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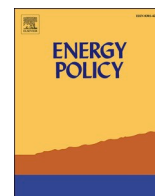
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Biofuels and food security: evidence from Indonesia and Mexico^{*}

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ABSTRACT

In this study, we analyze the food security effects of biofuel production using the synthetic control method. This retrospective and graphical analysis focuses on Indonesia and Mexico from 2000 to 2013. Indonesia is a major biodiesel producer, while Mexico specializes in maize and ethanol. Our findings show that biodiesel production positively affects food security through an increase in daily per capita energy consumption and the food production index, whereas we observe the reverse effect for bioethanol. After the adoption of biofuels, the gap between Indonesia and its counterfactual allows us to conclude that biodiesel production does not harm food security. This could be explained by the fact that biodiesel production uses some feedstocks that do not directly compete with food crops; moreover, biodiesel exports generate revenues that can be allocated to food imports. However, the gap between Mexico and its counterfactual suggests that bioethanol production reduces food security because it uses maize, which is the staple food of many Mexicans. Furthermore, Mexican ethanol exports compete with those of the United States. Our results are robust to several falsification tests.

1. Introduction

Fossil fuels account for about 80% of global energy consumption, 57% of which is due to the transport sector (IEA, 2012). Given increasing climate change, pollution, and dwindling oil reserves globally, humanity is in dire need of other energy sources to ensure sustainable development (Khanna and Chen, 2013). Among the many renewable energy sources, biofuels (primarily bioethanol and biodiesel) have been identified as some of the most promising alternatives to oil (Hahn-Hägerdal et al., 2006). Biofuels are therefore promoted by governments around the world, to meet their populations' growing energy needs.

Since the early 2000s, cropland has increased by 50 million hectares worldwide. The highest growth rates recorded for maize, soybean, rapeseed (Tyner, 2012), and palm oil (Thoenes, 2006), which are crops used for first-generation biofuel production. Their usage to meet food and energy needs leads to an increase in market prices. Consequently, such a rise in food prices is reducing food access for vulnerable people, leading authors such as Ferrett (2007) to consider biofuels to be a crime against humanity. However, for others, biofuel production can be

advantageous because it allows a country to generate employment as well as diversify energy sources and incomes for farmers (Ewing and Msangi, 2009); these revenues can therefore be allocated to food imports and improving food security. The effects of biofuels can differ depending on the raw material used in the production process and competitiveness of countries in the international market (Groom et al., 2008). Therefore, this study assesses and compares their consequences using two countries (Indonesia and Mexico) facing food insecurity issues and two biofuels (biodiesel and bioethanol). Approximately 19.3 million people in Indonesia and 5.4 million in Mexico were undernourished in 2013.¹ Specifically, two configurations are described in order to test biofuel effects. On the one hand, Indonesia, the largest producer of biodiesel, mainly produced with palm oil, of which it is one of the largest producers. It is also very competitive in the biodiesel and palm oil market. On the other hand, Mexico is one of the largest bioethanol producers in the developing world. This bioethanol is produced with maize, a widespread crop consumed by Mexicans. However, Mexican bioethanol and maize are not very competitive in the international market and face competition from the United States. We assume that biofuels help to

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¹ FAO database.

increase government revenue, which supports public spending and improves food security.

Previous studies of biofuels have used several methods, such as computable general equilibrium and theoretical models. We contribute to this literature by analyzing biofuel effects using the synthetic control method that compares case studies to highlight the effects of an event or a policy. Although this method has not yet been applied to examine the extent to which biofuel development affects food security, it is relevant for evaluating the sustainability of biofuel production. Moreover, a better understanding of synthetic control could help researchers improve their analytical tools and might interest to policymakers. This study also investigates the trajectories of the food production index and daily per capita energy consumption that these countries would follow if they did not produce biofuels. Following this method, we use a sample of 27 developing countries, including the two countries studied in this analysis, over 2000–2013, and find evidence of an increasing effect of food insecurity for Mexico and a decreasing effect for Indonesia.

The remainder of this paper is structured as follows. In the following section, we review the main ideas behind biofuels and food security in Indonesia and Mexico. Then, Section 3 presents our data and the empirical method we use to answer the research questions posed in this study. Section 4 presents the main results of our analysis. Section 5 shows the findings of the robustness check before concluding in Section 6.

2. Background

Biofuels are increasingly being studied, as they are the main alternative to the vast amounts of fossil fuels used in the transport sector. They can be solid, liquid, or gaseous and are classified into four groups from which we can distinguish first-, second-, third-, and fourth-generation biofuels. First-generation biofuels are the most used and are constituted by biofuels that use food crops such as sugarcane, maize, beet, wheat, and palm oil as feedstocks. We consider as second-generation biofuels those derived from biochemical and thermochemical conversion (Zilberman, 2013). This type of biofuel can be produced with feedstocks such as jatropha, switchgrass, poplar, willow, and other waste derived from agricultural production. Third-generation biofuels come from algae, seaweed, and microalgae, while the fourth-generation biofuels use microbes as feedstocks. Biofuels have many consequences, especially on food security.

2.1. Biofuel impacts on food security

Food insecurity can be defined as uncertain access to sufficient and appropriate food, or the fact that an individual or a household may go without food (Barrett, 2002). Despite growth in food production, more than one in seven people suffer from micronutrient malnourishment because they do not have access to sufficient energy from their diet (Godfray et al., 2010). This situation is measured by indicators such as daily per capita energy consumption, the number of people undernourished, and the food production index. Daily per capita energy consumption approximates nutrition well. The number of undernourished people represents those individuals with a dietary energy consumption less than a threshold measured in terms of the number of kilocalories necessary to conduct light activities. Likewise, the food production index covers all edible food crops available. Hence, these measures allow us to evaluate a country's level of food insecurity.

The United Nations Food and Agriculture Organization (FAO) defines food security as constituted by four dimensions, which are availability, access, utilization, and stability. As biofuels, mainly first-generation biofuels, are produced with food crops, each dimension of food security could be influenced by their development. The first impact is the reduction of food availability because biofuel production diminishes food supply, which raises food prices. A large expansion in biofuel production from agricultural feedstocks could create not only a

food crisis, but also volatility in food prices (Tenenbaum, 2008; Hochman et al., 2011). This situation would negatively affect food access and stability, which are determined by food prices and food price volatility, respectively. Likewise, it would influence food utilization, determined by access to a nutritious and safe diet. According to Hausman et al. (2012), the increase in the maize price between 2006 and 2007 was explained by U.S. ethanol production. For Mitchell (2008), biofuel growth accounts for the 70%–75% increase in world prices of agricultural products. In addition, in many developing countries, the poor allocate about 70% of their income to food consumption (Pingali et al., 2008). Thus, rising food prices could harm a household's purchasing power. On the contrary, farmers could benefit from higher commodity prices through their higher income. For example, trade openness in oil palm fruit markets in recent years has allowed direct sales to mills by smallholders, which account for about 35% of Indonesia's crude palm oil (CPO) production, stimulating growth in the smallholder sector (Peskett et al., 2007). Moreover, biofuel production creates employment in farms and factories. According to Rajagopal and Zilberman (2007), biofuel policies provided benefits such as job creation in rural areas and lower emissions of greenhouse gases (GHGs). Hence, their production might alleviate poverty and improve food access (Ewing and Msangi, 2009).

On the contrary, biofuel expansion worsens deforestation; indeed, farmland expansion is one of the main determinants of deforestation (Righelato and Spracklen, 2007). Since deforestation leads to soil degradation and decreases agricultural yields, biofuel expansion could thus negatively affect food security in the long run (Meyer et al., 1994).

