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Abstract

We analyze food security effects of biofuel production by 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 is specialized in maize and ethanol. Our findings show that biodiesel production positively affects food security through the increase in daily per capita energy consumption and food production index, but we observe the reverse effect for bioethanol. After the adoption of biofuels, the gap between Indonesia and its counter-factual 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 which do not directly compete with food crops; moreover, biodiesel exports generate revenues which are allocated to food imports. However, the gap between Mexico and its counter-factual suggests that bioethanol production leads to a reduction in food security, this because it uses maize which is the staple food of many Mexicans. Furthermore, Mexican ethanol exports compete with that of the U.S. Our results are robust to several falsification tests.

Keywords

Food security, Biofuels, Impact assessment.

JEL Codes

Q16, Q42, Q18, Q01.

1 Introduction

Currently, fossil fuels account for about 80% of global energy consumption, 57% of which is due to the transport sector (IEA, 2012). Given the increasing global climate change, pollution and dwindling oil reserves, humanity is in dire need of other sources of energy for sustainable development (Khanna and Chen, 2013). Thus, among 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, in order to meet the growing energy needs.

Since the early 2000s, cropland has increased by 50 million hectares worldwide and the highest growth rates were recorded for maize, soybean, rapeseed (Tyner, 2012) and palm oil (Thoenes, 2006), that are crops used for first-generation biofuel production. Their usage to meet food and energy needs leads to increasing their market prices. The rise in food prices reduces food access to vulnerable people, leading some authors such as Ferrett (2007) to consider biofuels as a crime against humanity. However, for others, biofuel production in a country can be advantageous because it allows generating employment, diversification of energy sources and incomes for farmers (Ewing and Msangi, 2009); these revenues can therefore be allocated to food import and improve food security.

Biofuel effects can differ, depending on the raw material used in the production process (Groom et al., 2008). Therefore, this article aims at assessing their consequences by using two countries and two different biofuels (biodiesel and bioethanol) for comparison purposes. Specifically, we focus on Indonesia and Mexico, that are two major biofuel producers among developing countries which are facing food insecurity issues, and a set of countries which have never produced biofuels. On average, we counted approximately 19.3 millions of people undernourished in Indonesia and 5.4 millions in Mexico in 2013.

Contrary to existing studies on biofuels, we use the synthetic control, which is a method that emphasizes on comparative case studies in order to highlight the effects of an event or a policy. This method is the first on the topic of biofuel development on food security and is important to evaluate the sustainability of biofuel production. Moreover, a better

understanding of synthetic control could provide helpful input for researchers trying to improve their analytical tools, and might be of interest for policy-makers. This article also presents the trajectories of 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 the period 2000-2013, and we find evidence of an increasing effect of food insecurity for Mexico and a decreasing effect for Indonesia.

In order to better address this issue, our work is structured as follows: in the following section we review the main ideas behind biofuels and food security in both Indonesia and Mexico. Then, section 3 presents our data and the empirical method we use to answer the above questions. Section 4 submits the main results of our analysis. Finally, section 5 gives the findings of robustness check before concluding in section 6.

2 Background

2.1 Biofuel impacts on food security

Biofuels are increasingly being studied as they are the main alternative to fossil fuels used in the transport sector. They can be solid, liquid or gaseous, and are considered as alternative energies which can allow facing the energetic deficiency. They are classified into four groups from which we can distinguish the first, second, third and fourth generation biofuels. First generation biofuels are the most used and are constituted by biofuels which use food crops as feedstocks. These feedstocks could be sugarcane, maize, beet, wheat, palm oil, etc. We consider as second generation biofuels, those derived from biochemical and thermochemical conversion (Smith, 2010). This type of biofuels can be produced with feedstocks like jatropha, switchgrass, poplar, willow and some wastes derived from agricultural production. The third generation biofuels come from algae, seaweed, microalgae, and the fourth generation biofuels use microbes as feedstocks. As previously announced, biofuels have many consequences, especially on food security.

Food insecurity can be defined as uncertain access to sufficient and appropriate food, or the fact that sometimes an individual or a household goes without food (Barrett, 2002). Despite the growth in food production, today many people (more than one in seven) suffer from micronutrient malnourishment, because they do not have access to sufficient energy from their diet (Godfray et al., 2010). This situation could be due to food unavailability and observed by the statistics of some indicators such as the daily per capita energy consumption, the number of people undernourished and food production index. The daily per capita energy consumption fairly approximates well nutrition. The number of undernourished people represents the total number of individuals with a dietary energy consumption less than a threshold measured in terms of the number of kilocalories necessary to conduct light activities. Likewise, food production index covers all edible food crops available. So these measures permit to evaluate a country level of food insecurity.

