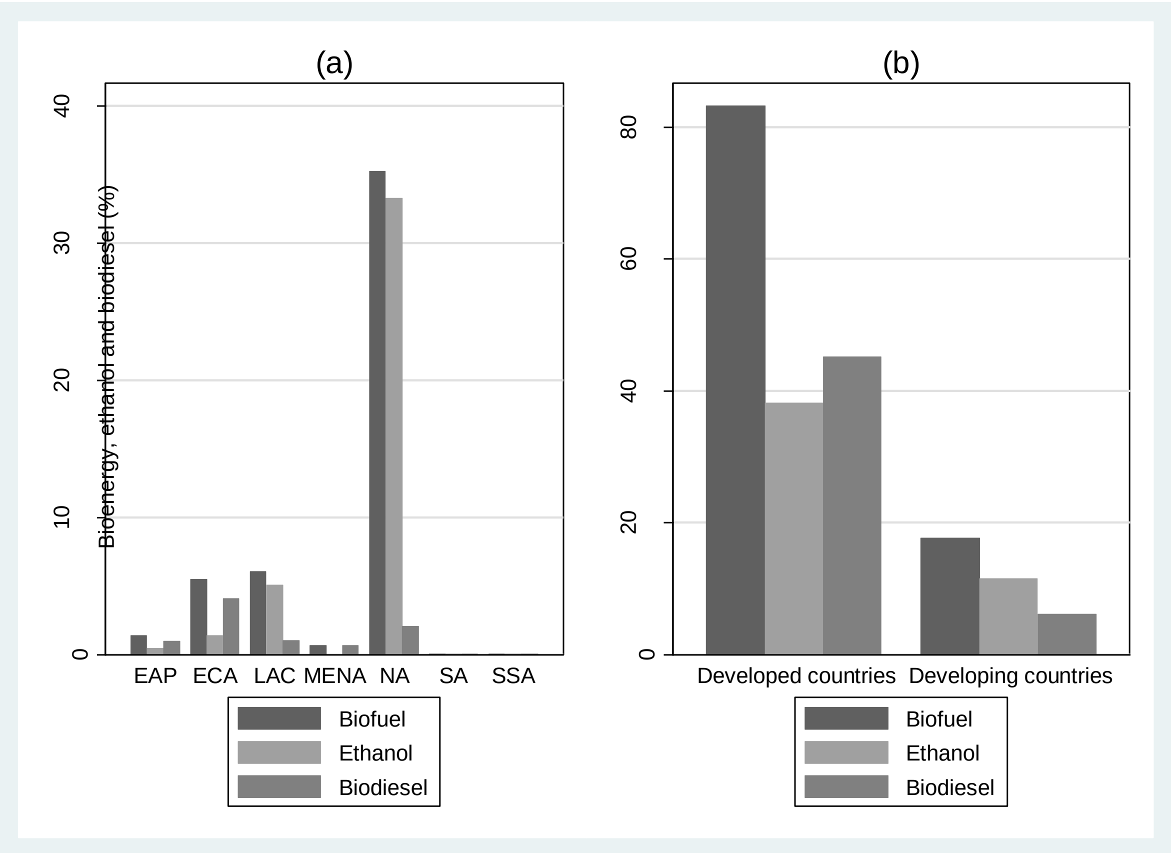
[4] Fixed effects tobit models developed by Honoré (1992) was implemented with STATA 'pantob' and is available at: http://www.princeton.edu/~honore/stata/#1._Pantob_version_0.6.

[5] For example, it is difficult to find homogeneous data on fuelwood production by country.

biodiesel, and total bioenergy (ethanol + biodiesel) as a proxy of bioenergy. So this assumption excludes mainly fuelwood and biogas. The study sample contains 112 countries over the period between 2000 and 2012. Data on bioenergy, renewable energy, international price of oil, and oil reserves are from EIA (2015b).

The other explanatory variables are from World Development Indicators (WDI 2015): gross domestic product (*GDP*), population density (*Pop_dens*), percentage of urban population (*Urban*) and cereal production (*Cereal_yield*), agricultural land (*Agri_land*), and financial development (*Financial*). In this study, we do not use the production of sugarcane as an explanatory variable because there are too many missing data. Figure 3 provides descriptive statistics on the distribution of global bioenergy production. It shows that North America is the largest bioenergy producer, followed by Latin America, Europe, and Central Asia. Latin America and North America are the largest producers of ethanol whereas Europe is the largest producer of biodiesel.

Figure 3: Distribution (percentage) of bioenergy, ethanol, and biodiesel by (a) region and (b) level of development in 2012



Note: EAP, East Asia and Pacific; ECA, Europe and Central Asia; LAC, Latin America and the Caribbean; MENA, Middle East and North Africa; SA, South Asia; SSA, Sub-Saharan Africa.

Source: Author's calculations using data from EIA (2015a).

Governance is an index of the overall quality of governance, constructed using six dimensions of governance of the International Country Risk Guide (ICRG 2015): bureaucracy quality, corruption, investment profile, democratic accountability, government stability, and law and order. We combined these indicators using the first two principal components (81 per cent of the overall variance) of the vector of six indicators of governance. We standardized the index by the following method: $Governance = [Index - \max(Index)]/[\max(Index) - \min(Index)]$. The results of the principal component analysis are presented in Appendix Table B1. The renewable energy variable and governance index are lagged by five years to avoid endogeneity problems.

Biofuel mandates are a prime targeted mechanism to stimulate the production of biofuel. Unfortunately, there are very few panel data on these policies. Moreover, these mandates do not vary much over time; therefore, they are captured by fixed effects of our empirical model. For these reasons and as a proxy, we use the composite indexes of EPS elaborated by Botta and Koźluk (2014): market and non-market instruments. These policies are the instruments used to achieve the mandates. The market component of the EPS includes taxes and charges applied on input or output of a production process (diesel) or pollution source (CO_2, NO_x, and SO_x); trading schemes (green certificate, white certificate, and CO_2 trading); feed-in tariffs (solar and wind); and deposit refund scheme (waste). The non-market component of the EPS includes standards (emission limit values: NO_x, SO_x, PM_x, and sulphur in diesel content limit) and research and development subsidies. Both indices can be used as a proxy of premium price because they allow internalizing the market and environmental externalities. Unfortunately, these variables exist only for OECD member countries. In developing countries, energy policies include policy statements on the development of bioenergy, often without concrete strategies or the institutional framework necessary for implementation (Jumbe et al. 2009).

Our measurement of financial development is the ratio of domestic credit allocated to private sector to GDP (excluding credit to central government and public enterprises and credit issued by central banks). This measure goes beyond the market interest rates because it allows us to account for the quality and capacity of the domestic financial system to finance the private sector.

Oil_reserve, representing the crude oil proved reserves, is an exogenous variable that does not vary much over time. The international price of oil (*Inter_Oil_price*) is the result of the interaction between global oil supply and demand. It is exogenous but does not vary across countries. Using these terms, we generate a new variable dividing oil reserves by the international oil prices (*Oil = Oil_reserves/Inter_Oil_price*). *Oil* is the relative value of oil reserves compared to international oil prices. This new variable is exogenous and varies over time and between countries.

Our definition of the legal origin of laws is based on the distinction made by La Porta et al (1999). According to the historic and legal tradition of company law, or commercial code, countries are classified as: British law (or common law), French civil law, German civil law, Scandinavian law, and Socialist law. These traditions historically come from Great Britain, France, Germany, Scandinavia, and the Soviet Union, respectively. For our purposes, the legal origins[6] are represented by binary variables that identify the legal origin of a country's laws as French, German, Scandinavian, or Socialist, with British law as the omitted group.

