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Aicha Lucie Sanou. Biofuels and food security. Economics and Finance. Université Clermont Auvergne, 2022. English. NNT : 2022UCFAD007 . tel-04028065

HAL Id: tel-04028065

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Ecole Doctorale des Sciences Economiques, Juridiques, Politiques et de Gestion

LEO, UMR CNRS, Orléans - France

Université Clermont Auvergne, Clermont-Ferrand, France

BIOFUELS AND FOOD SECURITY

Thèse Nouveau Régime

Présentée et soutenue publiquement le **13 Juillet 2022**

Pour l'obtention du titre de Docteur ès Sciences Économiques de l'Université
Clermont Auvergne

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L'Université Clermont Auvergne n'entend donner aucune approbation ni improbation aux opinions émises dans cette thèse. Ces opinions doivent être considérées comme propres à leur auteur.

A mon grand-père...

Tu as été la base. J'espère que de là-haut tu es fier de ta petite fille.

A mes parents!

Remerciements

Mes remerciements vont tout d'abord à mes directrices de thèse, Pr. Pascale Combes Motel et Pr. Sonia Schwartz pour leurs conseils avisés leurs encouragements et surtout leur confiance dans la réalisation de cette thèse. Ils s'adressent également aux membres du comité de thèse, les professeurs Marie-Hélène Hubert, Valérie Mignon, Camélia Turcu, Matthieu Clément, et Ernest Ruzindaza qui ont accepté de consacrer du temps à l'évaluation de ce travail. Je me réjouis à l'avance de bénéficier de votre expertise et de pouvoir échanger avec vous lors de ma soutenance.

Cette thèse est le résultat de belles années d'études passées à Clermont-Ferrand. Je remercie l'ensemble du corps professoral pour la qualité des enseignements reçus. J'ai une pensée particulière pour les professeurs Simone Bertoli et Emilie Caldera membre de mon comité de suivi; les professeurs, Alexandru Minea, Jean-François Brun, Marie-Eliette Dury, Théophile Azomahou, Francesca Marchetta, Bity Diene, Anne Viallefont et Florent Bresson avec qui j'ai collaboré plus étroitement durant la thèse à travers des conseils mais également dans le cadre de dispensation de cours et travaux dirigés. Encore merci pour les conseils et la confiance. Un grand merci à l'équipe administrative, Martine, Claudine, Hassen, Chantal, Johan, Flora, Sandra, Christelle, Patricia et Marie.

Je remercie également mes responsables et collègues de la Banque mondiale, Marianne Grausclaude, Tobias Baedeker, Asa Giertz, Elliot Mghenyi, Ernest Ruzindaza, Loic Braune, Lisa Saldanha Olivier Munos, Volana Andriamasinoro, Sebastian Heinz, Mitik Ayalew, Kaja Waldmann, Leonard Krapf et Steven Were Omamo pour leur confiance et le travail commun réalisé.

Dès le début de mon aventure Clermontoise, il y a eu une famille, la Famille Drabo, Alassane, Aissata, Salimata et Camélia qui m'ont accueillie chez eux sans même me connaître. Il y a eu également Mohamed Boly qui m'a toujours

soutenue tout au long de ce parcours. Je vous témoigne toute ma reconnaissance pour l'accueil, les précieux conseils et tout ce que vous avez fait pour moi. Si je suis en train de soutenir ma thèse, c'est également grâce à vous.

Cette thèse est le fruit de nombreuses interactions et échanges avec les amis. Je pense particulièrement à Camara, Jean Marc, Moulaye, Fataph, Fatoumata, Harouna, Bernard, Cédric, Yashmina, Cezara, Aimé, Cynthia, *Nestor*², Assi, Ali, Gildas, Alou, Aubin, Baowe, Apeti, Adil, Muhammad, Axelle, Ibrahim, Hamid, Naimatou, Yoro, Kabinet, Awa, Faycal, Abdoul-Akim, Mahamady, Ismael, Macoura, Mariam, Carole, Maïmouna et tous les autres. Un grand merci à mes aînés Constantin, Maimouna, Chirstelle Tchoupe, Falapalaki Lemou, Tanou Balde, Mélaine et Yacouba Samoura pour leurs encouragements et leurs conseils.

J'exprime également ma profonde gratitude à tous les membres de l'Association des Burkinabé de Clermont-Ferrand (ABUC), spécialement à Serge Koblavi, Inès et Simon Zanga, Luc et Sandrine Balima, Edgard Béré pour leurs constants efforts pour l'intégration des nouveaux.

Mention spéciale à Christian, Imelda, *Rachid*², Camille, Landry, Francis, Frans, Richard et Alima que je remercie du fond du cœur pour leur présence depuis toutes ces années et leur soutien.

Enfin et surtout, je ne serais pas là sans ma famille. Merci pour les prières, la confiance, les conseils, le soutien et les encouragements. Vous m'avez toujours poussé à aller plus loin et avez tout fait pour me mettre dans de bonnes conditions afin de réussir. Cette thèse est aussi la vôtre.