As defined by the United Nations Food and Agriculture Organization (FAO), food security is constituted by four dimensions which are availability, access, utilization and stability. As biofuels¹ 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, due to the fact that biofuel production diminishes the quantity of food supply; this results in higher food prices. A large expansion in biofuel production, from agricultural feedstocks, could create a food crisis, but also volatility in food prices (Tenenbaum, 2008; Hochman et al., 2011). This situation negatively affects food access, and stability as they are respectively determined by food price levels and food price volatility. Likewise, it influences food utilization determined by the access to nutritious and safe diet. According to Hausman et al. (2012), the increase in maize price between 2006 and 2007 was explained by the United States ethanol production. For Mitchell (2008), biofuel growth highlights 70% to 75% increase in the world prices of agricultural products. In addition, in many developing countries the poor allocate about 70% of their revenue to their consumption (Pingali et al., 2008). Thus, rising food prices could have a negative impact on household purchasing power. On the other hand, farmers could benefit from higher commodity prices, as these higher prices would increase their

¹Mainly first generation biofuels.

income. Moreover, biofuel production will create employment at farm and factory level. In accordance with Zarrilli (2008), the regulation of biofuel usage could provide benefits like job creation in rural areas and lower emissions of greenhouse gases (GHGs). So, their production might favor poverty alleviation and food access (Ewing and Msangi, 2009).

Otherwise, biofuel expansion enhances deforestation; indeed, farmland expansion is one of the main determinants of deforestation (Righelato and Spracklen, 2007; Goudie, 2018). Since deforestation leads to soil degradation and decreases agricultural yields, biofuel expansion could negatively affect food security in the long run (Meyer et al., 1994).

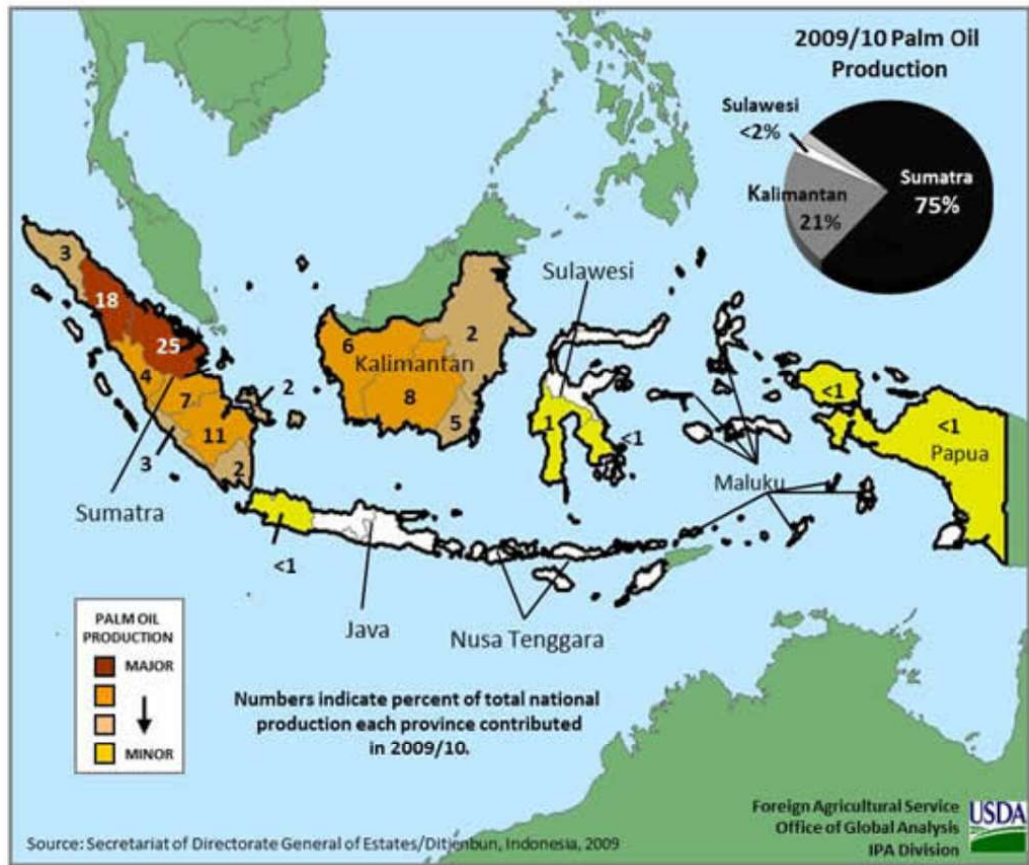
2.2 Indonesian context

Indonesia is a South-East Asian country, consisted of 17,504 tropical islands. With over 20 million hectares of arable land, Indonesia is considered as the main producer of crude palm oil (CPO) in the world (McCarthy et al., 2012), and provides around the half of the world's palm oil (Colbran and Eide, 2008). In order to stay the largest CPO producer, in 2008, Indonesia used nearly 7.3 million hectares of land for palm oil and cleared also 18 million hectares of forest land (Kharina et al., 2016). In 2009, CPO production was around 24,500 MT in an area of 7,500 thousand 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. Thereby, in 2006 with the presidential instructions on biofuels, Indonesia began its biofuel production. They are mainly produced with palm oil and also with jatropha.

The main areas of biofuel production in Indonesia are Sumatra, Kalimantan (formerly Borneo), Sulawesi, West Papua and Java as we can see in figure 1; there are also the main areas of palm oil production.