2.2. Indonesian context

Indonesia is a Southeast Asian country consisting of 17,504 tropical islands with over 20 million hectares of arable land. It is the leading CPO producer globally (McCarthy et al., 2012), providing around half of the world's palm oil (Colbran and Eide, 2008). To stay the largest CPO producer, in 2008, Indonesia used nearly 7.3 million hectares of land for palm oil and cleared 18 million hectares of forest land (Kharina et al., 2016). In 2009, CPO production was around 24,500 Megatons across 7.5 million hectares.

Although Indonesia is a member of the Organization of the Petroleum Exporting Countries (OPEC), it imports a large quantity of oil to meet its domestic needs. Under presidential instructions, Indonesia began its biofuel production in 2006 using mainly palm oil and jatropha.

The main areas of biofuel production in Indonesia are Sumatra, Kalimantan (formerly Borneo), Sulawesi, West Papua, and Java, as Fig. 1 shows; these are also the main areas of palm oil production.

In 2006, the area devoted to palm oil production in Sumatra reached more than four million hectares, with a further 1.5 million hectares dedicated to such production in Kalimantan. After Sumatra and Kalimantan, Sulawesi had more than 100,000 ha, Papua more than 40,000 ha, and Java, primarily Jakarta, more than 20,000 ha. This contributed to increasing palm oil production, as we can see in Figure A.4, to promote the production of biodiesel.

These archipelagoes are also arable land areas because of their equatorial and tropical climate. This kind of climate, characterized by an annual rainfall greater than 3000 mm and an average sunshine duration of 6 h per day (Sumatra and Kalimantan), is suitable for palm oil production. Moreover, these lands are also suitable for producing other crops.

Indonesian biofuel is mainly constituted by biodiesel. As shown in Fig. 2, biodiesel production is higher than bioethanol production, which remains very low. To be more competitive on the international market and promote biofuel adoption, Indonesia introduced a palm oil export tax and a palm oil export levy in July 2015. The palm oil export tax, defined by the Ministry of Finance, is a tax tariff of \$0 per ton when the international CPO price is below \$750 and \$200 per ton when the CPO price is above \$1250. The levy on palm oil exports is a tax collected

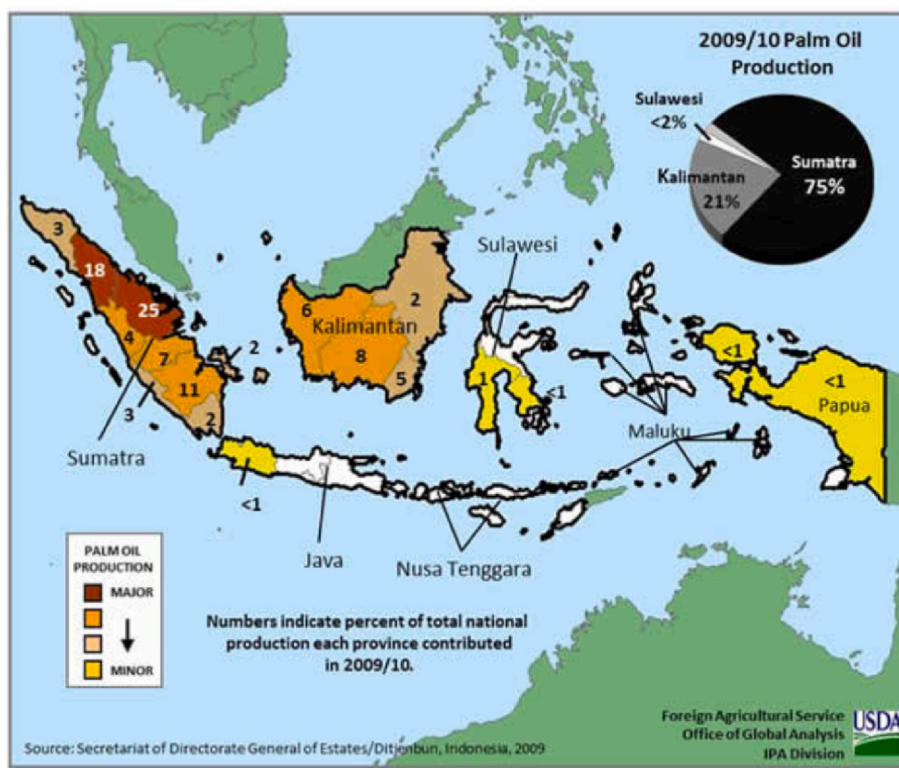


Fig. 1. Main areas of palm oil and biofuel production in Indonesia
Source: USDA, Foreign Agricultural Service, Commodities Intelligence Report.

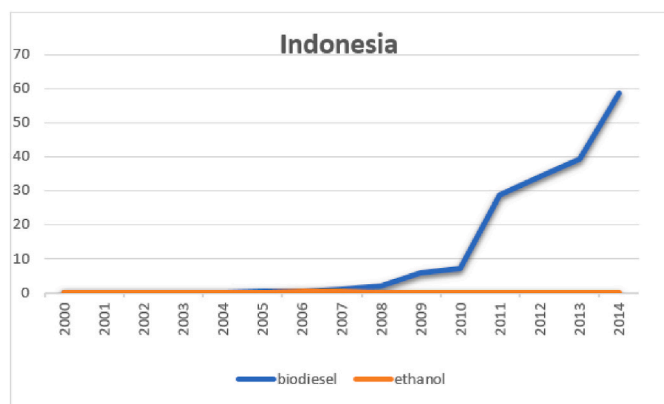


Fig. 2. Indonesia biofuel production in 1000 barrels/day.

temporarily by the government when the export tax falls to zero (i.e., if the CPO price is below \$750 per ton). This levy, which was introduced to finance the domestic biodiesel subsidy, is \$30 per ton for downstream products and \$50 per ton for CPO (Kharina et al., 2016); it is then redistributed to biofuel producers that sell their products for B20² mixing in the national market.

Biofuel production has many advantages. It is reducing Indonesia's dependence on fossil fuel imports as well as promoting food security through jatropha production, which is a non-food crop that can grow on marginal land in the eastern region (Suryahadi and Sumarto, 2003). Indeed, jatropha grows almost everywhere, even on gravelly, sandy, and saline soils. This plant can also be grown in nurseries by its stems or seeds, as well as planted in areas with poor soil, because it requires little

input (fertilizer or labor) due to its drought resistant nature. Furthermore, the intercropping system with jatropha has some advantages. It avoids dependency on one crop and reduces the use of fertilizers. Further, it offers the possibility of recovering one's investment in a shorter time and flexibility in the distribution of labor and availability of harvest over a longer period. Moreover, palm oil production employs more than five million people in Indonesia. This advantage alone promotes poverty alleviation and food security by creating jobs (Kharina et al., 2016). However, according to Van Der Werf et al. (2008), deforestation to make way for palm oil plantations leads to 680 million tons of CO₂ emissions per year.

2.3. Mexican context

Mexico, in Central America, is bounded to the south by Guatemala and Belize and the north by the United States. It is one of the leaders in maize production, with around 22.6 million metric tons in 2013³ and one of the largest oil producers in the world. Owing to the need to reduce GHG emissions and fossil fuel dependence and promote rural development, the Mexican government began its biofuel production in 2007. Production is concentrated on bioethanol rather than biodiesel, as illustrated in Fig. 3.

Because it is one of the largest maize producers, its bioethanol is mostly based on maize. As shown in Fig. 4, the main areas of maize production in Mexico are also areas in which bioethanol production units are present: Sinaloa, Jalisco, Michoacan, Mexico City, and Guerrero. These areas are considered to be the main agricultural lands in Mexico.