Un grand merci au Dieu en qui je crois et qui a facilité l'aboutissement de ce projet et sans qui cela n'aurait pas été possible.

Je vous souhaite une très bonne lecture.

Résumé

La lutte contre le réchauffement climatique nécessite de réduire les émissions de gaz à effet de serre. Une grande partie de ces émissions étant due au secteur du transport, les biocarburants constituent une source d'énergie alternative à l'utilisation des énergies fossiles. Cependant, l'utilisation des biocarburants pose le dilemme « nourriture contre carburant ». Ce dernier évoque l'idée que la production de biocarburants constituerait une menace à la disponibilité et à l'accessibilité aux denrées alimentaires. Par conséquent, l'objectif de la thèse est d'apporter un nouvel éclairage sur le possible lien entre la production de biocarburants et la sécurité alimentaire, afin de déduire des recommandations en termes de politiques économiques. Globalement, les résultats obtenus montrent que, sous certaines conditions, les biocarburants ne constituent pas un frein à l'atteinte du deuxième objectif de développement durable à court terme et ont une influence relativement faible à long terme. La thèse est constituée de trois chapitres. Le chapitre 2 considère les effets de la production de biocarburants sur la sécurité alimentaire. L'analyse porte sur l'Indonésie et le Mexique et utilise la méthode de contrôle synthétique. L'Indonésie est l'un des grands producteurs de biodiesel, tandis que le Mexique est spécialisé dans le maïs et l'éthanol. Les résultats montrent que la production de biodiesel affecte positivement la sécurité alimentaire grâce à une augmentation de la consommation énergétique quotidienne par habitant et de la production alimentaire. Toutefois, l'effet inverse est obtenu pour le bioéthanol. Ces résultats peuvent s'expliquer de la façon suivante. La production de biodiesel en Indonésie utilise des matières premières qui n'entrent pas dans la consommation humaine comme le jatropha. Par ailleurs, les exportations de biodiesel génèrent des revenus qui peuvent être alloués aux importations alimentaires. Au Mexique, la production de bioéthanol réduit la sécurité alimentaire parce qu'elle repose sur l'utilisation de maïs, aliment de base de nombreux Mexicains. En outre, les exportations mexicaines d'éthanol rivalisent avec celles des États-Unis. Par conséquent, l'analyse du lien entre sécurité alimentaire et biocarburants diffère selon les modalités de production de ces derniers.

Le chapitre 3 considère la question importante du possible lien entre la production de biocarburants et l'augmentation des prix des denrées alimentaires. Plus précisément, il analyse la transmission dynamique des chocs des prix mondiaux du bioéthanol aux prix alimentaires, en particulier les prix du maïs. La méthode des projections locales permet d'estimer les réponses dynamiques à chaque période prise en considération. Les résultats montrent qu'il y a une réponse positive des prix du maïs aux chocs de prix du bioéthanol qui s'estompent en moyenne au bout de trois ans. Par ailleurs, en moyenne, l'asymétrie par rapport à la direction des chocs révèle un effet net nul, suggérant que la production du bioéthanol n'affecte pas la sécurité alimentaire. Cependant, une analyse désagrégée de l'intensité des impacts révèle d'importantes hétérogénéités. En dépit des nombreux programmes visant à éradiquer la faim dans le monde, des millions de personnes font encore face à l'insécurité alimentaire. Le chapitre 4 vise à tester l'existence d'une trappe inconditionnelle de la faim et à déterminer si la production de biocarburants fait partie des déterminants de long terme de l'insécurité alimentaire. Le calcul des probabilités de passage d'un état d'insécurité alimentaire à l'aide d'une matrice de transition de chaîne de Markov et la distribution ergodique permettent de tester l'hypothèse d'une trappe inconditionnelle de la faim. Ensuite, l'estimation d'un arbre de régression d'inférence conditionnelle permet d'identifier les principaux moteurs de l'insécurité alimentaire. Les résultats indiquent que les pays en développement ne sont pas pris dans une trappe inconditionnelle de la faim. Le résultat de la matrice de transition montre que tous les pays ayant des niveaux élevés d'insécurité alimentaire ont une probabilité non nulle de passer à un niveau faible dans un temps limité. De plus, compte tenu des caractéristiques des pays, les résultats de l'arbre de régression d'inférence conditionnelle montrent que la variable la plus importante est le produit intérieur brut (PIB) par habitant et que la production de biocarburants ne fait pas partie des déterminants de long terme de l'insécurité alimentaire. Nos résultats suggèrent que la production de biocarburants peut être un moyen de lutte contre le changement climatique sans pénaliser la sécurité alimentaire.