In 2006, areas devoted to palm oil production in Sumatra accounted for more than 4 million hectares. The second archipelago after Sumatra is Kalimantan with an area of palm oil production superior to 1.5 million hectares. After Sumatra and Borneo, we have Sulawesi with more than 100 thousand hectares, and Papua with more than 40 thousand hectares.



Source: USDA, Foreign Agricultural Service, Commodities Intelligence Report

Figure 1: Main areas of palm oil and biofuel production in Indonesia

Finally, we can mention Java, primarily Jakarta, with an area of palm oil production of more than 20 thousand hectares.

Otherwise, these archipelagoes are also arable land areas due to equatorial and tropical climate. This kind of climate with an annual rainfall greater than 3000 mm and an average sunshine duration of 6 hours per day (Sumatra and Kalimantan), is suitable for palm oil production. Moreover, it means that these lands can also be suitable for other agricultural crops production.

Indonesian biofuel is mainly constituted by biodiesel. As we can see in figure 2, biodiesel production is higher than bioethanol production which remains very low over the whole period.

In order to be more competitive on the international market and to promote biofuel

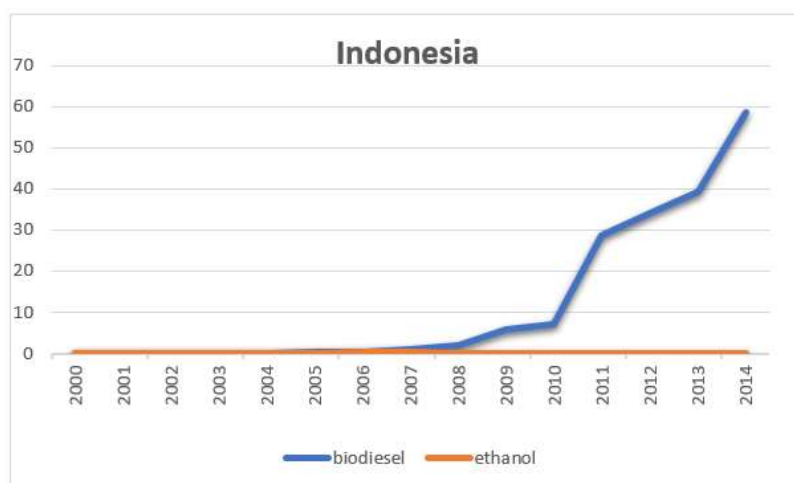


Figure 2: Indonesia biofuel production in 1000 barrels/day

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\$/ton when the international CPO price is below 750\$, and 200\$/ton when CPO price is above 1,250\$. The levy on palm oil exports is a tax collected temporary by the government when the existing export tax is reduced to zero, which occurs if the CPO price is below 750\$/ton. This levy, whose aims at financing the domestic biodiesel subsidy, was 30\$/ton for downstream products and 50\$/ton for CPO (Kharina et al., 2016); it is redistributed to biofuel producers who sell their products for B20² mixing in the national market.

Furthermore, this biofuel production has some advantages: indeed, it allows reducing Indonesia's dependence on fossil fuel imports. Also, it promotes food security through jatropha production which is a non-food crop that can grow on the marginal land of Indonesia's eastern region (Suryahadi and Sumarto, 2003). Moreover, palm oil production contributes to employ more than 5 million people. This advantage also promotes poverty alleviation and food security through income generated by jobs creation (Kharina et al., 2016). However, for Van Der Werf et al. (2008), deforestation caused by palm oil plantation leads to 680 million tons of CO_2 emission per year.

²Which means that we combine in a diesel engine 20% biodiesel and 80% diesel.

2.3 Mexican context

Mexico is located in South-America, bounded on the South by Guatemala and Belize, and on the North by the United States of America. It is considered as 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. Due to the necessity of reducing GHGs emissions, fossil fuel dependence, and promoting rural development, the Mexican government began its biofuel production in 2007. The production is more concentrated on bioethanol rather than biodiesel, as illustrated in figure 3.