Unlike Indonesia, Brazil, and the United States, Mexican biofuels are not competitive on the international market. Indeed, in 2007, Mexico enacted a law to promote bioenergy development, but not legislation to

² B20 means that a diesel engine uses 20% biodiesel and 80% diesel.

³ FAO database.

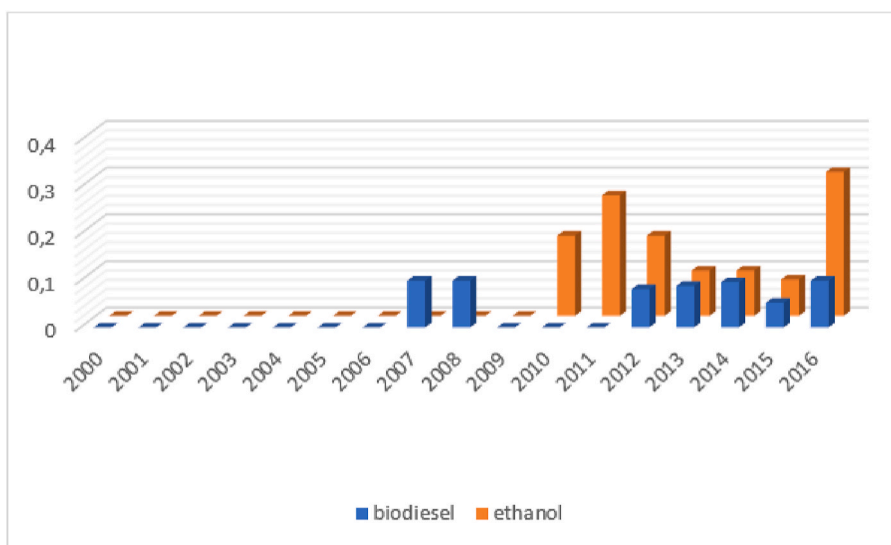


Fig. 3. Mexico biofuel production in 1000 barrels/day.

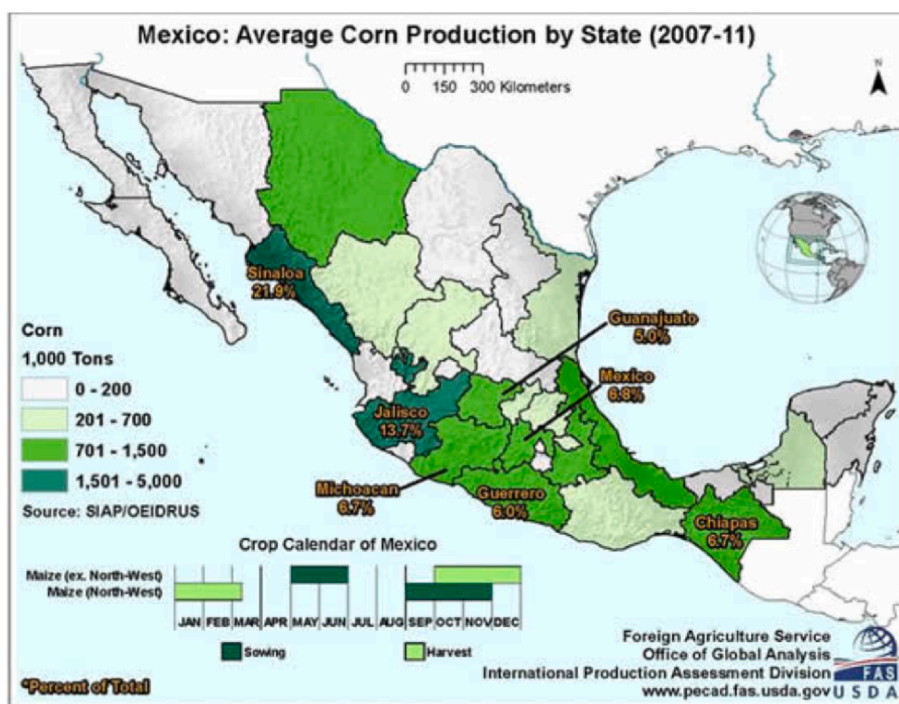


Fig. 4. Main areas of maize and biofuel production in Mexico
Source: USDA, Foreign Agricultural Service, Office of Global Analysis.

support biofuel production (Guerrero, 2008). It also established a program for sustainable and renewable fuels to develop information systems, research and development and technology transfer as well as promote and advise farmers’ associations. Bioethanol production has negative effects for many Mexicans according to Couch (2013). Maize is also one of the staple foods in Mexico. Thus, the use of this cereal for both energy and food purposes raises its price, which reduces access for rural populations vulnerable to food price fluctuations. Moreover, owing to U.S. maize subsidies, Mexico’s maize price is less competitive than that of the United States. (Fernández et al., 2012). Indeed, since the 1990s, the Mexican government has implemented measures to liberalize trade in agricultural products. Moreover, the implementation of NAFTA reduced the over-quota bound tariff from 206.4 to 18.2 percent. This

trade liberalization, combined with NAFTA, allowed higher integration of Mexico’s and United States’ agricultural markets. As a result, imports of cereals increased; for instance, maize imports rose from 1.7 million tons on average over 1990–1995 to 7.9 million tons over 2006–2010 (Jaramillo-Villanueva et al., 2015). Furthermore, employment in agriculture has declined, leading to a rise in internal migration (Beam, 2011).

3. Empirical method

To assess the food security effects of biofuel adoption, we use the synthetic control method (Abadie et al., 2010). This method allows us to estimate the effects of an event or a policy using comparative case

studies. Specifically, it tests the effect of the treatment by comparing the treated country to its counterfactual or synthetic which is a weighted average of the available units in the donor pool. This methods sheds light on the similarities between the treated country and its synthetic control regarding preintervention outcomes and other predictors of post-intervention outcomes. For these reasons, caution is needed in the construction of the donor pool that needs to only consider countries not affected by the treatment. Therefore, all countries producing, deciding to adopt biofuels during the study period, affected by any externalities due to biofuel production or adoption, as well as all countries that may have suffered large shocks to food security, have to be excluded from the donor pool. So that we can be sure the gap observed between treated country and its synthetic or counterfactual, after biofuel adoption, is only due to biofuels and not to other food security shocks that affect countries used to set up the synthetic.

3.1. Model specification

In this study, we consider the adoption of biofuels to be our event, and we compare the impact of this adoption in Indonesia and Mexico ⁴ with a set of countries that did not start producing biofuels during the study period. Because the synthetic control method is a systematic way to choose comparative units, it is an essential tool for promoting research accuracy in observational studies (Rubin, 2001). We choose this method because it does not require access to post-intervention outcomes and allows researchers to decide on study design without knowing how those decisions will affect the conclusions of their studies. The model allows the effects of unobserved variables on the outcome to vary over time by extending the traditional linear panel data (difference-in-differences) framework.

Suppose we have $P + 1$ developing countries, of which one has adopted biofuels. We consider Y_{it}^N , the level of food security that would be observed for country i at time t in the absence of biofuel adoption. Y_{it}^B is the level of food security that would be observed for country i at time t if biofuels are adopted. Because of the availability of data on biofuels, the time periods $t = 1, \dots, T$ go from 2000 to 2013, with T_0 the year in which a country started its biofuel production or formulated policies for biofuel adoption. Then, we suppose that biofuel production had no effect on food security before T_0 . Hence for $t \in (1, \dots, T_0)$ (preintervention periods) and all $i \in (1, \dots, P+1)$, we have $Y_{it}^B = Y_{it}^N$.