Mots-clés : Production des biocarburants · Sécurité alimentaire · Prix des biocarburants · Prix du maïs · Trappe de la faim · Analyse d'impact · Projection locale · Arbre de régression · Matrice de transition

Codes JEL : Q01 · Q11 · Q16 · Q18 · Q41 · Q42

Abstract

The fight against global warming requires reducing greenhouse gas emissions. Since a large part of these emissions is due to the transportation sector, biofuels are an alternative energy source to the use of fossil fuels. However, the use of biofuels poses the "food versus fuel" dilemma. The latter evokes the idea that biofuel production would pose a threat to the availability and accessibility of food. Therefore, the objective of the thesis is to shed new light on the possible link between biofuel production and food security in order to derive economic policy recommendations. Overall, the results obtained show that, under certain conditions, biofuels do not hinder the achievement of the second sustainable development goal in the short term and have a relatively small influence in the long term. The thesis consists of three chapters. Chapter 2 considers the effects of biofuel production on food security. The analysis focuses on Indonesia and Mexico and uses the synthetic control method. Indonesia is one of the major producers of biodiesel, while Mexico is specialized in corn and ethanol. The results show that biodiesel production positively affects food security through an increase in daily per capita energy consumption and food production. However, the opposite effect is obtained for bioethanol. These results can be explained as follows. Biodiesel production in Indonesia uses feedstocks that are not for human consumption such as jatropha. In addition, biodiesel exports generate revenues that can be allocated to food imports. In Mexico, bioethanol production reduces food security because it relies on the use of corn, a staple food for many Mexicans. In addition, Mexican ethanol exports rival those of the United States. Therefore, the analysis of the link between food security and biofuels differs depending on how the latter is produced. Chapter 3 considers the important issue of the possible link between biofuel production and rising food prices. Specifically, it analyses the dynamic transmission of world bioethanol price shocks to food prices, in particular corn prices. The local projection method is used to estimate the dynamic responses in each period considered. The results show that

there is a positive response of corn prices to bioethanol price shocks that fade away on average after three years. Furthermore, on average, the asymmetry with respect to the direction of the shocks reveals a net zero effect, suggesting that bioethanol production does not affect food security. However, a disaggregated analysis of the intensity of the impacts reveals significant heterogeneities. Despite numerous programs to eradicate hunger in the world, millions of people still face food insecurity. Chapter 4 aims to test the existence of an unconditional hunger trap and to determine whether biofuel production is among the long-term determinants of food insecurity. The hypothesis of an unconditional hunger trap is tested by calculating the probabilities of transition from a food insecure state using a Markov chain transition matrix and ergodic distribution. Then, estimation of a conditional inference regression tree identifies the main drivers of food insecurity. The results indicate that developing countries are not caught in an unconditional hunger trap. The transition matrix result shows that all countries with high levels of food insecurity have a non-zero probability of moving to a low level within a limited time. Furthermore, given the country characteristics, the results of the conditional inference regression tree show that the most important variable is gross domestic product (GDP) per capita and that biofuel production is not among the long-term determinants of food insecurity. Our results suggest that biofuel production can be a means to combat climate change without penalizing food security.

Keywords : Biofuel production · Food security · Biofuel prices · Maize prices · Hunger trap · Impact assessment · Local projection · Regression tree · Transition matrix

JEL Codes : Q01 · Q11 · Q16 · Q18 · Q41 · Q42

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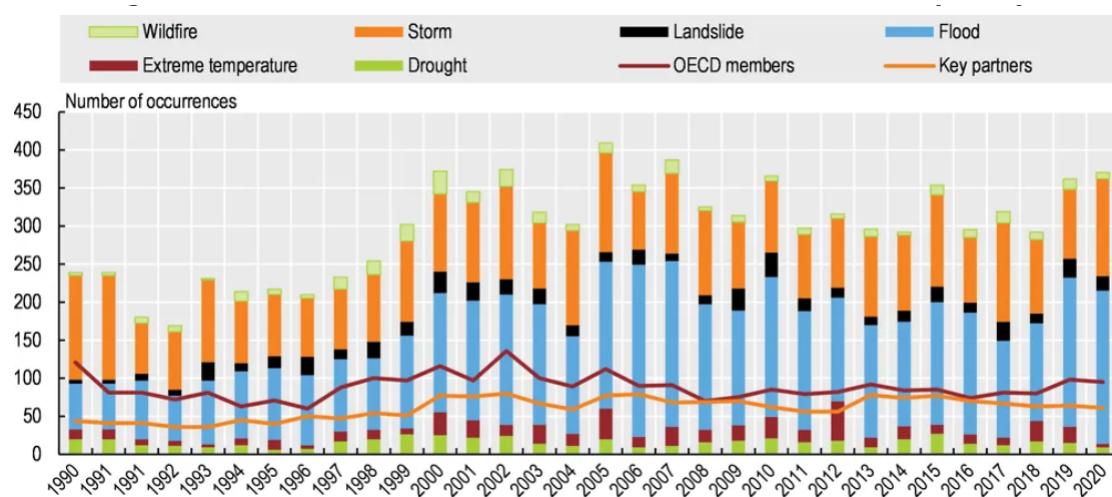
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CHAPTER 1

Introduction: Biocarburants et Sécurité alimentaire

Ces dernières décennies ont été marquées par des événements météorologiques extrêmes. Partout dans le monde, l'occurrence des inondations a augmenté de manière significative au cours des trente dernières années, tout comme les températures extrêmes depuis le début des années 2000. Les sécheresses et les incendies de forêt ont suivi une évolution en dents de scie, tandis que les tempêtes et les glissements de terrain sont restés constants à l'échelle mondiale sur cette période (figure 1.1).