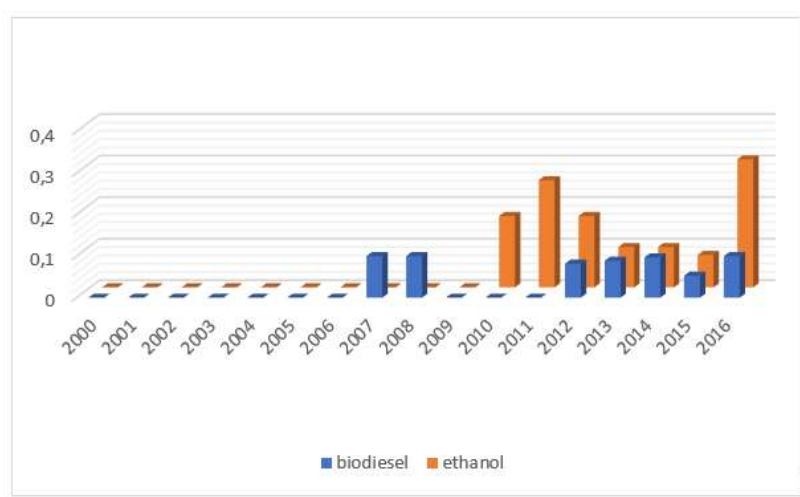
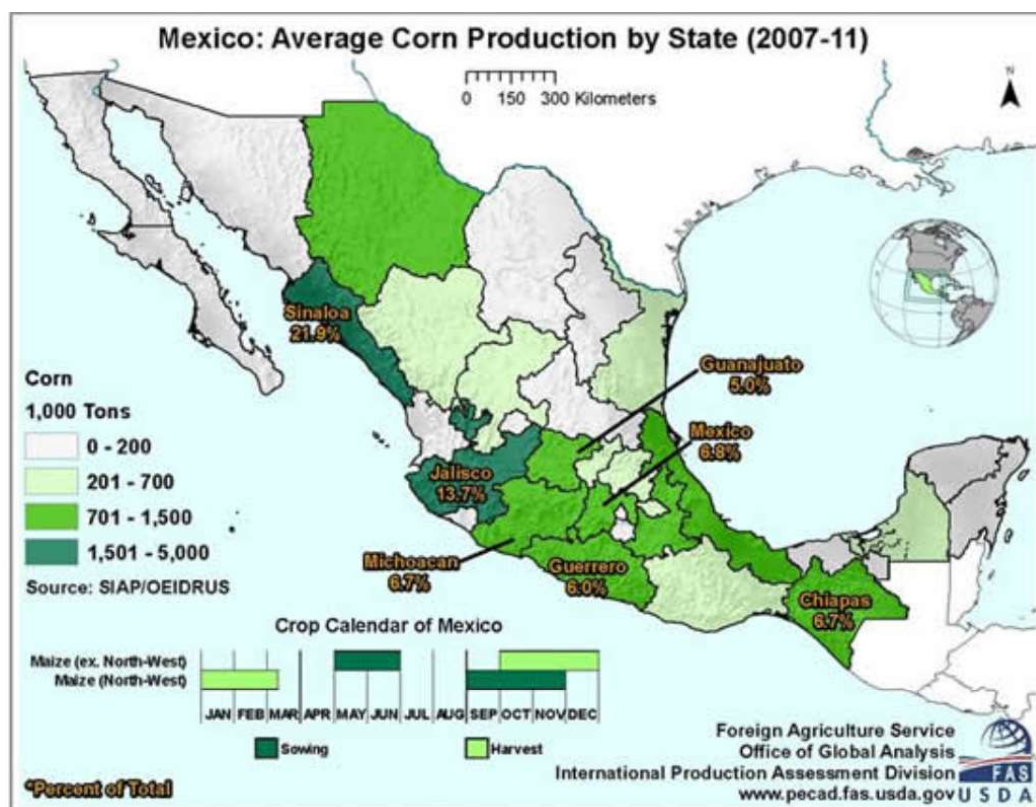


Figure 3: Mexico biofuel production in 1000 barrels/day

Thus, due to the fact that it is one of the largest maize producers, its bioethanol is mostly based on corn and corn stover. As presented in figure 4, the main areas of corn production in Mexico are also areas where bioethanol production units are present: Sinaloa, Jalisco, Michoacan, Mexico and Guerrero. These areas are considered as the main agricultural lands in Mexico.

Unlike Indonesia, Brazil or the US, Mexican biofuels are not competitive on the international market. Indeed, in 2007 Mexico voted a law in order to promote bioenergy development, but not a legislation to support biofuel production (Guerrero, 2008). Bioethanol

³FAO database.



Source: USDA, Foreign Agricultural Service, Office of Global Analysis

Figure 4: Main areas of corn and biofuel production in Mexico

production has negative effects which are harmful to many Mexicans according to Couch (2013). As stated, they are produced from maize, which is also one of the main staple foods in Mexico. Thus, the use of this cereal for energy and food purposes, promotes an increase in its price which reduces access to rural populations who are vulnerable to food price fluctuations. Moreover, due to alleged U.S. corn subsidies, Mexico maize production increased but for less money: its maize price was less competitive than that of the U.S (Fernández et al., 2012). Furthermore, employment in agriculture declined and led to a rise in internal migration (Beam, 2011).

3 Empirical method

3.1 Model specification

In order to assess 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 by using comparative case studies. This choice 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 studies. So it is an important device for promoting research honesty in observational studies (Rubin, 2001). The model allows that unobserved variables effects on the outcome vary with time, by extending the traditional linear panel data (difference-in-differences) framework.

Let's suppose that we have $P + 1$ developing countries, wherein one country 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 the level of food security that would be observed for country i at time t if biofuels are adopted. Due to the availability of data on biofuels, time periods $t = 1, \dots, T$, go from 2000 to 2013, with T_0 the year from which a country started its biofuel production or took some policies for biofuel adoption. Then, we suppose that biofuel production has no effect on food security before T_0 . So for $t \in (1, \dots, T_0)$ (preintervention periods) and all $i \in (1, \dots, P+1)$, we have $Y_{it}^B = Y_{it}^N$.