Therefore, the effect of biofuel adoption for country i at time t is

$$\lambda_{it} = Y_{it}^B - Y_{it}^N \tag{1}$$

Let B_{it} be the indicator of biofuel adoption for country i at time t :

$$B_{it} = \begin{cases} 1 & \text{if } t > T_0 \\ 0 & \text{Otherwise} \end{cases}$$

Hence, the outcome we observe is

$$Y_{it} = Y_{it}^N + \lambda_{it}B_{it} \tag{2}$$

In this equation, we have to estimate λ_{it} ; as Y_{it}^B is already observed, to estimate λ_{it} , we need to know the value of Y_{it}^N by estimating the following equation:

$$Y_{it}^N = \alpha_t + \beta_t X_{it} + \delta_t \mu_i + \epsilon_{it} \tag{3}$$

where α_t is an unknown common factor and X_{it} is the vector of predictor variables. β_t represents a vector of the unknown parameters associated with each X_{it} , and δ_t is the vector of the unobserved common factors. The vector of the unknown factor loadings is captured by μ_i , and the error term is ϵ_{it} .

⁴ We systematically exclude the other treated country, when performing the analysis for one of them.

We consider a vector of weights (W), which can be a potential synthetic control. Hence, we choose the value of W that allows the characteristics of the synthetic to be similar to that of the treated unit. Assume that Z_0 is a $(k \times P)$ matrix containing the preintervention characteristics of the units in the donor pool and Z_1 a $(k \times 1)$ vector with the values of the same variables for the treated unit. We also include our outcome variables in the preintervention characteristics. The vector $Z_1 - Z_0W$ provides the difference between the treated unit preintervention characteristics and those of the synthetic control. Thus, we choose the synthetic control, \widehat{W} that minimizes the size of this difference or the vector \widehat{W} that minimizes the distance:

$$\| Z_1 - Z_0W \|$$

The outcome value for each synthetic control indexed by W is

$$\sum_{p=2}^{P+1} w_p Y_{pt} = \alpha_t + \beta_t \sum_{p=2}^{P+1} w_p X_p + \delta_t \sum_{p=2}^{P+1} w_p \mu_p + \sum_{p=2}^{P+1} w_j \epsilon_{it} \tag{4}$$

with $0 \leq w_p \leq 1$.

We obtain $\widehat{w}_2, \dots, \widehat{w}_{P+1}$ as follows:

$$\begin{aligned} \sum_{p=2}^{P+1} \widehat{w}_p Y_{p1} &= Y_{11}, \sum_{p=2}^{P+1} \widehat{w}_p Y_{p2} = Y_{12}, \dots, \\ \sum_{p=2}^{P+1} \widehat{w}_p Y_{pT_0} &= Y_{1T_0}, \text{ and } \sum_{p=2}^{P+1} \widehat{w}_p X_p = X_1 \end{aligned} \tag{5}$$

As this study estimates λ_{it} at $t > T_0$, a counter-factual is approximated to obtain the pathway that the treated country⁵ (Indonesia, then Mexico) would have followed in the absence of biofuel production. According to Abadie and Gardeazabal (2003) and Abadie et al. (2010), synthetic control is the most suited method to estimate the counterfactual Y_{it}^N . The idea is that a single country rarely provides a better approximation of the treated country than the combination of P control countries. The weights (w) are chosen so that the counterfactual most resembles the country treated in the pre-treatment period.

In practice, there is rarely a set of weights such that Equation (5) is found exactly in the data. Therefore, the synthetic control region is selected so that Equation (5) holds approximately. Thus, a synthetic control such as

$$\sum_{p=2}^{P+1} \widehat{w}_p X_p = X_1 \text{ and } \sum_{p=2}^{P+1} \widehat{w}_p \mu_p = \mu_1 \tag{6}$$

would provide an unbiased estimator of Y_{it}^N .

The synthetic control method is implemented in five steps following Gathani et al. (2013): select the outcome variable, select the period of analysis, select the predictor variables of the outcome variable, select the potential control countries, and conduct various robustness checks.

3.2. Data

To carry out the method, we use a sample of 27 developing countries from 2000 to 2013; the treated countries are Indonesia and Mexico, and the other countries produced no biofuel throughout this period.

3.2.1. Biofuels

The data on biofuel production come from International Energy Agency (IEA) datasets, measured in barrels⁶ per day. According to Groom et al. (2008), biofuels reduce countries' dependence on fossil fuels and mitigate climate change by lowering GHGs; however, some authors are skeptical (Righelato and Spracklen, 2007).

⁵ For this country, $p = 1$.

⁶ One barrel is equivalent to 159 L.

3.2.2. Food security

Food security is considered a multidimensional concept, making it difficult to find a good indicator. In this study, we use the food production index and daily per capita energy consumption in kilocalories to measure food security. The food production index is chosen because it covers all edible food crops as well as food crops that contain nutrients (Hopfenberg, 2003). In addition, it focuses on the sum of the price-weighted quantities of different agricultural commodities produced after removing the quantities used for seed and animal feed. The food production index thus displays the aggregate volume of agricultural production for each year compared with the base period of 2004–2006 using Laspeyres' formula. These data are taken from the World Development Indicators in line with Esmaili and Shokoohi (2011). The food production index also enables us to measure human carrying capacity values, defined as the number of individuals that the resources can support (Hopfenberg, 2003). Daily per capita energy consumption (or calorie intake per capita), selected in line with Jenkins and Scanlan (2001) and Santangelo (2018), is one of the best indicators of nutrition and hunger. It is computed by the FAO for each country. We obtain it by applying to the food supply available the appropriate food composition factors; then, per capita consumption is obtained by dividing the total nutrient amount by the population.

3.2.3. Predictor variables

We also use predictor variables including arable land, gross domestic product (GDP) per capita, rainfall, and temperature. Consistent with Godfray et al. (2010), we use arable land, as this variable plays a crucial role in food security by favoring an increase in food production and food supply. In addition, we choose GDP per capita following Timmer (2000), who finds that a rise in GDP per capita positively affects food security by improving food access. These two variables come from the World Development Indicators. The climate variables comprise annual average temperature and rainfall following Lobell et al. (2008). These variables, which also have a high impact on food production and food security, come from Santoni (2017).

Because of the food crisis due to the rise in the maize price from 2006 to 2009, we add as a predictor variable the 2006 value of the food production index for Mexico. For Indonesia, we add as a predictor variable the 2002 value of the food production index because during this year, there were government policies of food supply and food stocks to ensure food security.

Table 1 provides the descriptive statistics of all the variables.

Table 1
Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
Food production index	378	108.29	22.2	43.49	207.44
Calorie intake per capita (kcal)	378	2558.42	379.25	1789	3402
Arable land (thousand hectares)	378	56,500	8400	1000	370,000
GDP per capita (US\$)	378	2377.39	2310.20	271.02	10,137.55
Rainfall (mm per year)	378	1069.41	856.21	50.62	3542.15
Temperature (degree Celsius)	378	22.38	6.92	-0.69	29.24
Biofuel (thousand barrels per day)	378	0.37	3.60	0	48.25

4. Empirical findings

According to the variables used in the model, the algorithm generated weights⁷ whose combination allow us to obtain a counterfactual resembling the treated country as much as possible.

4.1. The case of Indonesia

Table 2 presents the country weights obtained using the synthetic control method; it shows that Nigeria, Angola, Gabon, and Sierra Leone allow us to reproduce Indonesia's food production index pathway, which seems precisely like Indonesia before it starts producing biofuels. Using our second measure of food security, Table A.1 shows that Gabon, Cambodia, Sierra Leone, and Bangladesh contribute to reproducing a synthetic close to Indonesia during the period before 2006. The fact that these selected countries are not in the same geographical area as Indonesia can be a great advantage. Our analysis is thus more relevant because it is unlikely that they benefited from the positive or negative externalities of Indonesia's biofuel production, as would have been the case for a close neighbor. In addition, a simple graphical representation of the data on the food production index (see Figure A.1) of Indonesia as well as of the countries with the highest weights in the construction of its counterfactual, allows us to see that the values and the trend of the food production index of Nigeria are similar to those of Indonesia during the pre-treatment period (before 2006).