Based on the results of the theoretical model, the literature on the determinants of bioenergy production, and political economy literature, we classify the determinants of bioenergy production into six sets of explanatory variables: indicators of governance quality, EPS instruments, legal origins of law, macroeconomic policies, agricultural policy factors (supply factors), and market size (demand factors) (Table 1).

[6] See Section 3.4 for further explanation of the expected signs of legal origin.

Table 1: Expected signs of the explanatory variables

Explanatory variables	Indicators	Expected sign
Quality of governance	*Governance* (index of overall governance quality)	+
EPS	*Market-based instruments*	+
	Non-market-based instruments	+
Legal origins	*British*	Reference
	German	+
	Scandinavian	+
	French	+
	Socialist	–
Substitute products	*Oil scarcity* (oil reserve to oil price ratio)	–
	Renewable energy production (hydroelectric, geothermal, wind, solar, waste, tide, and wave)	–
Macroeconomic policies	*Financial development*	+
	Trade openness (trade to GDP ratio)	+
Agricultural productivity	*Cereal yield*	+
Market size	*GDP per capita*	+
	Population density	+
	Urban (%)	+

Source: Author's compilation.

3 Determinants of the production of bioenergy

3.1 Bioenergy and political economy factors: naïve evidence

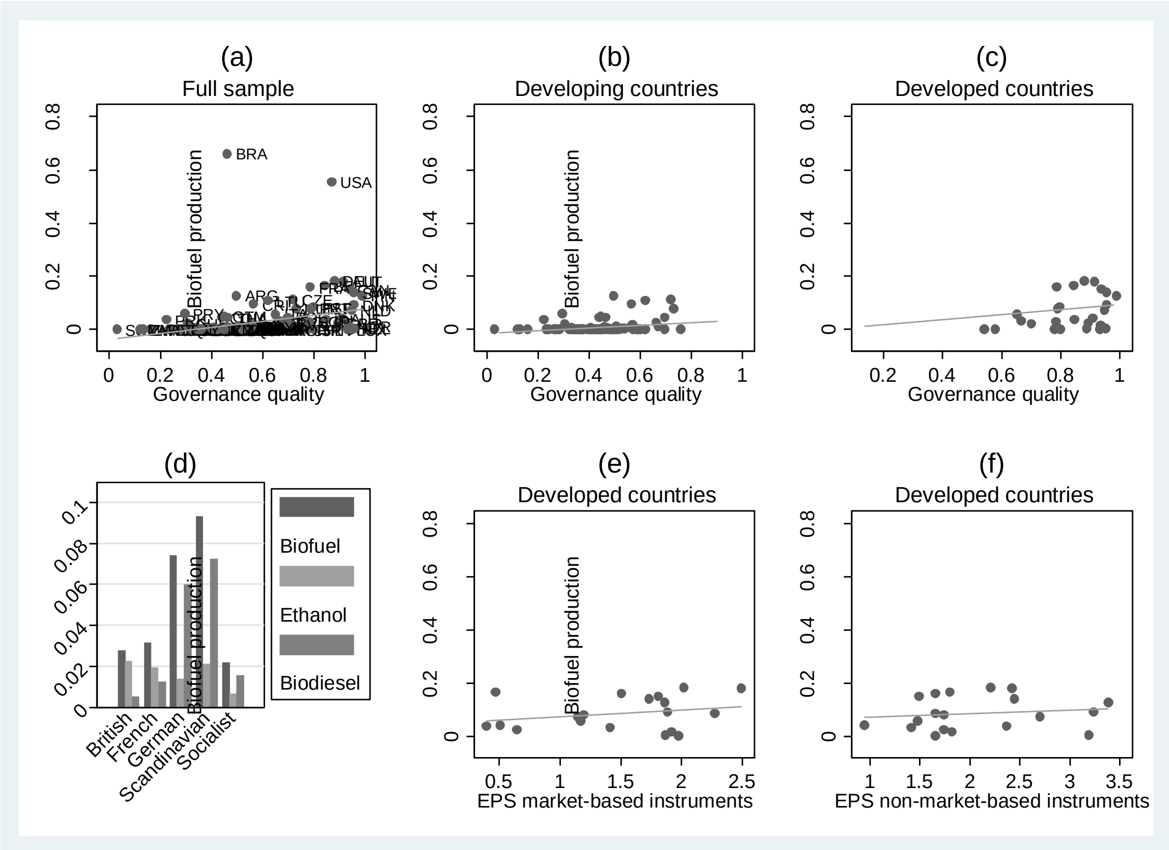
In this section, we give an insight into the relationships between our variables of interest. Figure 4 provides a combined visual analysis of the relationship between bioenergy and political economy factors over the entire sample of developing and developed countries. The graphs (Figures 4a–4f) suggest that there is a strong positive effect of governance and EPS instruments on bioenergy production. They also show that the United States and Brazil have levels of bioenergy production higher than other countries. These countries can be considered outliers. Indeed, the United States and Brazil are the world's largest producers of bioenergy, and have developed proactive policies of bioenergy production. For example, Brazil has committed to increase the share of ethanol to 27.5 per cent in its overall energy balance, and, as mentioned in the introduction, the United States set the goal of incorporating a minimum of 36 billion gallons of biofuels into the fuel market by 2022 (EPA 2010). For robustness, we will test the sensitivity of our results to the presence of these countries in our regressions.

Figure 4d analyses the average per capita production of bioenergy by legal origin.[7] This graph shows that countries with laws of Scandinavian and Germanic origin produce more bioenergy than others, whereas those of French and Socialist origin produce relatively less bioenergy. Taking into account the characteristics of the origin of a country's laws, highlighted by La Porta et al. (1999, 2008), these statistics are consistent with our expectations. Indeed, we think that countries following Scandinavian and German civil law are most likely to promote the production of bioenergy. The interventionist stance of their laws, and efficiency of their bureaucracy, will allow them to opt for clean energy, despite pressure. We expect countries subject to the French civil law to be intermediate regarding the adoption of clean energy. In these countries the bureaucracy is powerful and largely unconstrained, which helps in the implementation of environmental policies. However, this system typically generates more

[7] This analysis is a simple correlation that does not take into account other factors, such as mandates on both ethanol and biodiesel production, which can have a significant impact on the relationship between bioenergies and the legal origin of laws.

corruption, low financial development, and unemployment, which tends to reduce the effectiveness of environmental policies. However, laws of British origin rely on strong private property rights and low regulation, which promotes the development of private activity with low regulation. Therefore, binding environmental policies will be difficult to implement. Finally, countries with laws of Socialist origin have the least effective environmental policies because of the high probability of corruption associated with them.

Figure 4: Correlation between bioenergy, governance quality, and environmental policy stringency (EPS)