Thereby, 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 :

$$Y_{it} = Y_{it}^N + \lambda_{it} B_{it} \quad (2)$$

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 this equation:

$$Y_{it}^N = \alpha_t + \beta_t X_i + \delta_t \mu_i + \varepsilon_{it} \quad (3)$$

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

We consider a vector of weights W , which can be a potential synthetic control. The outcome value for each synthetic control indexed by W is :

$$\sum_{p=2}^{P+1} w_p Y_{pt} = \alpha_t + \beta_t \sum_{p=2}^{P+1} w_p X_p + \delta_t \sum_{p=2}^{P+1} w_p \mu_p + \sum_{p=2}^{P+1} w_j \varepsilon_{it} \quad (4)$$

We also assume that there are $\hat{w}_2, \dots, \hat{w}_{P+1}$ as follows:

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

The aim of this study is to estimate λ_{it} at $t > T_0$. For this reason, a counter-factual will be approximated, in order to get the pathway that the treated country⁴ (Indonesia, then Mexico) would have followed in the absence of biofuel production. According to Abadie and Gardeazabal (2003) and Abadie et al. (2010), the synthetic control is the better method to estimate the counter-factual Y_{it}^N . The idea is that any single country alone does not often

⁴For this country, $p = 1$.

provide a better approximation for the treated country than the combination of P control countries. The weights (w) are chosen so that the counter-factual most resembles the actually treated country in the pre-treatment period.

In practice, it often happens that there is no 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:

$$\sum_{p=2}^{P+1} \hat{w}_p X_p = X_1 \quad \text{and} \quad \sum_{p=2}^{P+1} \hat{w}_p \mu_p = \mu_1 \quad (6)$$

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

The synthetic control method implementation needs five steps which are in accordance with Gathani et al. (2013): select the outcome variable, the period of analysis, the predictor variables of the outcome variable, the potential control countries and conduct various robustness checks.

3.2 Data

To implement this method we use a sample of 27 developing countries from 2000 to 2013, wherein treated countries are Indonesia and Mexico; the other countries have produced no biofuel over the whole period. In order to do a comparative study, we have chosen these countries because Indonesia is a developing country which faces food insecurity, and which is also considered as one of the largest biodiesel producers (Bergmann et al., 2013). Mexico is also confronted with the problem of food insecurity; it has been chosen in order to assess the impact of its corn-based bioethanol production on food insecurity.

3.2.1 Biofuels

Data on biofuel production come from the International Energy Agency (IEA) datasets. It is measured in barrels⁵ per day. According to Groom et al. (2008), biofuels are advantageous due to the reduction of countries dependence on fossil fuels and the mitigation of climate

⁵Which is equivalent to 159 liters per day.

change by the reduction of GHGs; even if some authors are skeptic (Righelato and Spracklen, 2007; Goudie, 2018).

3.2.2 Food security

Food security is considered as a multidimensional concept and for this reason it is difficult to find a good indicator. In this study, we use the food production index and the daily per capita energy consumption in kilocalories to measure food security. Food production index has been chosen because it covers edible food crops available and all food crops which contains nutrients (Hopfenberg, 2003). In addition, it is focused on the sum of price-weighted quantities of different agricultural commodities produced after removing quantities used for seed and animal feed. It displays the aggregate volume level of agricultural production for each year in comparison with the base period 2004-2006 by using Laspeyres formula. These data have been taken from the World Development Indicators (WDI), in line with Esmacili and Shokoohi (2011). Food production index also enables to measure human carrying capacity values, which can be defined as the number of individuals that the resources could support (Hopfenberg, 2003). Daily per capita energy consumption (or calorie intake per capita) is one of the best indicators of well nutrition and hunger. This variable has been selected in line with Jenkins and Scanlan (2001), as well as Santangelo (2018); it is computed by the FAO for each country. We get 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 population.

3.2.3 Predictor variables

We also use some predictor variables such as arable land, gross domestic product(GDP) per capita, rainfall and temperature. Consistent with Godfray et al. (2010), we use arable land which plays a key role in food security by favouring an increase in food production and food supply. In addition, we choose gross domestic product per capita according to Timmer (2000) who finds that the raise in GDP per capita positively affects food security by improving food access. These two variables come from the WDI. Likewise, we include some climate variables

constituted by the annual average of temperature and rainfall in accordance with Lobell et al. (2008). These data which have also a high impact on food production and food security come from Santoni (2017).

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

Table 1 provides descriptive statistics of all 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	56500	8400	1000	370000
Gross domestic product per capita (US\$)	378	2377.39	2310.20	271.02	10137.55
Rainfall (mm per year)	378	1069.41	856.21	50.62	3542.15
Temperature (degree celcius)	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

4.1 The case of Indonesia

Table 2 presents country weights obtained with the synthetic control method; it shows that Nigeria, Angola, Gabon and Sierra Leone allow reproducing Indonesia food production index pathway, which seems exactly as that of Indonesia before it starts producing biofuels. By using our second measure of food security we notice in table 6 that Gabon, Cambodia, Sierra Leone and Bangladesh contribute to reproduce a synthetic which is very close to Indonesia during the periods prior to 2006.

Table 2: Country weights in the 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		

Table 3 and table 7 give a comparison of Indonesian characteristics with that of the 25 countries weighted average in the donor pool during the pretreatment period, for the two food security measures. We observe that the average of countries that did not adopt or start bio-fuels, seems to provide a suitable control group for Indonesia; synthetic Indonesia reproduces the values of Indonesian food production index and daily per capita energy consumption before 2006.