Table 3 and Table A.2 compare Indonesia's characteristics with that of the 25 countries' weighted average in the donor pool during the pre-treatment period for the two food security measures. The average of the countries that did not adopt or start biofuel production seems to provide a suitable control group for Indonesia; synthetic Indonesia reproduces the values of Indonesia's food production index and daily per capita energy consumption before 2006.

Fig. 5 shows the food production index trend for Indonesia and its synthetic during 2000–2013. As stated in the previous paragraph, the food production index in synthetic Indonesia closely follows the path of this variable in Indonesia before biofuel adoption. Therefore, any discrepancy between the synthetic Indonesia and Indonesia that we can observe after biofuel adoption necessarily comes from the biofuel effect alone. After 2006, we can see a gap between Indonesia and its counterfactual, showing that biofuel production, mainly biodiesel, does not harm food security. Likewise, we find the same effect with daily per capita energy consumption; after starting producing biofuels, calorie intake per capita rises.

This result is in accordance with Ewing and Msangi (2009), who show that biofuel production positively affects food security through the improvement in food access. In Indonesia, this impact may be due to the

Table 2
Country weights in synthetic Indonesia (food production index).

Country	Weight	Country	Weight	Country	Weight
Albania	0	Guinea-Bissau	0	Niger	0
Algeria	0	Iraq	0	Nigeria	.48
Armenia	0	Jordan	0	Rwanda	0
Angola	.06	Lesotho	0	Senegal	0
Bangladesh	0	Liberia	0	Sierra Leone	.14
Cambodia	0	Madagascar	0	Sri Lanka	0
Djibouti	0	Mauritania	0	Tunisia	0
Gabon	.32	Mongolia	0		
Ghana	0	Morocco	0		

⁷ Such weights allow obtaining a very similar counterfactual if the treated country characteristics are similar to those of donor pool countries and lie between all of them, as shown in appendix.

Table 3
Food security predictors (food production index).

Predictor balance	Indonesia	Synthetic
Food production index (2002)	86.08	86.16
Arable land (log)	16.89	15.24
GDP per capita (log)	7.74	7.72
Rainfall (log)	7.95	7.28
Temperature	26.30	26.30

country’s biodiesel competitiveness in the international market (McCarthy et al., 2012); indeed, in 2013, it exported 1942 million liters of biodiesel, mainly to Europe and Asia. These export revenues raised its national income. Hence, the revenue generated from palm oil and biodiesel sales can be reallocated to food imports, to enhance the domestic food supply. Figure A.3 shows a slight increase in the value of palm oil exports from 2000 to 2005, followed by strong growth in the value of exports from 2006 (the year of biofuel adoption). In addition, according to the IMF database, government revenue rose from around 485 trillion Indonesian rupiah in 2005 to 626 trillion in 2006 and 697 trillion in 2007; this increase was also due to tax and levy implemented to support biofuel production. Similarly according to the FAO database, public spending on agriculture increased after adopting biofuels in 2006. Indeed, from about US\$480 million in 2005, the value rose to US\$750 million in 2007 and about US\$5600 million in 2013. A report was written by the World Bank (Armas et al., 2010) on public agricultural expenditure in Indonesia also showed an increase mainly after 2005. This increase in public spending on agriculture was accompanied by an increase in food availability in kilocalories per capita per day. According to FAO database, there was an increase from 2005 to 2006 (2483 kcal/capita/day) and then to 2013 (2777 kcal/capita/day). Moreover, biodiesel production uses feedstocks that do not directly compete with food crops. As mentioned in the background, biodiesels are mainly produced with palm oil and jatropha, the latter of which is not fit for human consumption and is produced in the marginal lands of Indonesia where food crops cannot be grown. Moreover, for Bazongo et al. (2015), jatropha production helps restore the soil, favoring food crop production.

4.2. The case of Mexico

Table 4 shows that Algeria, Armenia, Gabon, and Morocco enable us to reproduce a synthetic for a food production index that is close to that of Mexico during the period before biofuel adoption. Figure A.1 and Figure A.2, displaying Mexico and countries with the highest weights, allows us to see that the values and the trend of the food production index of Gabon are similar to those of Gabon during the pre-treatment period. For the second measure, the results of which are presented in

Table A.3, Albania, Gabon, Morocco, and Tunisia provide a good synthetic Mexico.

We test the trustworthiness of the counterfactual. As shown in Table 5 and Table A.4, synthetic Mexico and Mexico have similar characteristics before biofuel adoption. Moreover, synthetic Mexico provides a good representation of the values of the Mexican food production index.

As shown in Fig. 6, before biofuel production, Mexico and its counterfactual have a similar trajectory. However, after biofuel production, there is a gap between Mexico and synthetic Mexico, suggesting biofuels are hampering food security. Indeed, the food production index for Mexico is lower than the one it would reach in the absence of biofuels. This gap is observed from 2009, the year in which production, mostly of bioethanol, started to become important (Fig. 3). In addition, we can observe the same gap for daily per capita energy consumption.

This reverse effect can be explained as follows. First, Mexico is a member of the North American Free Trade Agreement (NAFTA) and faces U.S. dumping in the maize market (Wise et al., 2012; Abbott Chavas et al., 2014), resulting in lower competitiveness for Mexican farmers. Thus, the country was already a net maize importer before biofuel adoption because its lack of competitiveness and lower export values reduced farmers’ short-term revenues and discouraged domestic maize production (Aragie et al., 2018). Mexico’s exports of maize have been on a roller-coaster ride, characterized by episodes of strong

Table 4
Country weights in synthetic Mexico (food production index).

Country	Weight	Country	Weight	Country	Weight
Albania	0	Guinea-Bissau	0	Niger	0
Algeria	.05	Iraq	0	Nigeria	0
Armenia	.14	Jordan	0	Rwanda	0
Angola	0	Lesotho	0	Senegal	0
Bangladesh	0	Liberia	0	Sierra Leone	0
Cambodia	0	Madagascar	0	Sri Lanka	0
Djibouti	0	Mauritania	0	Tunisia	0
Gabon	.68	Mongolia	0		
Ghana	0	Morocco	.13		

Table 5
Food security predictors (food production index).

Predictor balance	Mexico	Synthetic
Food production index (2006)	103.46	103.13
Arable land (log)	16.96	13.33
GDP per capita (log)	9.07	8.72
Rainfall (log)	6.63	6.90
Temperature	21.29	21.79

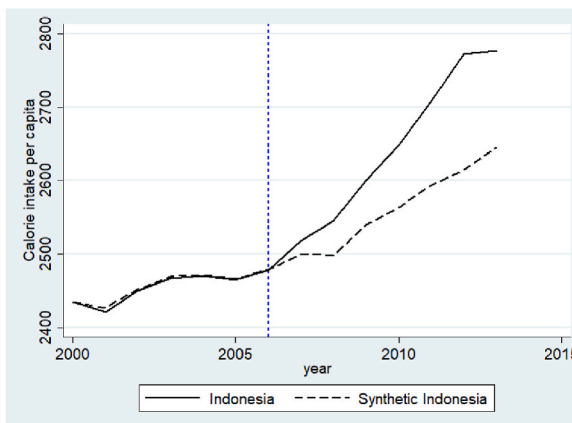
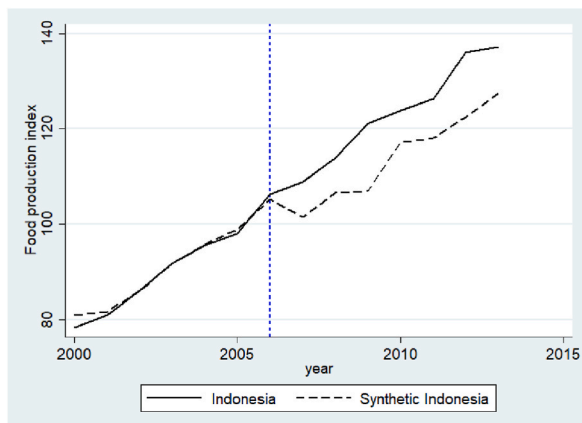


Fig. 5. Trends in food security: Indonesia vs. synthetic Indonesia.