Source : OECD (2021), calculs basés sur les données extraites de EM-DAT, CRED / UCLouvain, Bruxelles, Belgique

Figure 1.1: Fréquence des phénomènes météorologiques extrêmes

Les différents rapports et études indiquent que ces événements météorologiques extrêmes sont des manifestations du changement climatique. Ce dernier émane de l'augmentation des émissions de gaz à effet de serre (GES) provenant des activités humaines, plus précisément des combustibles fossiles (IPCC, 2007; Bernstein et al., 2008; Dodman, 2009; O'Neill et al., 2001).

Selon le dernier rapport du *Working Group II* publié par le groupe d'experts intergouvernemental sur l'évolution du climat (GIEC), si la tendance des émissions se maintient, le réchauffement induit pourrait dépasser les 2°C en 2050 ; et toute hausse supplémentaire, même de dixièmes de degré, augmentera l'intensité et la fréquence des événements extrêmes identifiés (IPCC, 2022). Un réchauffement mondial de 1,5°C entrainera des pics de températures 4,1 fois plus fréquents ; tandis qu'à 2°C, ils le seront 5,6 fois plus (Chow et al., 2022).

Ainsi depuis plusieurs décennies, les conférences annuelles sur le changement climatique cherchent à réduire les émissions de GES et la dépendance aux énergies fossiles. Lors de la dernière conférence à Glasgow - la COP26 - les pays ont réaffirmé l'objectif de l'Accord de Paris, qui consiste à maintenir la température mondiale à un niveau inférieur à 2°C par rapport au niveau préindustriel et à continuer les efforts visant à la limiter à 1,5°C (Falkner, 2016). Partant du constat que les émissions mondiales de GES proviennent principalement des combustibles fossiles, une des solutions proposées afin de limiter ces émissions et la dépendance aux énergies fossiles a été la promotion des énergies renouvelables incluant les biocarburants.

En effet, selon Demirbas (2009), les biocarburants sont une source d'énergie renouvelable. Ils contribuent à la réduction des émissions de GES par rapport aux carburants d'origine fossile (Righelato and Spracklen, 2007; Janda et al., 2012). Comme l'illustre le tableau 1.1, les biocarburants, principalement le biodiesel de jatropha, le diesel de lignocellulose et l'éthanol issu de la canne à sucre permettent de réduire les GES. Par conséquent, ils pourraient répondre à plusieurs questions cruciales telles que la sécurité énergétique et la réduction des émissions de GES, en particulier dans les pays en développement (Rajagopal et al., 2007). De plus, selon le rapport McKinsey (2009), les biocarburants principalement de première génération comptent parmi les solutions les plus profitables car ils sont coût-efficaces. La production de biocarburants assurerait la sécurité des économies en réduisant la dépendance aux combustibles fossiles et en créant des emplois dans une industrie des biocarburants en pleine croissance.

Depuis le début des années 2000, nous assistons à une croissance de la production des énergies renouvelables. Selon les données de l'Administration américaine des Informations sur l'Énergie (AIE), la part de la production mondiale des énergies renouvelables dans l'énergie totale est passée de 8,5% en 2000 à environ 11% en 2019. Parmi ces énergies renouvelables, la part de biocarburants a également augmenté entre 2000 et 2019, passant d'environ 3,8% à 21%.

Biofuel	Emission reductions (%) [*]	Biofuel	Emission reductions (%) [*]
Sugar-cane ethanol	65–105	Palm oil biodiesel	30–75
Wheat ethanol	-5–90	Jatropha biodiesel	40–100
Corn ethanol	-20–55	Soybean biodiesel	52–70
Sugar-beet ethanol	30–60	Lignocellulose diesel	5–120
Rapeseed biodiesel	20–80	Lignocellulose ethanol	45–112 ^a

Source : OECD (2008). *: Les chiffres négatifs signifient une augmentation nette des émissions de GES. a : Il comprend les résidus forestiers, les cultures énergétiques (telles que les rotations courtes d'arbres et le panic raide) et les résidus de culture.

Table 1.1: Réductions des émissions de GES de certains biocarburants

Cependant, en dépit des avantages des biocarburants dans la lutte contre le changement climatique grâce à leur potentiel de réduction des émissions de GES, de nombreux auteurs mettent en avant leurs inconvénients. En effet, la production des biocarburants pourrait avoir des effets négatifs sur la sécurité alimentaire car elle entraînerait une baisse de l'offre et de l'accessibilité alimentaire, ce qui est bien connu dans la littérature économique sous le vocable « nourriture contre biocarburants ». L'objectif de la thèse est de contribuer à ce débat.