Table 3: Food security predictors (food production index)

Predictor balance	Indonesia	Synthetic Indonesia
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

Figure 5 shows food production index trend for Indonesia and its synthetic during the period 2000-2013. As stated in the previous paragraph, food production index in the synthetic Indonesia very closely follows the path of this variable in Indonesia during the period prior to biofuel adoption. However, after 2006, we can see a gap between Indonesia and its counter-factual, showing that biofuels, mostly biodiesel production do not harm food security. Likewise, we find the same effect with the daily per capita energy consumption; after starting producing biofuels, we can see an important increase of calorie intake per capita.

This result is in accordance with Ewing and Msangi (2009) who show that biofuel pro-

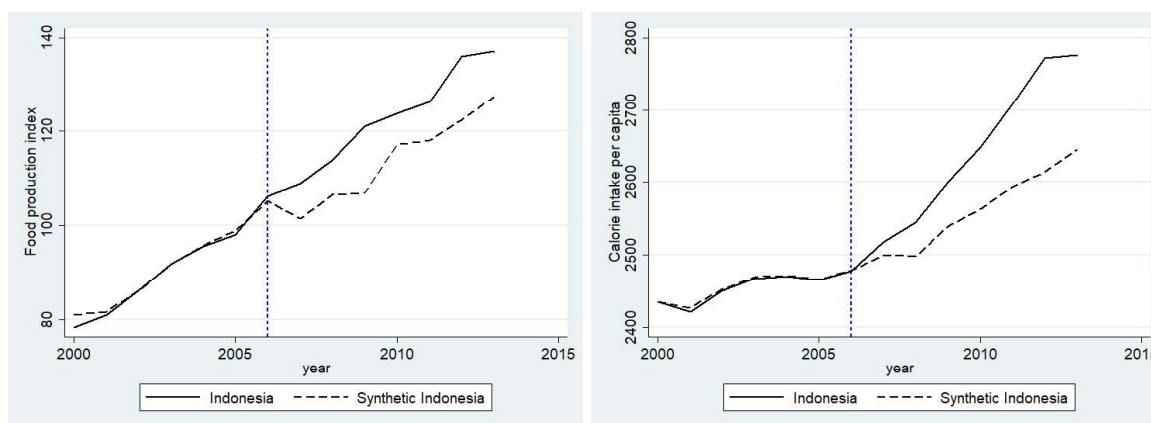


Figure 5: Trends in food security: Indonesia vs. synthetic Indonesia

duction positively affects food security through the improvement of food access. In the case of Indonesia, this impact may be due to Indonesian biodiesel competitiveness in the international market (McCarthy et al., 2012); indeed, in 2013, it exported 1,730 million liters of biodiesel mainly in Europe and Asia. So, palm oil and biodiesel sales allow getting money which can be reallocated to food import, in order to enhance the domestic food supply. Moreover, biodiesel production uses some feedstocks which do not directly compete with food crops. As mentioned in the background, biodiesels are mainly produced with palm oil and jatropha; thus, even if palm oil can be used for human consumption, jatropha production does not enter into human consumption. Likewise, jatropha is produced in the marginal lands of Indonesia where it cannot be advantageous to produce food crop. For Bazongo et al. (2015), jatropha production helps to restore the soil by its cakes. Indeed, he finds that producing sorghum on a soil where jatropha was produced significantly raises sorghum yields.

4.2 The case of Mexico

In the case of Mexico, we can see in table 4 that Algeria, Armenia, Gabon and Morocco have enabled to reproduce a synthetic for food production index which is very close to that of Mexico during the periods prior to biofuel adoption. For the second measure, which results are presented in table 8, Albania, Gabon, Morocco and Tunisia allow representing a good synthetic Mexico.

We test the trustworthiness of the counter-factual in table 5 and table 9. We can see

Table 4: Country weights in the 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		

that before biofuel adoption, synthetic Mexico and Mexico have some similar characteristics. Moreover, synthetic Mexico gives a good representation of the values of Mexican food production index.

Table 5: Food security predictors (food production index)

Predictor balance	Mexico	Synthetic Mexico
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

As shown in figure 6, before biofuel production, Mexico and its counter-factual very closely attend the same trajectory. However, after biofuel production, there is a gap between Mexico and synthetic Mexico which suggests that biofuels are penalizing food security. Indeed, the level of food production index for Mexico is lower than the one it would reach in the absence of biofuels. This gap is observed from 2009 because it is from this year that the production, mostly of bioethanol, started to become very important as we can see in figure 3. In addition, we can observe the same gap with the daily per capita energy consumption.