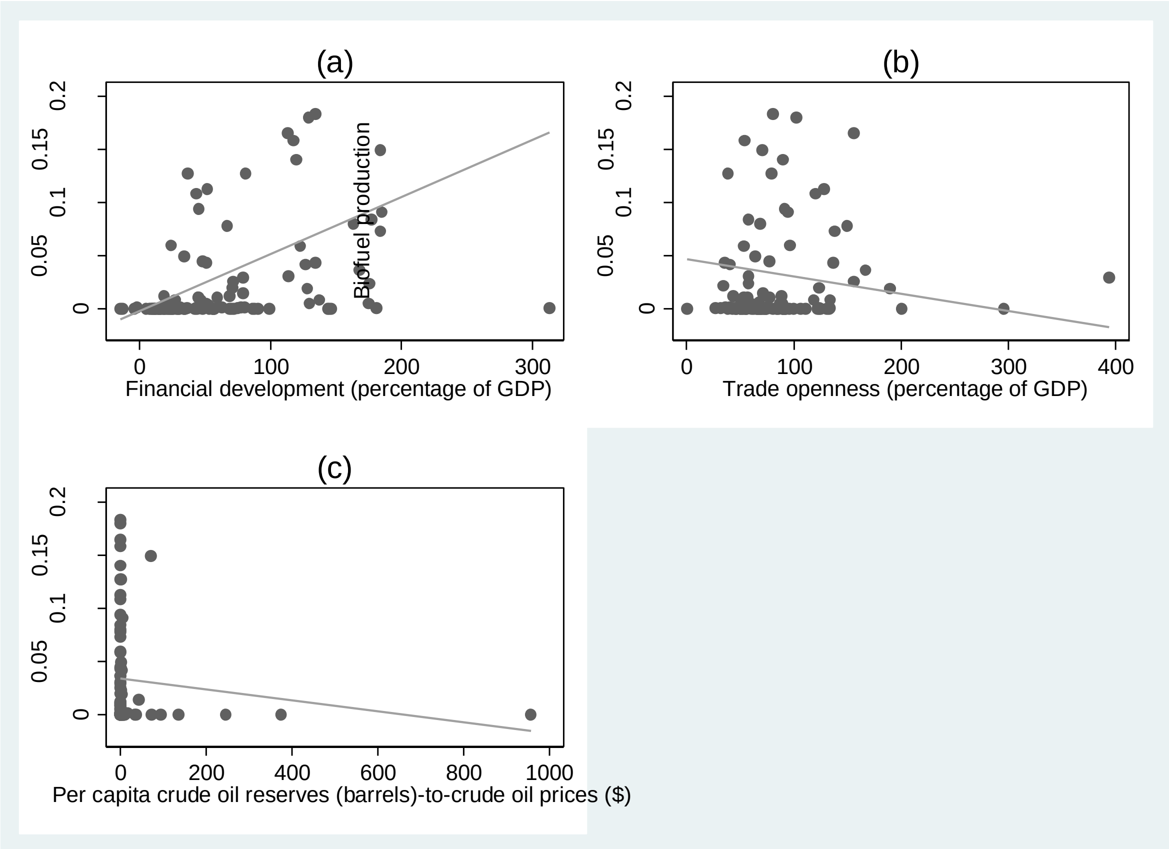


Note: Biofuel is measured in 1000 barrels per year; governance quality and EPS are index.

Source: Author's calculations using data from EIA (2015a), ICRG (2015), and Botta and Koźluk (2014).

Figure 5 shows the impact of macroeconomic policies on bioenergy. As expected, these results show that financial development and oil reserves influence the production of bioenergy positively and negatively, respectively, whereas the impact of trade openness is negative. Indeed, the least competitive countries may choose to import bioenergy from the most competitive countries and therefore reduce their own productions. However, this result seems counterintuitive because bioenergy trade is not very developed.

Figure 5: Correlation between bioenergy and macroeconomic policies of (a) financial development, (b) trade openness, and (c) oil scarcity



Note: Biofuel is measured in 1000 barrels per year.

Source: Author's calculations using data from EIA (2015a) and WDI (2015).

3.2 Results of tobit model with fixed effects

The estimation results using the tobit model with fixed effects are presented in Table 2 and random effects results are presented in Appendix Table C1. The drivers of bioenergy production can be classified into four categories: governance quality, macroeconomic policies, size of market, and agricultural factors.

Governance quality

Across the entire sample, the index of the quality of governance has a significant positive effect at 5 per cent level on the production of biodiesel. When looking at the results by level of development, governance quality promotes the production of bioenergy. According to our results, quality of governance significantly influences the production of ethanol in developing countries and biodiesel in developed countries.

Regarding the impact of EPS instruments, non-market-based instruments positively affect the total production of bioenergy and biodiesel in developed countries whereas market-based instruments do not have a significant effect. Such results are not surprising. Indeed, non-market-based instruments (standards and research and development subsidies) provide research support for the introduction of new technologies and improve the profitability and social acceptance of clean energy including bioenergy. In contrast, market-based instruments (taxes on carbon, diesel, or sulphide and feed-in tariffs for solar and wind) are intended for promoting renewable energy such as solar and wind.

Table 2: Tobit model with fixed effect of bioenergy supply

Variable	All countries			Developing countries			Developed countries		
	Biofuel	Ethanol	Biodiesel	Biofuel	Ethanol	Biodiesel	Biofuel	Ethanol	Biodiesel
Governance quality									
Governance	0.4132	0.2917	0.3858**	0.3593**	0.3124**	0.0924	–0.1823	–0.4648	0.3385*
	(0.2684)	(0.2450)	(0.1540)	(0.1747)	(0.1400)	(0.0970)	(0.4606)	(0.3381)	(0.1948)
EPS market							–0.0323	–0.0782*	0.0107
							(0.0304)	(0.0426)	(0.0111)
EPS non-market							0.0464*	–0.0023	0.0555***
							(0.0273)	(0.0238)	(0.0149)
Other energy									
Renewable	–0.0280	–0.0532	0.0126	–0.0408***	–0.0261	–0.0200	–0.0403	–0.0147	–0.0034
	(0.0310)	(0.0564)	(0.0214)	(0.0125)	(0.0238)	(0.0163)	(0.0421)	(0.0301)	(0.0221)
Oil	–0.0009***	–0.0006	0.0003	–0.1230	–0.0693	–0.0380**	–0.0003	0.0009	0.0009**
	(0.0002)	(0.0004)	(0.0004)	(0.0897)	(0.1380)	(0.0176)	(0.0003)	(0.0006)	(0.0004)
Macroeconomic policies									
Financial	0.0028	0.0027	0.0013	0.0056***	0.0046*	0.0029***	–0.0009	–0.0012	0.0000
	(0.0018)	(0.0018)	(0.0009)	(0.0017)	(0.0025)	(0.0010)	(0.0015)	(0.0009)	(0.0010)
Openness	0.0025	0.0064	0.0002	0.0023*	0.0040**	0.0003	–0.0022	0.0024	–0.0003
	(0.0018)	(0.0044)	(0.0008)	(0.0012)	(0.0020)	(0.0005)	(0.0033)	(0.0050)	(0.0015)
Market size									
GDP	0.0342***	0.0330***	0.0209***	–0.0062	0.0412	–0.0008	0.0481***	0.0114	0.0177**
	(0.0109)	(0.0085)	(0.0056)	(0.0111)	(0.0456)	(0.0067)	(0.0148)	(0.0417)	(0.0078)
Population density	0.0881**	0.0572**	0.0568*	0.0097	0.0271	0.0026	0.1789***	0.1150	0.0523**
	(0.0449)	(0.0287)	(0.0313)	(0.0573)	(0.0653)	(0.0352)	(0.0641)	(0.1796)	(0.0259)
Urban	0.0193	0.0056	0.0285***	0.0062	–0.0026	0.0063	0.1381	0.3337**	0.0169
	(0.0376)	(0.0116)	(0.0110)	(0.0090)	(0.0139)	(0.0068)	(0.1267)	(0.1438)	(0.0146)
Agricultural productivity									
Cereal yield	0.1099**	0.1745**	0.0307***	0.0575***	0.0616***	0.0181	0.1129**	0.1467***	0.0236***
	(0.0450)	(0.0772)	(0.0080)	(0.0189)	(0.0182)	(0.0133)	(0.0488)	(0.0277)	(0.0083)
Observations	1338	1338	1338	1021	1021	1021	243	243	243
(Hausman test)									
χ^2	59.827	389.80	40.151	90.113	146.83	15.421	279.42	165.83	221.30
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.2013	0.0000	0.0000	0.0000

Note: Standard errors in parentheses; *p<0.10, **p<0.05, ***p<0.01.

Source: Author's calculations using data from EIA (2015a), ICRG (2015), Botta and Koźluk (2014), and WDI (2015).