Afin d'introduire notre travail, nous définirons, dans la section 6.1, les notions de biocarburants et de sécurité alimentaire. La section 6.2 présentera les déterminants de la sécurité alimentaire et la section 6.3 les effets des biocarburants sur la sécurité alimentaire. Nous présenterons les résultats obtenus dans la thèse dans la section 6.4.

1.1 Biocarburants et Sécurité alimentaire : définitions

Le sujet de cette thèse est d'analyser le lien entre les biocarburants et la sécurité alimentaire. Cette section s'attardera sur la définition des biocarburants et de la sécurité alimentaire.

1.1.1 Biocarburants

Les biocarburants sont des agrocarburants produits directement ou indirectement à partir de la biomasse des matières organiques, notamment les matières végétales et

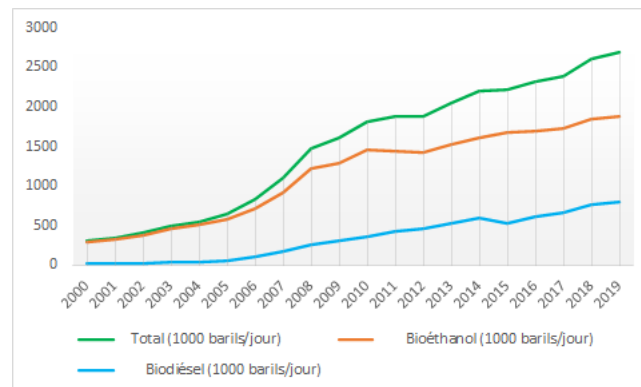
les déchets animaux (Demirbas, 2008; Pathak et al., 2013). Ils peuvent se présenter sous trois principales formes : solide (le bois de chauffage, le charbon de bois, etc.), gazeuse (le biogaz), et liquide (le bioéthanol, le biodiesel, l'huile de pyrolyse, etc.).

En fonction du type de traitement des matières premières, une distinction fondamentale peut être faite entre les biocarburants primaires et secondaires (Nigam and Singh, 2011). Les biocarburants primaires sont le bois de chauffage, les copeaux de bois et les granulés. Ces combustibles sont brûlés directement, généralement pour répondre aux besoins de cuisson, de chauffage ou d'énergie dans des applications industrielles à petite ou grande échelle. Les biocarburants secondaires, quant à eux, se présentent sous la forme de solides, de liquides ou de gaz et peuvent être utilisés dans un plus large éventail d'applications, notamment les transports et les processus industriels à haute température (Nijs, 2014).

Les biocarburants sont classés en deux catégories : les biocarburants conventionnels ou de première génération (les plus utilisés) et les biocarburants avancés qui regroupent les deuxième, troisième et quatrième générations (Janda et al., 2012). Ceux de première génération sont essentiellement produits grâce aux cultures traditionnellement utilisées pour l'alimentation. Les types les plus courants sont le biodiesel et le bioéthanol. Le biodiesel est généralement produit à partir d'huile de ricin, de palme, de soja, de tournesol, de colza ou de jatropha, tandis que le bioéthanol est obtenu à partir de la canne à sucre, du manioc, du blé, du maïs, des pommes de terre ou du sorgho. L'enjeu des biocarburants de deuxième génération est d'utiliser les parties non alimentaires des cultures telles que le bois, la paille, les tiges, les feuilles, les déchets végétaux, ainsi que d'autres cultures qui n'ont pas de destination alimentaire comme le jatropha ou le miscanthus. Les biocarburants de troisième génération, quant à eux, sont obtenus à partir d'algues. Ceux de quatrième génération sont très expérimentaux et n'ont pas encore été clairement définis. Toutefois, certaines technologies de quatrième génération regroupent la décomposition des biocarburants à haute température, les réactions de photosynthèse artificielle et la modification génétique d'organismes pour qu'ils sécrètent des hydrocarbures.

Selon les données de l'AIE des États-Unis et comme l'illustre la figure 1.2, entre 2000 et 2019 la production de biocarburants de première génération a augmenté, passant d'environ 315.000 barils par jour en 2000 à une production estimée à 2.690.000 barils par jour en 2019 avec un taux de croissance annuel moyen de 12,4%.

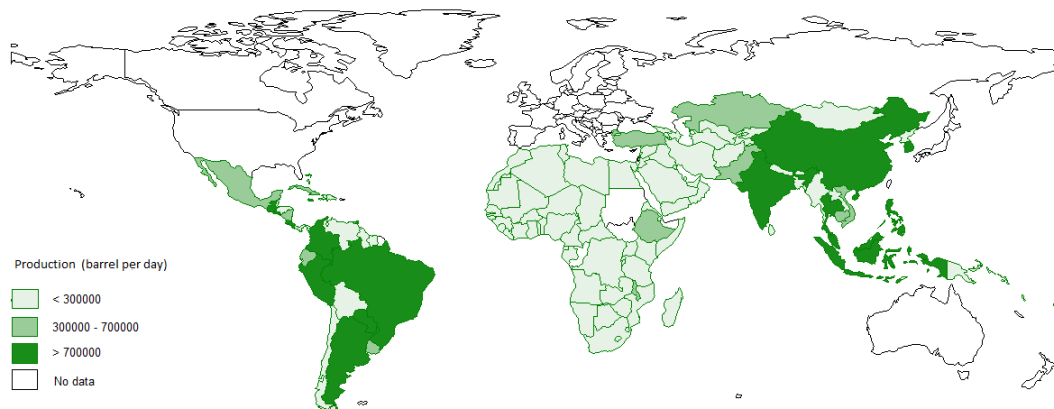
Cette croissance est principalement due à la production des États-Unis, considérés comme le principal producteur de biocarburants au monde avec une production