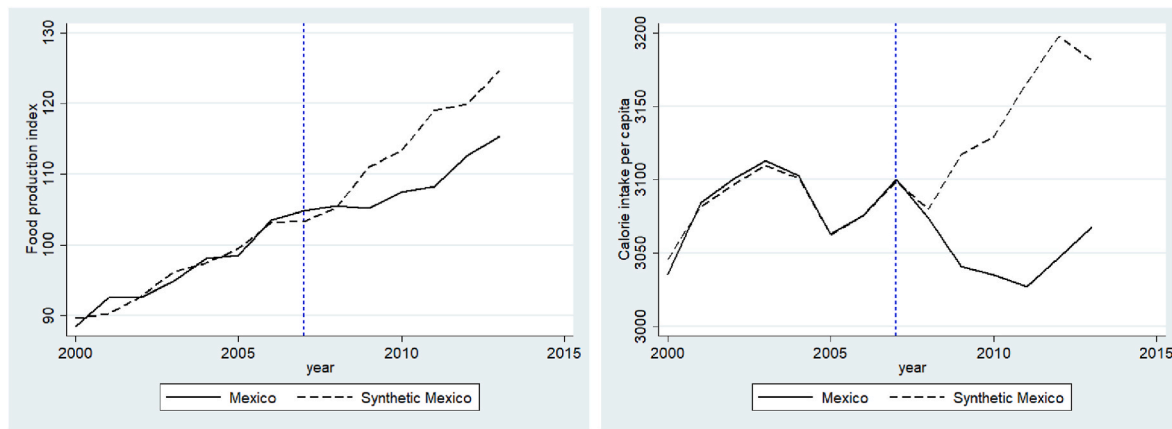


Fig. 6. Trends in food security: Mexico vs. synthetic Mexico.

increases and declines since 2007 (the year of biofuel adoption) (see Figure A.3). Second, the U.S. biofuel expansion, combined with biofuel adoption in Mexico from 2007, led to higher maize prices. Indeed the producer price of maize was much higher than the international price during this period (see Figure A.5), which increased maize import cost for Mexico⁸ that is a price-taker (Jaramillo-Villanueva et al., 2015). This also attests to Mexico’s lack of competitiveness in the international market for maize, but also for bioethanol, and explains in part the increase in maize imports, and therefore a decline in profits for local producers and food insecurity.

5. Robustness check: placebo test

The synthetic control method is considered to have weak external validity for the impact analysis. As testing the statistical significance of biofuel impacts with this method is challenging, we use a placebo test, also called a falsification test. This test is like a permutation test, where we enforce the synthetic control method to each potential control in our sample to evaluate whether the effect of biofuel production estimated by the synthetic control for Indonesia and Mexico is larger than the impact estimated for a country chosen at random (Abadie et al., 2010). In this way, we consider that every country in the donor pool adopts biofuels. Specifically, we extend this method to all countries other than the treated countries. As a result, we obtain separate weights for constructing the counterfactual for each country in the donor pool.⁹

The gap between the real food production index and food production index of the synthetic control is the mean square prediction error (MSPE). If, on the one hand, the placebo test creates the same gaps as those obtained for Indonesia and Mexico, the conclusion is that this analysis does not provide a significant evidence of biofuel effects. If, on the other hand, the placebo test finds that the gap estimated for Mexico and Indonesia is unusually large compared with the gaps for the countries present in the donor pool, it means that our analysis shows significant evidence.

The figures below illustrate the MSPE ratio for the post- and pre-biofuel production periods for the countries. According to Abadie et al. (2015), the placebo’s p-value can be interpreted as “the probability of obtaining an estimate at least as large as the one obtained for the unit representing the case of interest when the intervention is reassigned at random in the data set”. The test statistic is given by the following equation:

$$t_i^{ratio} = \frac{\frac{1}{T-T_0} \sum_{t=T_0+1}^T [Y_{it} - \sum_{i \neq j} \hat{w}_i^j Y_{jt}]^2}{\frac{1}{T_0} \sum_{t=1}^{T_0} [Y_{it} - \sum_{i \neq j} \hat{w}_i^j Y_{jt}]^2} \tag{7}$$

5.1. Placebo test for Indonesia

Fig. 7 shows the MSPE ratio for each country. Indonesia continues to have the highest MSPE ratio. The post-biofuel gap is on average 700 and 23,500 times larger than the pre-biofuel gap for the food production index and daily per capita energy consumption respectively. This finding suggests that the effect noted in Indonesia is unusual relative to the distribution of the results obtained when we hold the same analysis for the countries in our donor pool. This provides significant evidence of the food security effects of biofuels in Indonesia. The probability of obtaining the same impact with another control country, selected at random, is very low (1/26 ≈ 0.038).

5.2. Placebo test for Mexico

Fig. 8 presents the MSPE ratio for each country and shows that Mexico continues to have the highest MSPE ratio. Its post-biofuel gap is on average 900 and 24,000 times larger than the pre-biofuel gap for the food production index and daily per capita energy consumption respectively, which indicates that the effect noted in Mexico is unusual. This again provides significant evidence of the biofuel adoption effect. As for Indonesia, the probability of obtaining a post/pre-biofuel adoption MSPE ratio as large as that of Mexico with another country present in our donor pool, selected at random, is low (1/26 ≈ 0.038).

6. Conclusion and policy implications

Biofuels, which are produced in many countries from organic material, mainly agricultural crops, as considered to be one solution to the energy crisis. This type of production promotes economic development in developing countries and reduces GHG emissions. However, the use of agricultural feedstocks raises questions about food security.

Focusing on Indonesia and Mexico, this study assesses the food security effects of biofuel adoption using the synthetic control method. This method aims to detect the effect of an event or policy intervention on certain outcomes, using a particular case in which the event or intervention amplitude is large. Using this method, our results show that biofuel production has a positive effect and does not harm food security in Indonesia, whereas the effect is the reverse for Mexico because the level of food security the country could achieve if it did not adopt biofuels would be higher than its current level.

This contrasting finding could be because Indonesian biodiesels are

⁸ Mexico was forced to import around one-third of its maize from the United States, which cost about \$1.5 billion because of ethanol-related maize price rises.

⁹ We systematically remove Indonesia and Mexico from the donor pool when running the placebo since they are treated.