Other energy

Oil reserves have a negative effect on the production of bioenergy in the overall sample and on biodiesel in developing countries. Large oil reserves represent a guarantee of availability of oil at low cost, which tends to discourage the production of bioenergy. However, oil reserves significantly promote the production of ethanol and biodiesel in developed countries. In fact, the rich oil-producing countries tend to invest more in clean energy.

Renewable energy has a significant negative impact only on the total bioenergy production in developing countries. Unlike developed countries, these countries lack the financial capacities to invest in both renewable energy and biofuels.

Macroeconomic policies

The impact of macroeconomic policies is contrasted with the level of development. Our results show that financial development positively influences the production of bioenergy in developing countries. These countries face enormous difficulties financing their economies, yet they have vast unexploited fertile farmland. A structured and efficient financial system would allow projects for bioenergy production to be financed at a lower cost. Financial development has no impact on the production of bioenergy in developed countries because they have little problem financing promising projects. Finally, as expected, trade openness has a positive impact on bioenergy and ethanol, but only in the subsample of developing countries.

Market size

In developed countries, the size of the market plays a key role in the development of bioenergy. Per capita income, urbanization, and population density promote energy demand. Given the relatively high income in these countries, according to the environmental Kuznets curve, a part of the energy demand will be transferred to clean energy, including bioenergy.

Market size factors do not significantly influence the production of bioenergy in developing countries. This result can be explained by the relatively higher cost of bioenergy; they are mainly produced using subsidies. It is difficult for developing countries, which have other priorities such as food security or fighting against poverty, to engage in subsidized bioenergy production.

Agricultural factors

Cereal yield is an important determinant of bioenergy production. As expected, it has a positive and significant influence on the production of bioenergy, ethanol, and biodiesel in the total sample of developing and developed countries.

Estimation results without the United States and Brazil

As a test of robustness, we excluded Brazil and the United States in our sample because their production of bioenergy represents a large portion of total world production. For example, in 2012, these two countries accounted for 30 per cent of the world's production (EIA 2015a). In addition, as shown in Figure 4, these two countries can be considered outliers. The results presented in Appendix Table D1 are in line with the previous results. Therefore, these countries have no influence on the quality of our results.

3.3 Decision to produce bioenergy: results of random effects probit model

To identify the influence of political economy factors on the decision of whether or not to produce bioenergy, we use a random effects probit model. As noted earlier, more than half the numbers of countries in our estimation sample do not produce bioenergy; therefore, it is important to study the determinant of this decision to better target energy policies.

The results presented in Table 3 show that governance quality is an important factor in the decision to produce bioenergy in developed countries. Indeed, governance has a positive effect on all types bioenergy production (total bioenergy, ethanol, and biodiesel) in developed countries, bioenergy and ethanol in the total sample, and no effect in developing countries. EPS instruments favour the production of bioenergy in developed countries. Non-market-based instruments have a positive impact on all types of bioenergy whereas market-based instruments only favour biodiesel production. The impact of governance quality and EPS is more important in the decision to produce bioenergy in developed countries because they create favourable conditions that encourage the development of business and investments. The high level of income and subsidies increase demand and profitability of bioenergy.

Table 3: Random effects probit model of the decision to produce bioenergy

Variable	All countries			Developing countries			Developed countries		
	Biofuel	Ethanol	Biodiesel	Biofuel	Ethanol	Biodiesel	Biofuel	Ethanol	Biodiesel
Governance quality									
Governance	2.2511*	1.7955	3.0700**	0.6822	−1.2634	0.8945	18.622***	12.840***	16.779***
	(1.1825)	(1.1439)	(1.2867)	(1.3074)	(1.3792)	(2.3536)	(5.6353)	(3.7821)	(5.8535)
EPS market							0.8480	0.1780	2.5593**
							(1.0153)	(0.2827)	(1.1744)
EPS non-market							3.1558***	0.7220***	4.8830***
							(0.8699)	(0.2601)	(0.9087)
Other energy									
Renewable	0.3149**	0.1021	0.0828	0.4512**	0.3105	0.2981*	0.2232	−0.0584	−0.1196
	(0.1571)	(0.1048)	(0.1570)	(0.2102)	(0.2392)	(0.1710)	(0.3653)	(0.1603)	(0.2798)
Oil	−0.1013***	−0.0322**	−0.0166**	−0.0880**	−0.0731**	−9.9969***	−0.0748**	−0.0160	−0.0186
	(0.0158)	(0.0163)	(0.0067)	(0.0345)	(0.0298)	(2.4561)	(0.0318)	(0.0169)	(0.0136)
Macroeconomic policies									
Financial	0.0353***	0.0297***	0.0351***	0.0182***	0.0189***	0.0221**	0.1022***	0.0233***	0.0492***
	(0.0051)	(0.0047)	(0.0054)	(0.0069)	(0.0073)	(0.0107)	(0.0265)	(0.0086)	(0.0189)
Openness	0.0210***	0.0126**	0.0150**	0.0158**	0.0081	0.0208*	0.0762	0.0093	−0.0020
	(0.0064)	(0.0064)	(0.0062)	(0.0067)	(0.0077)	(0.0119)	(0.0483)	(0.0153)	(0.0338)
Market size									
GDP	0.0831**	−0.0117	0.0386	0.9492***	0.7657***	1.3620***	0.0760	0.0032	0.4271***
	(0.0381)	(0.0371)	(0.0426)	(0.1796)	(0.1378)	(0.2674)	(0.1658)	(0.0824)	(0.1517)
Population density	0.0433*	0.0198	0.0329	0.0480**	0.0420**	0.0744***	−0.5121***	−0.1143*	−0.2221*
	(0.0255)	(0.0328)	(0.0227)	(0.0200)	(0.0199)	(0.0269)	(0.1645)	(0.0628)	(0.1335)
Urban	0.1437***	0.0707***	0.1555***	0.0253	0.0021	0.2007***	0.1818	0.1227*	0.1799
	(0.0167)	(0.0244)	(0.0283)	(0.0255)	(0.0302)	(0.0472)	(0.1821)	(0.0678)	(0.1185)
Agricultural productivity									
Cereal yield	1.0549***	0.7913***	0.9557***	1.0669***	0.9406***	0.9855***	0.7682	0.1918	0.4427
	(0.1592)	(0.1655)	(0.1913)	(0.1928)	(0.2337)	(0.3672)	(0.5729)	(0.3176)	(0.5389)
$\ln\sigma^2_\mu$	4.0946***	3.3494***	3.7872***	3.5999***	3.5530***	4.8731***	4.3027***	2.0114***	4.7753***
	(0.2055)	(0.2250)	(0.2097)	(0.2561)	(0.2605)	(0.3027)	(0.4997)	(0.5537)	(0.4480)
Constant	−21.00***	−14.74***	−23.25***	−12.88***	−10.37***	−27.23***	−49.60***	−25.46***	−55.44***
	(1.0763)	(1.1142)	(1.1590)	(1.0807)	(1.2486)	(2.5000)	(13.4772)	(6.4594)	(9.8595)
Observations	1338	1338	1338	1021	1021	1021	243	243	243

Note: Standard errors in parentheses; *p<0.10, **p<0.05, ***p<0.01.

Source: Author's calculations using data from EIA (2015a), ICRG (2015), Botta and Koźluk (2014), and WDI (2015).

Among factors of macroeconomic policies, financial development promotes the production decision of all bioenergy types, whatever the level of development. Our results also show that trade openness promotes all types of bioenergy in the total sample and developing countries.

Oil reserves reduce the production of all types of bioenergy in the overall sample and the developing countries sample, but only bioenergy production in developed countries. In contrast, the production of renewable energy favours the decision to produce bioenergy in the total sample. It promotes bioenergy and biodiesel production in developing countries, but it has no significant effect in developed countries.