Source : Données de l'AIE

Figure 1.2: Production mondiale des biocarburants (1000 barils/jour)

moyenne estimée à 690.000 barils/jour entre 2000 et 2019. En 2019, sa production de bioéthanol s'élevait à 1.029.000 barils/jour de bioéthanol et 112.000 bbl/jour de biodiésel. Après les États-Unis, le deuxième plus grand producteur de biocarburants au monde est le Brésil. Ses productions de bioéthanol et de biodiesel étaient respectivement de 540.000 barils/jour et 99.000 barils/jour en 2019. Certains pays comme l'Allemagne, la France, le Canada, l'Indonésie sont également classés parmi les principaux producteurs de biocarburants. Les plus gros producteurs sont donc les pays développés ou en développement, comme le Brésil et l'Indonésie. La carte ci-dessous (figure 1.3) présente les pays en développement producteurs des biocarburants. On note que les pays d'Amérique Latine et d'Asie sont de grands producteurs, les pays d'Afrique, quant à eux, ont une production relativement faible



Source : Données de l'AIE

Figure 1.3: Production des biocarburants dans les pays en développement en 2017 (barils par jour)

1.1.2 Sécurité alimentaire

Lors de la Conférence mondiale de l'alimentation de 1974, la sécurité alimentaire était largement considérée comme un problème de production alimentaire insuffisante et instable (Lang and Barling, 2012; Weiss and Jordan, 1976). En effet, dans les années 1970, le débat sur la sécurité alimentaire portait principalement sur la capacité collective des nations du monde à produire suffisamment d'aliments pour nourrir une population en expansion (Stringer and Anderson, 2000).

En 1996, le Sommet Mondial de l'alimentation propose la définition suivante de la sécurité alimentaire "la sécurité alimentaire existe lorsque toutes les personnes, à tout moment, ont un accès physique et économique à une nourriture suffisante, saine et nutritive qui répond à leurs besoins et à leurs préférences alimentaires pour mener une vie active et saine".

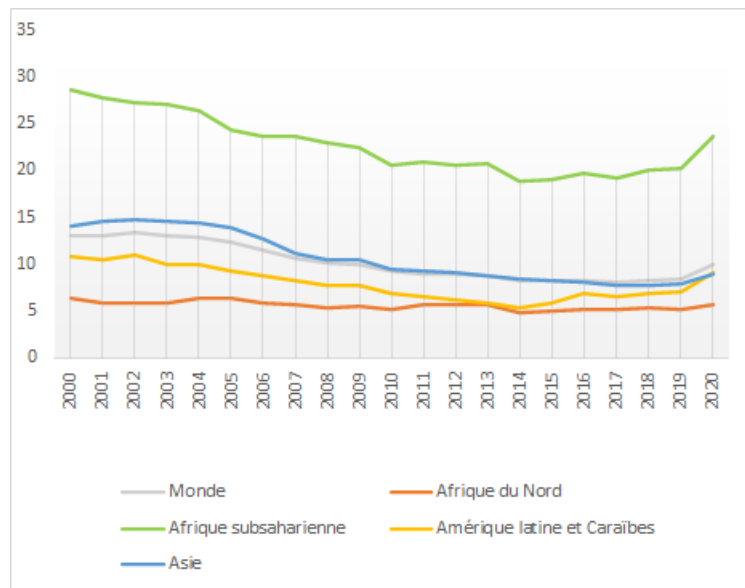
La sécurité alimentaire est un concept large, comprenant quatre dimensions qui sont l'accès, la disponibilité, la stabilité et l'utilisation (Barrett, 2002). Selon Roy et al. (2006), l'accès à la nourriture peut être décrit comme la capacité ou le droit d'un individu à accéder à des ressources adéquates, pour acquérir des aliments appropriés. Les droits sont identifiés comme l'ensemble de toutes les commodités sur lesquelles une personne peut établir un choix étant donné les dispositions légales, politiques, économiques et sociales de la communauté dans laquelle elle vit. La disponibilité alimentaire prend en compte la quantité et la qualité appropriées de nourriture fournie par la production nationale ou les importations, y compris l'aide alimentaire. Pangaribowo et al. (2013) définissent cette dimension comme la quantité de nourriture qui est et sera physiquement disponible pour une population pendant une certaine période ce qui est très probablement liée à la production et à la disponibilité du marché. L'utilisation fait référence à l'aspect sanitaire et fait ressortir l'importance des intrants non alimentaires dans la sécurité alimentaire. Cette dimension se rapporte donc à un régime alimentaire adéquat, une eau propre, de l'assainissement et des soins de santé pour atteindre un état de bien-être nutritionnel où tous les besoins physiologiques sont satisfaits. La stabilité alimentaire renvoie à la capacité d'obtenir de la nourriture au fil du temps, quels que soient les chocs soudains ou événements cycliques. Elle considère ainsi les dimensions de disponibilité et d'accessibilité précédemment définies.