In contrast to Zarrilli (2008) who finds that the regulation of biofuel usage could provide benefits, this effect can be attributed to the fact that bioethanol production in Mexico is based on corn and corn stover. This production reduces the amount of corn available for human consumption and increases maize market price, leading to a reduction in access to

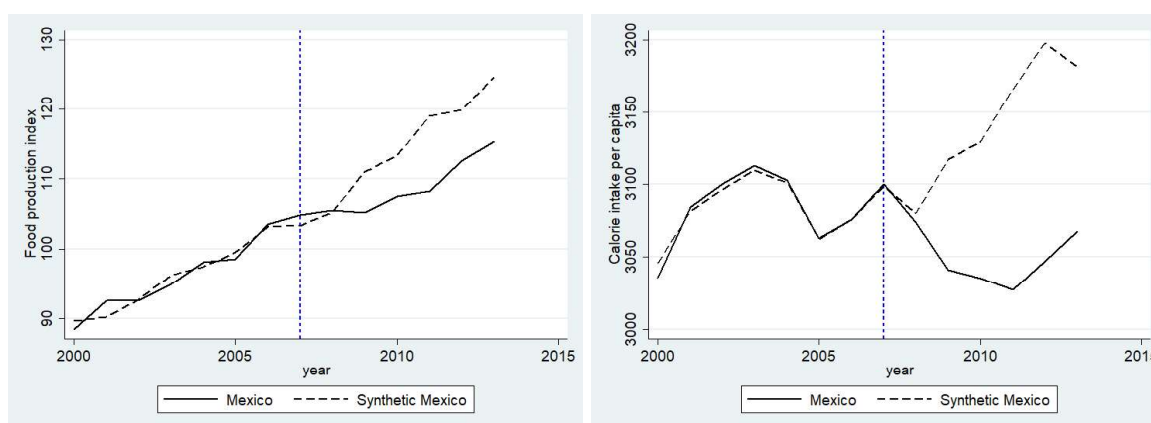


Figure 6: Trends in food security: Mexico vs. synthetic Mexico

food for vulnerable people.

Moreover, Mexico has an export-oriented market economy and is a member of the North American Free Trade Agreement (NAFTA). Thereby, it faces the U.S dumping in the maize and bioethanol market. Thus, even if Mexico is one of the largest maize producers, this production does not allow farmers to get enough money in order to buy food. Due to the lack of competitiveness and higher maize market price, bioethanol production leads to a decrease in food production index. In the long run, the lack of export discourage agricultural production, which may negate the short-term revenues (Aragie et al., 2018). According to Wise et al. (2012), the expansion of U.S. production and consumption of corn-based ethanol has been promoted by subsidies and incentives offered by the government. This biofuel program is one of the main causes of upward pressure on food prices. As a result of this program, from 2006 to 2011, Mexico was obliged to import around one-third of U.S. corn, which cost about \$1.5 billion due to ethanol-related corn price raises.

5 Robustness check: Placebo test

The synthetic control method is considered as a graphical analysis with a weak external validity for impact analysis. As it is not easy to test the statistical significance of biofuel impacts with this method, we use a placebo test, also named falsification test. This test is like a permutation test, where we enforce the synthetic control method to each potential

control in our sample. It helps us to evaluate if the effect estimated by the synthetic control for Indonesia or Mexico by biofuel production is large relative to 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. The gap between the real food production index and food production index of the synthetic control refers to the Mean Square Prediction Error (MSPE). If, on the one hand, placebo test creates the same gaps as the one obtained for Indonesia or Mexico, the conclusion will be that this analysis does not give a significant evidence of biofuel effects. If, on the other hand, placebo test displays that the gap estimated for Mexico or Indonesia is unusually large in comparison with the gaps for states present in the donor pool, it will mean that our analysis gives significant evidence.

The figures below illustrate the MSPE ratio of post and pre-biofuel production periods for countries. According to Abadie et al. (2015), 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:

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

5.1 Placebo test for Indonesia

Figure 7 exposes the MSPE ratio for each country. Indonesia remains the country with the highest MSPE ratio. The post-biofuel gap is in average 700 and 23500 times larger than the pre-biofuel gap for respectively food production index and daily per capita energy consumption, involving that the effect noted in Indonesia is unusual relative to the distribution of results obtained when we hold the same analysis to states in our donor pool. So it provides significant evidence of food security effects of biofuels in Indonesia. The probability of getting the same impact with another control country, selected at random, is very low ($1/26 \approx 0.038$).