Finally, both the size of the market and agricultural factors increase the likelihood of producing bioenergy, excluding the density of the population that negatively influences bioenergy developed in the country.

3.4 Long-run analysis: impact of legal origins on bioenergy production

The energy transition generates a significant additional cost. The production of bioenergy is currently more expensive than that of gasoline or diesel. To be competitive, bioenergy needs to be widely supported and provided tax exemptions, duty incorporation in fuels, etc. However, the cost of inaction with regard to climate change is much more important. Therefore, the development of clean energy requires significant investment, a political will, along with the state's willingness to impose binding environmental standards on its industries, as well as capacity for the economy to absorb additional costs in the short term (Table 4).

Table 4: Long-run analysis: impact of legal origins on bioenergy production

Variable	All countries			Developing countries			Developed countries		
	Biofuel	Ethanol	Biodiesel	Biofuel	Ethanol	Biodiesel	Biofuel	Ethanol	Biodiesel
Legal origins[a]									
French	–0.0049	–0.0139	0.0093	0.0189	0.0370	–0.0021	0.0165	–0.0802	0.0962**
	(0.0329)	(0.0361)	(0.0124)	(0.0423)	(0.0493)	(0.0132)	(0.3089)	(0.2983)	(0.0345)
Socialist	0.0265	0.0125	0.0175	0.0502	0.0602	0.0142	0.0000 (.)	0.0000 (.)	0.0000 (.)
	(0.0411)	(0.0458)	(0.0149)	(0.0480)	(0.0566)	(0.0140)			
German	–0.0663	–0.1013	0.0266				–0.0899	–0.2259	0.1349**
	(0.0624)	(0.0644)	(0.0216)				(0.3219)	(0.3111)	(0.0356)
Scandinavian	–0.0341	–0.0742	0.0521*				0.0176	–0.1790	0.1959***
	(0.0764)	(0.0786)	(0.0266)				(0.2907)	(0.2812)	(0.0404)
Governance quality									
Governance	0.0629	–0.1022	0.1169**	–0.0477	–0.1479	–0.0010	1.0546	0.4204	0.6348***
	(0.1458)	(0.1548)	(0.0538)	(0.1854)	(0.2051)	(0.0542)	(0.9761)	(0.9307)	(0.1529)
EPS market							0.8480	0.1780	2.5593**
							(1.0153)	(0.2827)	(1.1744)
EPS non-market							3.1558***	0.7220***	4.8830***
							(0.8699)	(0.2601)	(0.9087)
Other energy									
Renewable	0.0043	0.0064	–0.0002	0.0197	0.0205	0.0008	–0.0090	0.0023	–0.0113**
	(0.0057)	(0.0058)	(0.0021)	(0.0132)	(0.0138)	(0.0037)	(0.0189)	(0.0181)	(0.0033)
Oil	–0.0019	–0.0016	–0.0007	–0.0044	–0.0035	–0.0049*	–0.0003	–0.0020	0.0017**
	(0.0014)	(0.0013)	(0.0005)	(0.0030)	(0.0026)	(0.0029)	(0.0041)	(0.0040)	(0.0006)
Macroeconomic policies									
Financial	0.0005	0.0006*	0.0000	0.0007	0.0009*	–0.0000	–0.0002	0.0003	–0.0005**
	(0.0003)	(0.0003)	(0.0001)	(0.0005)	(0.0005)	(0.0001)	(0.0008)	(0.0007)	(0.0001)
Openness	–0.0007**	–0.0010**	–0.0000	–0.0006	–0.0010*	0.0000	–0.0001	–0.0003	0.0002
	(0.0003)	(0.0004)	(0.0001)	(0.0004)	(0.0005)	(0.0001)	(0.0020)	(0.0019)	(0.0002)
Market size									
GDP	0.0002	0.0009	–0.0005	0.0057	0.0053	0.0018	–0.0002	0.0003	–0.0005
	(0.0018)	(0.0020)	(0.0006)	(0.0072)	(0.0080)	(0.0020)	(0.0082)	(0.0078)	(0.0013)
Population density	–0.0020	–0.0015	–0.0004	–0.0009	–0.0000	–0.0004	–0.0033	–0.0030	–0.0002
	(0.0013)	(0.0013)	(0.0004)	(0.0015)	(0.0014)	(0.0005)	(0.0062)	(0.0061)	(0.0009)
Urban	0.0012	0.0012	0.0004	0.0010	0.0011	0.0005	–0.0011	0.0018	–0.0029**
	(0.0008)	(0.0009)	(0.0003)	(0.0011)	(0.0012)	(0.0004)	(0.0051)	(0.0046)	(0.0009)
Agricultural productivity									
Cereal yield	0.0666***	0.0627***	0.0291***	0.0360***	0.0404***	0.0122***	0.0625***	0.0659***	0.0170**
	(0.0093)	(0.0100)	(0.0054)	(0.0083)	(0.0084)	(0.0043)	(0.0169)	(0.0178)	(0.0074)
σ	4.0946***	3.3494***	3.7872***	3.5999***	3.5530***	4.8731***	4.3027***	2.0114***	4.7753***
	(0.2055)	(0.2250)	(0.2097)	(0.2561)	(0.2605)	(0.3027)	(0.4997)	(0.5537)	(0.4480)
Constant	0.1065***	0.1082***	0.0368***	0.1042***	0.1082***	0.0286***	–0.7818	–0.6046	–0.1786
	(0.0097)	(0.0110)	(0.0037)	(0.0121)	(0.0140)	(0.0039)	(0.7648)	(0.7333)	(0.1098)
Observations	112	112	112	86	86	86	20	20	20

Note: [a]British civil law is excluded. Standard errors in parentheses; *p<0.10, **p<0.05, ***p<0.01.

Source: Author's calculations using data from EIA (2015a), ICRG (2015), Botta and Koźluk (2014), La Porta et al. (1999), and WDI (2015).

Since legal origin does not vary over time, we analyse its impact on the production of bioenergy in the long term. Moreover, we believe that the impact of these historical factors should be more noticeable over the long term. To do this, we take the average of all the variables used in the estimation across the reporting period. This produces a new bioenergy variable that is censored (44 and 54 per cent of countries do not produce bioenergy in the overall sample and the developing countries sample, respectively). We use a tobit model in cross-section to estimate the impact of legal origin in these two samples and ordinary least square of developed countries.

Legal origin only affects the production of biodiesel in the total sample. It has no effect on biodiesel in developing countries, but it affects the production of bioenergy in developed countries. As expected, countries whose laws are of Scandinavian origin produce relatively more biodiesel than countries whose laws are of British origin. Other legal origins have no significant effects on the production of bioenergy.

4 Summary and policy implications

The adverse effects of climate change and the need to find an alternative to fossil fuels have significantly increased the interest of states and investors in bioenergy. The objective of this study was to analyse the impact of political economy factors on bioenergy production. Our methodological contribution is a theoretical and empirical analysis of the determinants of bioenergy production.

First, we showed theoretically that governance quality and premium price (EPS instruments) promote the development of bioenergy production. We also showed that the factors favouring oil production (oil reserves and low price of oil) negatively influence the development of bioenergy production. This result is due to these products being substitutable. The conditions of production (cereal yield) and demand (GDP, population density, and urbanization) tend to favour the production of bioenergy.

Second, we showed empirically that the political economy factors (governance quality, EPS instruments, and macroeconomic policies) create the necessary conditions (subsidies, standards, less corruption, strong properties rights, effective governance, etc.) for development and investment in bioenergy. However, once the investment decision is made, factors of supply and demand determine the quantity produced. Indeed, cereal yield increases production by reducing production costs when the purchasing power of the population (per capita income), urbanization, and population density increase demand.