Alors que la sécurité alimentaire fait référence à un accès adéquat à une quantité suffisante de nourriture à tout moment, l'insécurité alimentaire mesure principalement la faim. Par conséquent, la faim peut être liée à l'une ou à toutes les dimensions

de la sécurité alimentaire. Selon [Sen \(1981\)](#), nous pouvons distinguer l'insécurité alimentaire chronique et l'insécurité alimentaire transitoire. L'insécurité alimentaire chronique est associée à des problèmes de pauvreté continue ou structurelle et à de faibles revenus. L'insécurité alimentaire transitoire, quant à elle, implique des périodes d'intensification de la pression sur les denrées alimentaires causée par des catastrophes naturelles, un effondrement économique ou un conflit. Pour [Barrett \(2002\)](#), l'insécurité alimentaire transitoire se subdivise en trois catégories : l'insécurité alimentaire périodique, régulière et conjoncturelle. Un exemple d'insécurité alimentaire périodique est le cycle saisonnier typique de l'agriculture à faible revenu. L'insécurité alimentaire régulière est causée par des événements répétitifs et/ou quasi-périodiques. Enfin, l'insécurité alimentaire conjoncturelle est due à la conjonction d'une insécurité alimentaire périodique ou régulière avec des catastrophes irrégulières telles que les troubles civils et les guerres.

L'insécurité alimentaire se mesure en général en fonction de la disponibilité et de la consommation apparente des aliments de base ou de l'apport énergétique lorsque nous voulons établir un lien entre la faim et la sous-nutrition ([Clay, 2002](#)). Cette mesure correspond aux anciennes définitions plus étroites de l'insécurité alimentaire ([Jarosz, 2011](#)). Des études ([Wiesmann, 2004](#)) font référence à l'indice de la faim dans le monde comme mesure de l'insécurité alimentaire. Bien que les données soient peu disponibles, cet indice semble être l'un des meilleurs indicateurs de mesure de l'insécurité alimentaire car il permet de surveiller la faim dans le monde par pays et par région. Par ailleurs, d'autres indicateurs permettent également d'évaluer le niveau d'insécurité alimentaire à travers une estimation du nombre de personnes affectées. Il s'agit, entre autres, du nombre de personnes sous-alimentées et de la prévalence de la sous-alimentation. Cette dernière indique le pourcentage de personnes sous-alimentées dans la population totale.

La figure [1.4](#) donne un aperçu de l'évolution de la prévalence de la sous-alimentation au cours des 20 dernières années. Nous constatons que la prévalence de la sous-alimentation a connu une baisse entre 2000 et 2019 suivie d'une hausse entre 2019 et 2020. Cette hausse peut être attribuée à la pandémie de la covid-19 qui a eu des effets négatifs sur la sécurité alimentaire dans le monde. De même, nous constatons que la sous-alimentation reste l'un des problèmes majeurs principalement en Afrique subsaharienne qui affiche les valeurs les plus élevées. Ces niveaux de sécurité alimentaire enregistrés par région peuvent être imputés à de nombreux facteurs que nous examinons dans la section suivante.



Source : Données de la FAO

Figure 1.4: Prévalence de la sous-alimentation (% de la population)

1.2 Les déterminants de la sécurité alimentaire

La sécurité alimentaire est considérée comme l'un des enjeux majeurs du monde actuel. Elle est indispensable pour que tous les individus puissent être en santé et développer leur plein potentiel. Plusieurs études ont été réalisées afin d'identifier les déterminants de la sécurité alimentaire (Barrett, 2002, 2010; Pinstrup-Andersen, 2009). Ces facteurs incluent entre autres les caractéristiques socio-économiques, l'environnement naturel, la qualité des institutions et les conflits ainsi que les politiques sectorielles.

1.2.1 Les caractéristiques socio-économiques

Selon Timmer (2004), la faim est liée à la pauvreté car les personnes vivant dans l'indigence sont souvent confrontées à l'insécurité alimentaire. Par conséquent, à l'échelle macroéconomique, plus il y a de croissance économique et une bonne redistribution des richesses, moins il y a d'insécurité alimentaire. En effet, parmi les approches pour assurer la sécurité alimentaire, la première est le taux et la répartition de la croissance économique, également appelée croissance pro-pauvre. Cela peut favoriser la création d'emplois et l'augmentation des revenus de la population. Ainsi, une croissance économique durable peut contribuer à faire reculer la famine et la sous-alimentation, principalement dans les pays en développement (Manap and

Ismail, 2019).