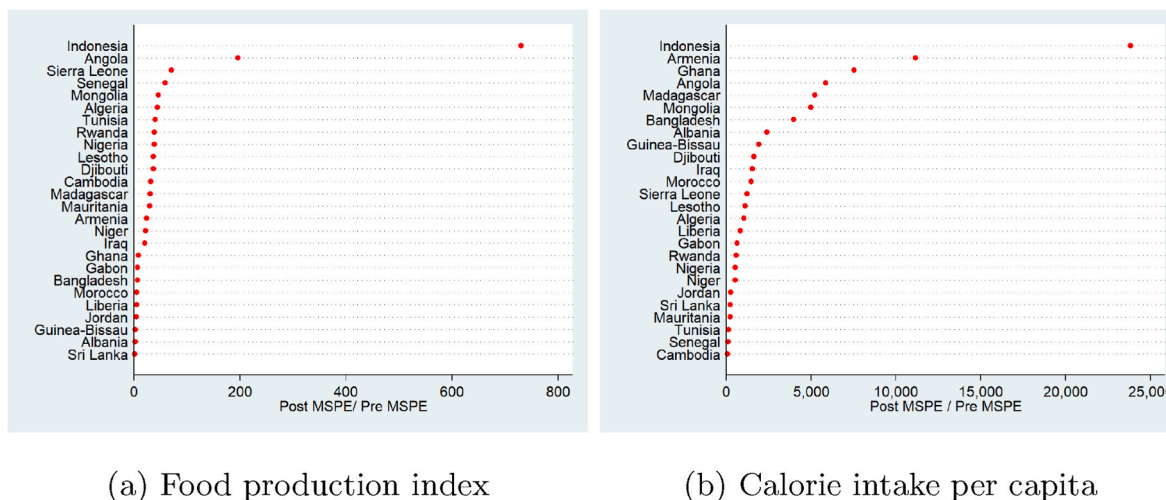


Fig. 7. Placebo test for Indonesia.

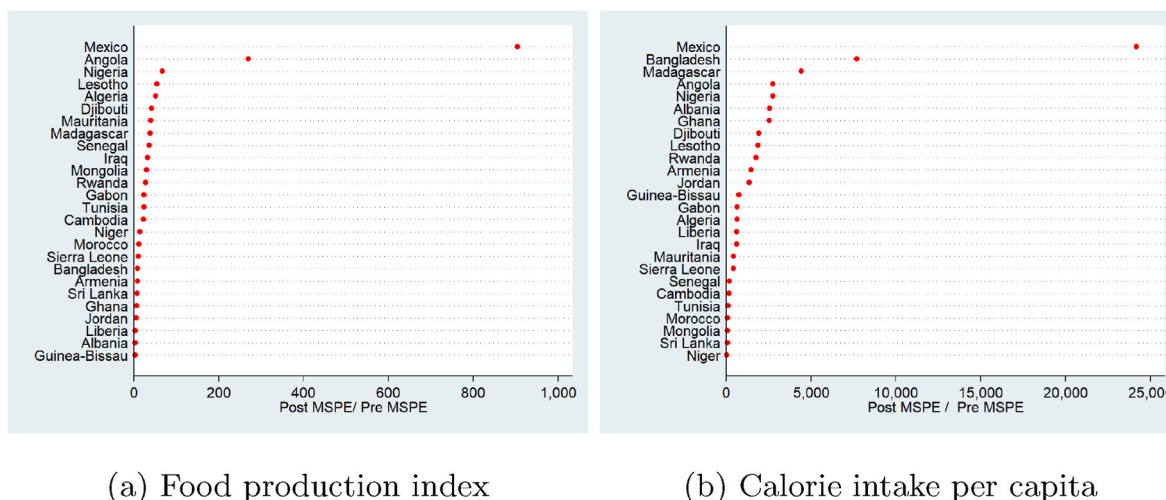


Fig. 8. Placebo test for Mexico.

primarily produced with palm oil and jatropha, the latter not being directly used for food. Moreover, as Indonesia is the highest palm oil and biodiesel exporter, it sells a high quantity of these products, the revenue of which can then be allocated to food imports. The negative effect observed in Mexico, could be because it mainly uses maize to produce bioethanol; even if Mexico is one of the highest maize producers, it faces competition from the United States in the international maize market. In addition, biofuel production raises the maize price.

As a robustness check, a placebo study was carried out to test the significant evidence of biofuel effects. The findings suggest that the effects in Indonesia and Mexico are larger than the donor pool. We show that if we relabel the intervention state at random, the probability of obtaining results with the same amplitude as Indonesia and Mexico is small, close to 3.8%.

In general, the food security effects of biofuel production in developing countries could be positive if certain factors are taken into account such as the type of agricultural feedstocks used for biofuel production and the country's competitiveness in the international market. Thus, strict regulation of biofuel use in addition to strengthened policies and plans to promote competitiveness in the international market could benefit biofuel production and food security in developing countries.

This analysis could be extended by assessing the direct effects of biofuel production, through consumer food prices, if such data become

easily available. At the country level, the most accessible food price data are producer prices or the consumer price index but not consumer prices for palm oil or maize in USD or any other local currency. Even if they exist, there are a lot of missing values. Also, one major caveat could be that the synthetic control method is deemed to be better appropriated at a micro-level. In addition, according to [Abadie et al. \(2015\)](#), the synthetic control method is not recommended when the pretreatment fit is poor. However, the satisfactory pretreatment fit we obtained here for our treated units allows us to confidently rely on it for this study which is at the country-level.

CRedit authorship contribution statement

Mohamed Boly: Writing – original draft, Conception and design of study, acquisition of data, analysis and/or interpretation of data, Drafting the manuscript, revising the manuscript critically for important intellectual content, Approval of the version of the manuscript to be published. **Aicha Sanou:** Writing – original draft, Conception and design of study, acquisition of data, analysis and/or interpretation of data, Drafting the manuscript, revising the manuscript critically for important intellectual content, Approval of the version of the manuscript to be published.

Declaration of competing interest

interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare that they have no known competing financial

Appendix**Table A.1**

Country weights in the synthetic Indonesia for daily per capita energy consumption

Country	Weight	Country	Weight	Country	Weight
Albania	0	Guinea-Bissau	0	Niger	0
Algeria	0	Iraq	0	Nigeria	0
Armenia	0	Jordan	0	Rwanda	0
Angola	0	Lesotho	0	Senegal	0
Bangladesh	.17	Liberia	0	Sierra Leone	.17
Cambodia	.14	Madagascar	0	Sri Lanka	0
Djibouti	0	Mauritania	0	Tunisia	0
Gabon	.52	Mongolia	0		
Ghana	0	Morocco	0		

Table A.2

Food security predictors

Predictor balance	Indonesia	Synthetic
Calorie intake per capita (2006)	2450	2452.41
Arable land (log)	16.90	13.77
GDP per capita (log)	7.74	7.73
Rainfall (log)	7.95	7.58
Temperature	26.30	26.02

Table A.3

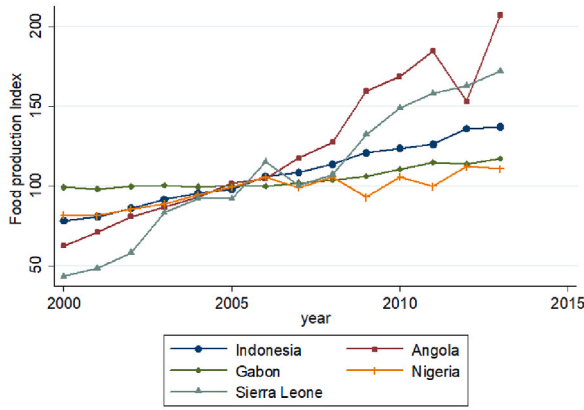
Country weights in the synthetic Mexico for daily per capita energy consumption