Third, we showed that bioenergy production is guided by the factors of demand (market size) in developed countries, but in developing countries the impact of supply factors (cereal yield, financial development, and governance quality) is more important.

Bioenergies are not a magic solution to the fight against climate change due to the relatively high costs of these energies and indirect changes in land uses that could cause increase in greenhouse gas emissions. However, they can contribute to the fight against global warming and the fight against poverty in developing countries if technical innovations reduce their production costs and measures taken to minimize indirect land use changes. Therefore, in developing countries, global and national efforts should be made to attract more investors in this area, including: (i) research and innovation to reduce production costs, (ii) adding bioenergy to national energy policies, (iii) creating a legal framework for their development, (iv) promoting the development of the application, and (v) providing a basis for learning more about the development of viable and sustainable bioenergy models. In this context, Sub-Saharan Africa has an important role to play. It is lagging in the production of bioenergy, despite its enormous potential (<1 per cent of world production). According to Fischer and Shah (2010), 445 million hectares of land area is available for agriculture worldwide, 201 million hectares of which is in Sub-Saharan Africa. These are not protected areas or forests, they are not yet being used for agriculture, and they have a low population density (less than 25 inhabitants per square kilometre). The development of these lands could significantly increase the production of bioenergy and contribute to the growth of these countries. For example, using a computable general equilibrium model, Arndt et al. (2010) showed that the expansion of biofuels production in Mozambique and Tanzania can contribute to boost growth, reduce the dependence on imports of fossil fuels, increase investment, and positively influence the agricultural sector and processors downstream. However, as pointed out by Jumbe et al. (2009), bioenergy development in Sub-Saharan Africa could have a negative impact on food security. Furthermore, no regulatory framework should come at the expense of small rural farmers. In this context, it is important for each country to develop its own bioenergy policies, taking into account the need to provide food at acceptable prices for its citizens. Such policies should encourage local and foreign investments that benefit the entire agricultural sector, while protecting small farmers.

References

Acemoglu, D., S. Johnson, and J.A. Robinson (2001). 'The Colonial Origins of Comparative Development: An Empirical Investigation'. *The American Economic Review*, 91(5): 1369–401.

Arndt, C., S. Msangi, and J. Thurlow (2010). 'Are Biofuels Good for African Development? An Analytical Framework with Evidence from Mozambique and Tanzania'. WIDER Working Paper 2010/110. Helsinki: UNU-WIDER.

Baum, M.A., and D.A. Lake (2003). 'The Political Economy of Growth: Democracy and Human Capital'. *American Journal of Political Science*, 47(2): 333–47.

Botta, E., and T. Koźluk (2014). 'Measuring Environmental Policy Stringency in OECD Countries: A Composite Index Approach'. OECD Economics Department Working Paper 1177. Paris: OECD Publishing.

Christopoulos, D.K., and E.G. Tsionas (2004). ''Financial Development and Economic Growth: Evidence from Panel Unit Root and Cointegration Tests.' *Journal of Development Economics*, 73(1): 55–74.

EIA (2015a). 'International Energy Statistics (IES)'. Washington, DC: US Department of Energy, US Energy Information Administration (EIA). Available at: http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm (accessed 15 February 2015).

EIA (2015b). 'International Energy Statistics (IES), Renewables, Biofuels Production, 2008–2012'. Washington, DC: US Department of Energy, US Energy Information Administration (EIA). Available at: http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=79&pid=79&aid=1 (accessed 22 May 2015).

EPA (2010). 'Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis'. Washington, DC: US Environmental Protection Agency (EPA). Available at: http://www.epa.gov/sites/production/files/2015-08/documents/420r10006.pdf (accessed 5 March 2016).

Fischer, G., and M. Shah (2010). 'Part 2: Statistical Annex'. *Farmland Investments and Food Security*. Washington, DC: World Bank. Available at:

http://documents.worldbank.org/curated/en/2010/08/14999367/farmland-investments-food-security (accessed 8 March 2016).

Gan, J., and C.T. Smith (2011). 'Drivers for Renewable Energy: A Comparison among OECD Countries'. *Biomass and Bioenergy*, 35: 4497–503.

Grafton, R.Q., T. Kompas, and N.V. Long (2012). 'Substitution between Biofuels and Fossil Fuels: Is There a Green Paradox?'. *Journal of Environmental Economics and Management*, 64(3): 328–341.

Greene, W.H. (2002). *Econometric Analysis*, 5th edition. Upper Saddle River, NJ: Prentice Hall.

Heun, M.K., and M. de Wit (2012). 'Energy Return on (Energy) Invested (EROI), Oil Prices, and Energy Transitions'. *Energy Policy*, 40(C): 147–158.

Honoré, E.B. (1992). 'Trimmed Lad and Least Squares Estimation of Truncated and Censored Regression Models with Fixed Effects'. *Econometrica*, 60(3): 533–65.

Hotelling, H. (1931). 'The Economics of Exhaustible Resources'. *Journal of Political Economy*, 39(2): 137–75.

ICRG (2015). 'International Country Risk Guide'. New York: The PRS Group. Available at: http://www.prsgroup.com/about-us/our-two-methodologies/icrg (accessed 22 May 2015).

IPCC (2014). *Climate Change 2014: Synthesis Report* [Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), edited by R.K. Pachauri and L.A. Meyer]. Geneva: IPCC. Available at: http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_All_Topics.pdf (accessed 5 March 2016).

Jumbe, C.B., F.B. Msiska, and M. Madjera (2009). 'Biofuels Development in SubSaharan Africa: Are the Policies Conducive?'. *Energy Policy*, 37(11): 4980–6.

La Porta, R., F.L. de Silanes, and A. Shleifer (2008). 'The Economic Consequences of Legal Origins'. *Journal of Economic Literature*, 46(2): 285–332.

La Porta, R., F.L. de Silanes, A. Shleifer, and R.W. Vishny (1999). 'The Quality of Government'. *Journal of Law, Economics and Organization*, 15(1): 222–79.

Nelson, M.A., and R.D. Singh (1998). 'Democracy, Economic Freedom, Fiscal Policy, and Growth in LDCs: A Fresh Look'. *Economic Development and Cultural Change*, 46(4): 677–96.

Powell, J.L. (1984). 'Least Absolute Deviations Estimation for the Censored Regression Model'. *Journal of Econometrics*, 25(3): 303–25.

Powell, J.L. (1986). 'Symmetrically Trimmed Least Squares Estimation for Tobit Models'. *Econometrica*, 54(6): 1435–60.

WDI (2015). 'World Development Indicators, World Databank'. Washington, DC: World Bank. Available at: http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators (accessed 22 May 2015).

Wooldridge, J.M. (2010). *Econometric Analysis of Cross Section and Panel Data*, 2nd edition. Cambridge, MA: The MIT Press.