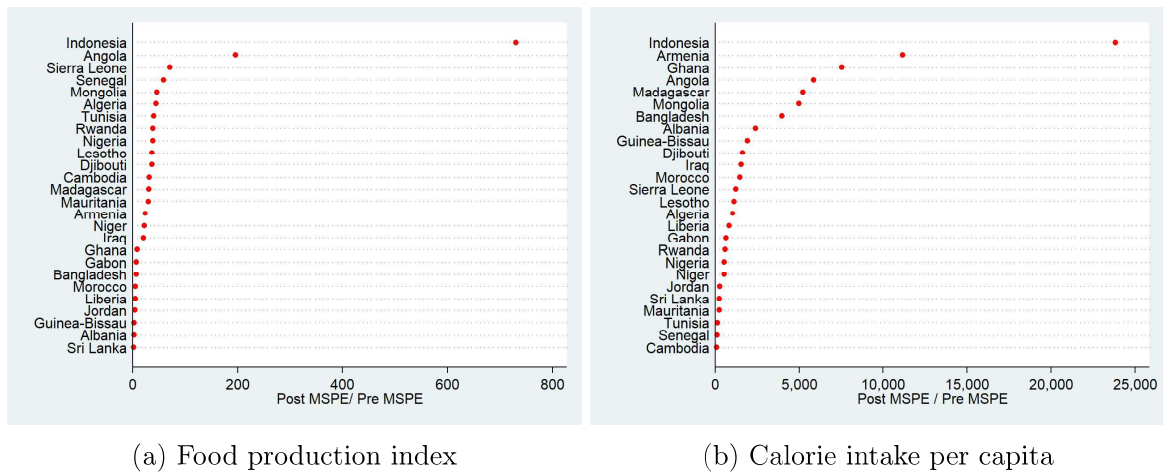


Figure 7: Placebo test for Indonesia

5.2 Placebo test for Mexico

Figure 8 presents the MSPE ratio for each country and shows that Mexico stays the country with the highest MSPE ratio. Its post-biofuel gap is in average 900 and 24000 times larger than the pre-biofuel gap for respectively food production index and daily per capita energy consumption, which indicates that the effect noted in Mexico is unusual. It provides significant evidence of biofuel adoption effect. As in the case of Indonesia, the probability of getting a post/pre-biofuel adoption MSPE ratio as large as Mexico with another country present in our donor pool, selected at random, is very low ($1/26 \approx 0.038$).

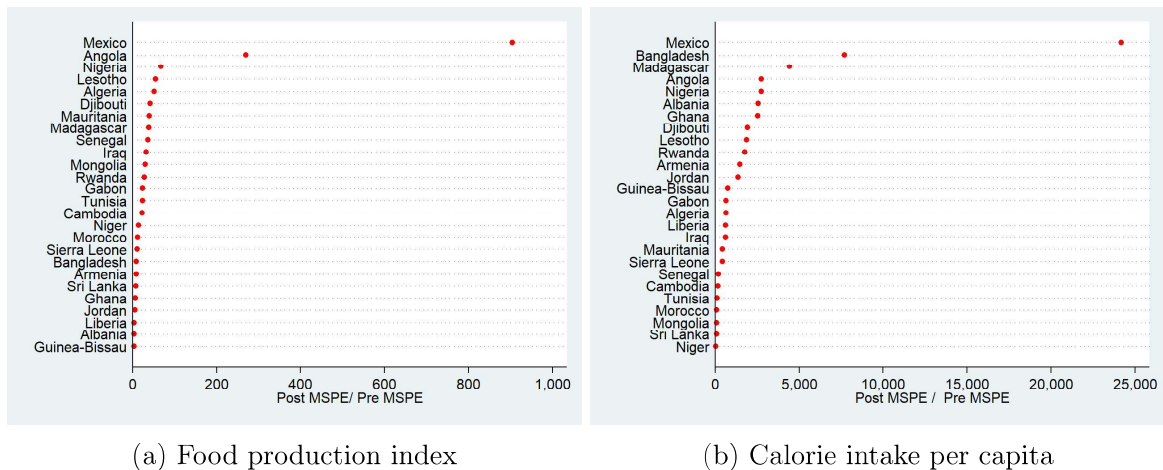


Figure 8: Placebo test for Mexico

6 Conclusion

Biofuels are considered as an alternative solution to the current energy crisis. They are produced in many countries from the organic material mainly agricultural crops. This production promotes economic development in developing countries and the reduction of greenhouse gas emissions. However, the use of agricultural feedstocks raises questions about food security.

Focusing on Indonesia and Mexico, this article tries to assess food security effects of biofuel adoption by using the synthetic control method analysis. This method's motivations are to detect an event or policy intervention effects on some outcomes, by using a particular case in which the event or intervention amplitude is large. Following this method, our results show us that biofuel production has a positive effect and does not harm food security in Indonesia, but the effect is reversed for Mexico because the level of food security it could achieve if it did not adopt biofuels would be higher than its current level.

This could be due to the fact that Indonesian biodiesels are primarily produced with palm oil and jatropha, two crops which are not directly used for food. Moreover, Indonesia is the highest palm oil and biodiesel exporter, so it sells a high quantity of these products, whose incomes can be allocated to food import. The negative effect observed in Mexico, can be attributed to the fact that it mainly uses maize to produce bioethanol; likewise, even if Mexico is one of the highest maize producers, it faces with US competition in the international maize market. In addition, biofuel production allows increasing the maize market price.

As a robustness check, a placebo study has been done to test the significant evidence of biofuel effects. Findings suggest 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 getting the same results as the amplitude of Indonesia and Mexico would be very small, close to 3.8%.

In general food security effects of biofuel production in developing countries could be positive if some factors are taken into account. These factors might be the kind of agricultural feedstock using for biofuel production and the country competitiveness in the international market. Thus, a good regulation of biofuel usages and policies could provide benefits to developing countries.

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7 Appendix

Table 6: 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 7: Food security predictors

Predictor balance	Mexico	Synthetic Mexico
Daily per capita energy consumption (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 8: 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 9: Food security predictors

Predictor balance	Mexico	Synthetic Mexico
Daily per capita energy consumption (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