Country	Weight	Country	Weight	Country	Weight
Albania	.08	Guinea-Bissau	0	Niger	0
Algeria	0	Iraq	0	Nigeria	0
Armenia	0	Jordan	0	Rwanda	0
Angola	0	Lesotho	0	Senegal	0
Bangladesh	0	Liberia	0	Sierra Leone	0
Cambodia	0	Madagascar	0	Sri Lanka	0
Djibouti	0	Mauritania	0	Tunisia	.61
Gabon	.30	Mongolia	0		
Ghana	0	Morocco	.01		

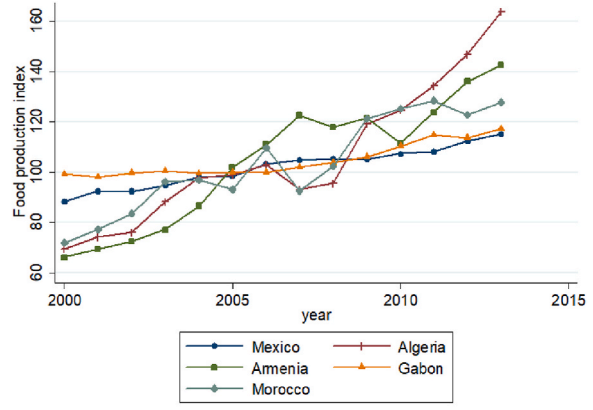
Table A.4

Food security predictors

Predictor balance	Mexico	Synthetic
Calorie intake per capita (2006)	3076	3075.77
Arable land (log)	16.96	14.09
GDP per capita (log)	9.07	8.40
Rainfall (log)	6.63	6.22
Temperature	21.29	21.29

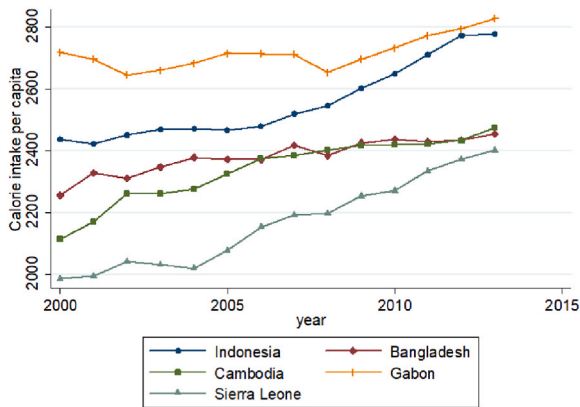


(a) Indonesia

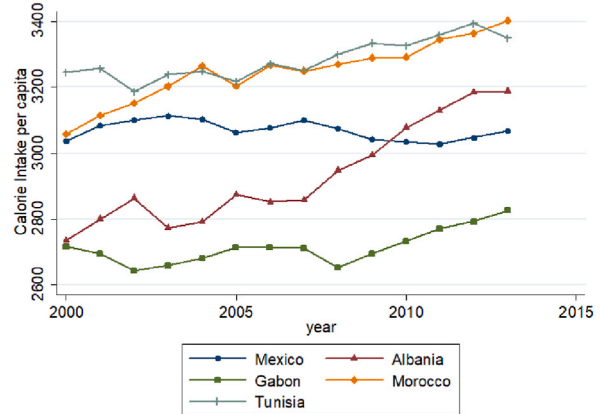


(b) Mexico

Fig. A.1. Food production index for Indonesia, Mexico and countries entering in their synthetic construction



(a) Indonesia



(b) Mexico

Fig. A.2. Calorie intake per capita for Indonesia, Mexico and countries entering in their synthetic construction

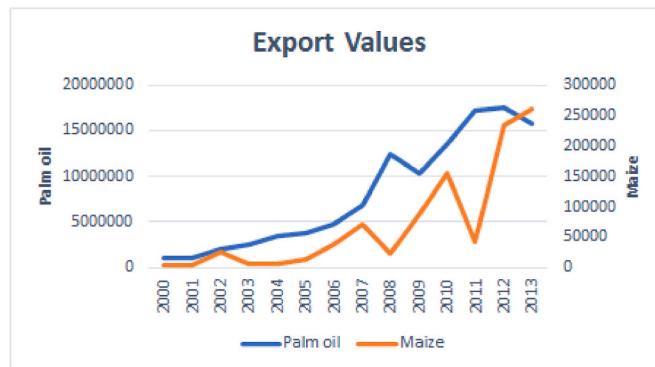


Fig. A.3. Export values (1000\$) of Indonesian palm oil and Mexican maize

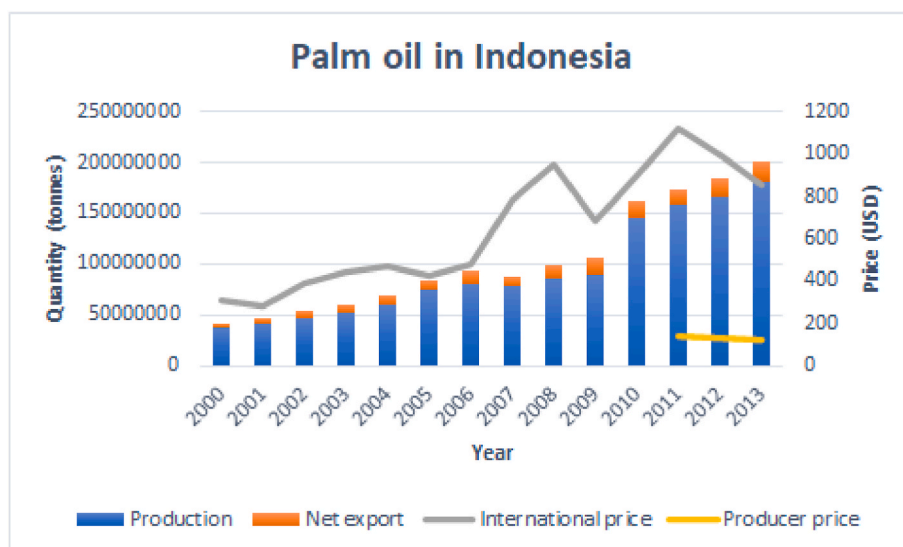


Fig. A.4. Palm oil quantity and price

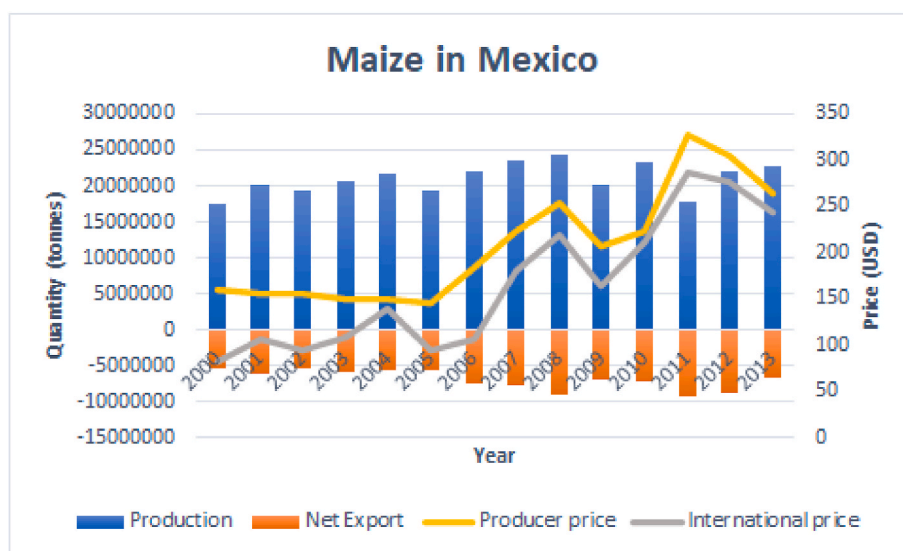


Fig. A.5. Maize quantity and price

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