Appendix A: Description and sources of data, summary statistics, and list of countries

Table A1: Description and sources of data

Variable	Description	Source
Bioenergy	Bioenergy per capita (1000 barrels per year)	EIA (2015a)
Ethanol	Fuel ethanol per capita (1000 barrels per year)	EIA (2015a)
Biodiesel	Biodiesel per capita (1000 barrels per year)	EIA (2015a)
Renewable	Renewable energy per capita (billion kilowatt-hours)	EIA (2015a)
Governance	Aggregated governance index	Author's calculations using ICRG (2015) data
Bureaucracy quality	Bureaucracy quality	ICRG (2015)
Government stability	Government stability	ICRG (2015)
Corruption	Corruption	ICRG (2015)
Investment profile	Investment profile	ICRG (2015)
Law and order	Law and order	ICRG (2015)
Democratic accountability	Democratic accountability	ICRG (2015)
EPS market	Market-based instrument of environmental policy stringency (EPS)	Botta and Koźluk (2014)
EPS non-market	Non-market-based instrument of EPS	Botta and Koźluk (2014)
Legal origin	Dummy variables identify the legal origin of law of a country as British, French, German, Scandinavian, or Socialist	La Porta et al. (1999)
Financial	Domestic credit to private sector by banks (percentage of gross domestic product, GDP)	WDI (2015)
Openness	Trade openness: imports plus exports in percentage of GDP	WDI (2015)
Oil	Per capita crude oil proved reserves (barrels)-to-crude oil prices ratio	EIA (2015a)
GDP	Real GDP per capita (USD 1000, constant 2005)	WDI (2015)
Pop_dens	Population density (1000 people per square kilometre of land area)	WDI (2015)
Urban	Urban population (percentage of total population)	WDI (2015)
Cereal_yield	Cereal yield (1000 kilogrammes per hectare)	WDI (2015)

EIA, (United States) Energy Information Administration; ICRG, International Country Risk Guide; WDI, World Development Indicators; GDP, gross domestic product.

Source: Author's compilation.

Table A2: Summary statistics

Variable	All countries			Developing countries			Developed countries		
	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.
Bioenergy	1338	0.0341	0.1101	1021	0.0179	0.0835	243	0.1115	0.1736
Ethanol	1334	0.0192	0.0919	1017	0.0131	0.0763	243	0.0503	0.1445
Biodiesel	1337	0.0150	0.0452	1021	0.0048	0.0201	242	0.0614	0.0833
Renewable	1338	0.9641	2.8366	1021	0.3997	0.9723	243	2.8662	5.2294
Governance	1338	0.6053	0.1730	1021	0.5355	0.1248	243	0.8476	0.0826
Bureau	1338	2.1553	1.1216	1021	1.7056	0.8135	243	3.7296	0.4806
Corrupt	1338	2.6650	1.1812	1021	2.2005	0.7350	243	4.3613	0.9817
Invest	1338	8.6975	2.1729	1021	7.9751	1.8717	243	11.133	1.220
Land_order	1338	3.7212	1.3589	1021	3.2194	1.1043	243	5.3342	0.6998
Demo	1338	4.1170	1.5859	1021	3.6791	1.4756	243	5.8009	0.4160
Stability	1338	8.5838	1.5395	1021	8.5873	1.5560	243	8.3981	1.3415
EPS market							243	1.5277	0.8742
EPS non-market							243	2.0031	0.9754
French	1338	0.5000	0.5002	1021	0.5289	0.4994	243	0.3745	0.4850
Socialist	1338	0.1442	0.3515	1021	0.1812	0.3854	243	0.0000	0.0000
German	1338	0.0486	0.2151	1021	0.0127	0.1122	243	0.2140	0.4110
Scandinavian	1338	0.0344	0.1823	1021	0.0000	0.0000	243	0.1893	0.3926

British	1338	0.2728	0.4456	1021	0.2772	0.4478	243	0.2222	0.4166
Financial	1338	68.067	61.768	1021	44.960	40.724	243	156.04	57.325
Openness	1338	81.241	41.020	1021	78.742	35.301	243	77.219	36.459
Oil	1338	19.951	125.106	1021	7.9386	37.666	243	5.2580	21.621
GDP	1338	11.340	16.392	1021	3.1495	3.6056	243	36.613	9.552
Pop_dens	1338	10.532	14.183	1021	9.2560	14.460	243	15.036	13.209
Urban	1338	58.641	21.948	1021	52.073	20.201	243	78.271	9.220
Cereal_yield	1338	3.0985	2.0229	1021	2.4169	1.5057	243	5.3604	1.9152

Note: Obs., observations; Std. Dev., standard deviation.

Source: Own calculations using data from EIA (2015a), ICRG (2015), Botta and Koźluk (2014), La Porta et al. (1999), and WDI (2015).

Table A3: Countries in sample (*N*=112)

Developing countries			Developed countries
Angola	Guatemala	Peru	Australia
Albania	Guyana	Philippines	Austria
Argentina	Honduras	Poland	Belgium
Armenia	Croatia	Paraguay	Canada
Azerbaijan	Hungary	Russian Federation	Switzerland
Burkina Faso	Indonesia	Saudi Arabia	Germany
Bangladesh	India	Sudan	Denmark
Bulgaria	Iran, Islamic Republic of	Senegal	Spain
Belarus	Iraq	Sierra Leone	Finland
Bolivia	Jordan	Suriname	France
Brazil	Kazakhstan	Syrian Arab Republic	United Kingdom
Botswana	Kenya	Togo	Greece
Chile	Korea, Republic of	Thailand	Ireland
China	Liberia	Tunisia	Israel
Cote d'Ivoire	Libya	Turkey	Italy
Cameroon	Sri Lanka	Tanzania	Japan
Congo, Republic of	Lithuania	Uganda	Kuwait
Colombia	Morocco	Ukraine	Luxembourg
Costa Rica	Moldova	Uruguay	Netherlands
Czech Republic	Madagascar	Venezuela	Norway
Algeria	Mexico	Vietnam	New Zealand
Ecuador	Mali	Yemen, Republic of	Portugal
Egypt, Arab Republic of	Mozambique	South Africa	Qatar
Estonia	Malawi	Congo, Democratic Republic of	Slovenia
Ethiopia	Malaysia	Zambia	Sweden
Gabon	Namibia	Zimbabwe	United States
Ghana	Niger		
Guinea	Nigeria		
Gambia, The	Nicaragua		
Guinea-Bissau	Pakistan		

Source: Author's compilation.

Appendix B: Principal component analysis

Table B1: Principal component analysis

	Comp1	Comp2	Comp3	Correlation with composite index
Eigenvalues	3.20828	1.15693	0.673064	
Percentage of variance	0.5347	0.1928	0.1122	
Cumulative percentage	0.5347	0.7275	0.8397	
Variable	Vector 1	Vector 2	Vector 3	
Bureaucracy quality	0.4971	−0.1061	−0.0617	0.8371
Corruption	0.4693	−0.0211	−0.3763	0.7841
Investment profile	0.4070	0.2058	0.6461	0.8056
Law and order	0.4330	0.1962	−0.5216	0.7594
Democratic accountability	0.4205	−0.3586	0.3916	0.6807
Government stability	0.0506	0.8825	0.1080	0.2982

Note: The last column represents the correlation of the aggregate index of governance quality with the corresponding governance variable.

Source: Author's calculations using ICRG (2015) rating.

The index of each component is obtained using the following formula:

$$Index1 = 0.4971 \times Gov1 + 0.4693 \times Gov2 + 0.4070 \times Gov3 + 0.4330 \times Gov4 + 0.4205 \times Gov5 + 0.0506 \times Gov6,$$

$$Index2 = -0.1061 \times Gov1 - 0.0211 \times Gov2 + 0.2058 \times Gov3 + 0.1962 \times Gov4 - 0.3586 \times Gov5 + 0.8825 \times Gov6,$$

$$Index3 = -0.0617 \times Gov1 - 0.3763 \times Gov2 + 0.6461 \times Gov3 + 0.5216 \times Gov4 - 0.3916 \times Gov5 + 0.1080 \times Gov6,$$

where *Gov1*, *Gov2*, *Gov3*, *Gov4*, *Gov5*, and *Gov6* represent standardized measures of bureaucracy quality, corruption, investment profile, law and order, democratic accountability, and government stability, respectively. The aggregate index of governance quality can be computed as follow:

$$Governance = [(Index1 \times 0.5347) + (Index2 \times 0.1928) + (Index3 \times 0.1122)] / 0.8397.$$

Appendix C: Results of random effects tobit model

Table C1: Tobit model with random effects of bioenergy supply

	All countries			Developing countries			Developed countries		
	Biofuel	Ethanol	Biodiesel	Biofuel	Ethanol	Biodiesel	Biofuel	Ethanol	Biodiesel
Governance quality									
Governance	0.1788**	0.1260*	0.1539***	0.0513	0.0272	−0.0056	0.2774	0.4038*	0.2638***
	(0.0696)	(0.0726)	(0.0482)	(0.0535)	(0.0552)	(0.0341)	(0.1798)	(0.2234)	(0.0818)
EPS market							0.0279	−0.0001	0.0358***
							(0.0172)	(0.0169)	(0.0074)
EPS non-market							0.0763***	0.0374**	0.0513***
							(0.0138)	(0.0150)	(0.0069)
Other energy									
Renewable	−0.0020	−0.0066	0.0039	0.0093	0.0090	0.0025	−0.0135	−0.0125	−0.0008
	(0.0088)	(0.0088)	(0.0050)	(0.0153)	(0.0157)	(0.0078)	(0.0093)	(0.0102)	(0.0033)
Oil	−0.0009**	−0.0007*	−0.0008*	−0.0053***	−0.0039**	−0.0238***	−0.0006	−0.0005	−0.0003
	(0.0004)	(0.0004)	(0.0004)	(0.0016)	(0.0015)	(0.0066)	(0.0005)	(0.0006)	(0.0004)
Macroeconomic policies									
Financial	0.0019***	0.0015***	0.0011***	0.0018***	0.0011***	0.0010***	0.0003	0.0010**	−0.0001
	(0.0002)	(0.0002)	(0.0001)	(0.0003)	(0.0003)	(0.0002)	(0.0004)	(0.0004)	(0.0002)
Openness	0.0014***	0.0008*	0.0009***	0.0005*	0.0003	0.0002	0.0005	−0.0000	0.0005
	(0.0004)	(0.0005)	(0.0002)	(0.0003)	(0.0003)	(0.0001)	(0.0010)	(0.0010)	(0.0004)
Market size									
GDP	0.0053**	0.0010	0.0016	0.0232***	0.0222***	0.0093***	0.0096	0.0059	−0.0020
	(0.0027)	(0.0031)	(0.0019)	(0.0054)	(0.0049)	(0.0026)	(0.0075)	(0.0057)	(0.0021)
Population density	−0.0019	−0.0021	0.0008	−0.0006	0.0001	−0.0002	−0.0110***	−0.0118***	−0.0020
	(0.0028)	(0.0044)	(0.0015)	(0.0014)	(0.0011)	(0.0008)	(0.0042)	(0.0038)	(0.0013)
Urban	0.0034**	0.0020	0.0038***	0.0023*	0.0011	0.0013	0.0080	0.0100**	0.0013
	(0.0016)	(0.0015)	(0.0013)	(0.0013)	(0.0012)	(0.0008)	(0.0051)	(0.0045)	(0.0014)
Agricultural productivity									
Cereal yield	1.0549***	0.7913***	0.9557***	1.0669***	0.9406***	0.9855***	0.7682	0.1918	0.4427
	(0.1592)	(0.1655)	(0.1913)	(0.1928)	(0.2337)	(0.3672)	(0.5729)	(0.3176)	(0.5389)
$\ln\sigma^2_\mu$	0.3782***	0.2969***	0.1993***	0.2494***	0.2532***	0.0947***	0.2000***	0.1657***	0.0517***
	(0.0484)	(0.0464)	(0.0401)	(0.0308)	(0.0312)	(0.0162)	(0.0717)	(0.0449)	(0.0147)
Constant	−1.0774***	−0.8271***	−0.7969***	−0.6453***	−0.5847***	−0.2886***	−1.5418***	−1.7517***	−0.4336***
	(0.1289)	(0.1390)	(0.1190)	(0.0918)	(0.0879)	(0.0692)	(0.5136)	(0.4296)	(0.1412)
Observations	1338	1334	1337	1021	1017	1021	243	243	242

Note: Standard errors in parentheses; *p<0.10, **p<0.05, ***p<0.01.

Source: Author's calculations using data from EIA (2015a), ICRG (2015), Botta and Koźluk (2014), and WDI (2015).

Appendix D: Results of robustness tests

Table D1: Panel fixed effects: producers sub-sample, without USA and Brazil.

	All countries			Developing countries			Developed countries		
	Biofuel	Ethanol	Biodiesel	Biofuel	Ethanol	Biodiesel	Biofuel	Ethanol	Biodiesel
Governance quality									
Governance	0.4463***	0.1632	0.4090**	0.1879	0.1640	0.1040	0.2781	0.0336	0.2978
	(0.1243)	(0.1297)	(0.1600)	(0.1636)	(0.1364)	(0.1041)	(0.1903)	(0.1340)	(0.1872)
EPS market							0.0214*	0.0071	0.0106
							(0.0129)	(0.0072)	(0.0116)
EPS non-market							0.0612***	0.0066	0.0578***
							(0.0209)	(0.0119)	(0.0149)
Other energy									
Renewable	−0.0103	−0.0139	0.0122	−0.0393***	−0.0292***	−0.0231	−0.0048	−0.0035	−0.0039
	(0.0183)	(0.0124)	(0.0285)	(0.0063)	(0.0113)	(0.0174)	(0.0242)	(0.0024)	(0.0177)
Oil	−0.0006***	−0.0002***	0.0003	−0.0318	0.0023	−0.0434*	−0.0004*	−0.0002**	0.0010**
	(0.0002)	(0.0001)	(0.0004)	(0.0292)	(0.0025)	(0.0228)	(0.0002)	(0.0001)	(0.0005)
Macroeconomic policies									
Financial	0.0015*	0.0002	0.0014	0.0037***	0.0019*	0.0030***	−0.0009	−0.0006**	0.0000
	(0.0009)	(0.0003)	(0.0009)	(0.0013)	(0.0010)	(0.0011)	(0.0007)	(0.0002)	(0.0010)
Openness	0.0027***	0.0024*	0.0002	0.0022**	0.0035*	0.0003	−0.0001	−0.0011**	−0.0003
	(0.0010)	(0.0013)	(0.0008)	(0.0010)	(0.0019)	(0.0005)	(0.0013)	(0.0005)	(0.0015)
Market size									
GDP	0.0236***	0.0092**	0.0207***	−0.0009	−0.0033	−0.0016	0.0215***	0.0144***	0.0184**
	(0.0055)	(0.0046)	(0.0057)	(0.0105)	(0.0095)	(0.0067)	(0.0080)	(0.0053)	(0.0079)
Population density	0.1046***	0.0621***	0.0560*	0.0225	0.0525**	0.0035	0.1403***	0.1065***	0.0513**
	(0.0397)	(0.0190)	(0.0313)	(0.0140)	(0.0238)	(0.0197)	(0.0352)	(0.0229)	(0.0259)
Urban	0.0057	0.0017	0.0278**	0.0043	0.0008	0.0057	0.0189	0.0117	0.0162
	(0.0108)	(0.0036)	(0.0110)	(0.0039)	(0.0033)	(0.0048)	(0.0153)	(0.0138)	(0.0148)
Agricultural productivity									
Cereal yield	0.0532***	0.0276***	0.0315***	0.0348**	0.0322**	0.0182	0.0332**	0.0121	0.0244***
	(0.0115)	(0.0095)	(0.0080)	(0.0145)	(0.0160)	(0.0133)	(0.0163)	(0.0077)	(0.0084)
Observations	1338	1338	1338	1021	1021	1021	243	243	243

Note: Standard errors in parentheses; *p<0.10, **p<0.05, ***p<0.01.

Source: Author's calculations using data from EIA (2015a), ICRG (2015), Botta and Koźluk (2014), and WDI (2015).