En plus de la croissance économique, la structure démographique fait également partie des déterminants de la sécurité alimentaire (Bremner, 2012). En effet, la plupart des pays qui comptent le plus grand nombre de personnes sous-alimentées ont également des taux de fécondité et une croissance démographique élevés. La croissance démographique implique une augmentation considérable de la quantité d'aliments nécessaires pour nourrir convenablement la population. Par conséquent, la pression démographique peut compromettre à la fois la disponibilité et l'accès à la nourriture (Jenkins and Scanlan, 2001; Tilman et al., 2001; Senauer and Sur, 2001). Cependant, plus la population est jeune, plus elle peut avoir un effet bénéfique sur la sécurité alimentaire car un capital humain important peut contribuer aux activités productives, notamment du secteur agricole.

1.2.2 L'environnement naturel

Le changement climatique représente une menace importante pour la sécurité alimentaire. Selon Molotoks et al. (2021), il est l'une des principales causes de l'augmentation de la faim dans le monde et des graves crises alimentaires. Le réchauffement de la planète contribue à augmenter la fréquence des événements extrêmes, mais aussi à diminuer la qualité des terres et la disponibilité des ressources en eau dans certaines régions (Harvey, 2011). Les événements extrêmes tels que la sécheresse ou les inondations ont un impact négatif sur les quatre dimensions de la sécurité alimentaire (FAO et al., 2018), et notamment sur la disponibilité et l'accessibilité alimentaire en raison de la diminution du rendement des cultures (Wheeler and Von Braun, 2013). Par ailleurs, les régions ne sont pas exposées de la même façon. Par exemple, Barrios et al. (2008) montrent que les changements climatiques survenus depuis les années 1960 peuvent expliquer une part importante de l'écart de production agricole entre l'Afrique Sub-saharienne et le reste du monde en développement.

1.2.3 Qualité institutionnelle et conflits

Les conflits et événements armés contribuent à accroître l'insécurité alimentaire en raison de la baisse de la production et de l'offre alimentaire. Les conflits sont également un facteur clé des crises alimentaires graves, comme la famine (Bode, 2018; Martin-Shields and Stojetz, 2019). En effet, sur les 144 millions d'enfants souffrant d'un retard de croissance, 85% vivent dans des pays touchés par des conflits. La

faim et la malnutrition sont bien pires lorsque les conflits se prolongent et que les institutions sont faibles.

En effet, en plus des troubles civils, la qualité institutionnelle des pays peut affecter la sécurité alimentaire. La corruption, l'instabilité gouvernementale et les tensions religieuses pourraient éroder la sécurité alimentaire en réduisant, entre autres, la production et l'accès alimentaire ([Barrett, 2013](#); [Önder, 2021](#)).

1.2.4 Les politiques sectorielles

Les politiques agricoles peuvent avoir un impact direct sur la disponibilité alimentaire intérieure par leur effet sur la production alimentaire. Elles agissent également par le biais des marchés des facteurs, des intrants et des produits, qui déterminent les niveaux, la répartition géographique et temporelle de la production, du stockage et de la transformation ([Magrini et al., 2017](#)).

En plus des politiques agricoles, le commerce international affecte également la sécurité alimentaire, mais son effet global n'est pas clair. En effet, l'intégration des marchés a un impact positif sur la sécurité alimentaire car elle contribuerait à assurer un équilibre entre les pays déficitaires et ceux excédentaires en denrées alimentaires ([World Bank, 2020](#)). De même, l'ouverture commerciale réduit la variabilité de l'offre d'aliments de base en aidant à compenser les chocs négatifs comme des sécheresses sur l'offre domestique. Toutefois, il faut noter que la libéralisation des échanges pourrait exacerber cette variabilité des quantités de denrées alimentaires en présence d'un marché mondial moins stable. En effet, la volatilité des prix alimentaires qui en résulte peut négativement affecter la disponibilité alimentaire ([Asche et al., 2015](#); [Kang, 2015](#)).

Outre les déterminants cités ci-dessus, la sécurité alimentaire peut aussi être affectée par l'adoption et la production des énergies renouvelables tels les biocarburants. En effet, nombreuses sont les études analysant les effets positifs et négatifs des biocarburants sur la sécurité alimentaire.

1.3 Impacts des biocarburants sur la sécurité alimentaire

La demande de biocarburants de première génération augmente en raison de nombreux facteurs tels que les besoins énergétiques croissants liés à l'augmentation de

la population, l'augmentation du prix du pétrole, la recherche de sources d'énergie décarbonées et renouvelables, et le désir d'augmenter les revenus agricoles dans les pays développés (Afiff et al., 2013). Cependant, la production de biocarburants peut avoir divers impacts sur la sécurité alimentaire (Gasparatos et al., 2015). Les effets peuvent provenir directement de la production ou indirectement des politiques de soutien aux biocarburants.

1.3.1 Effets liés à la production des biocarburants

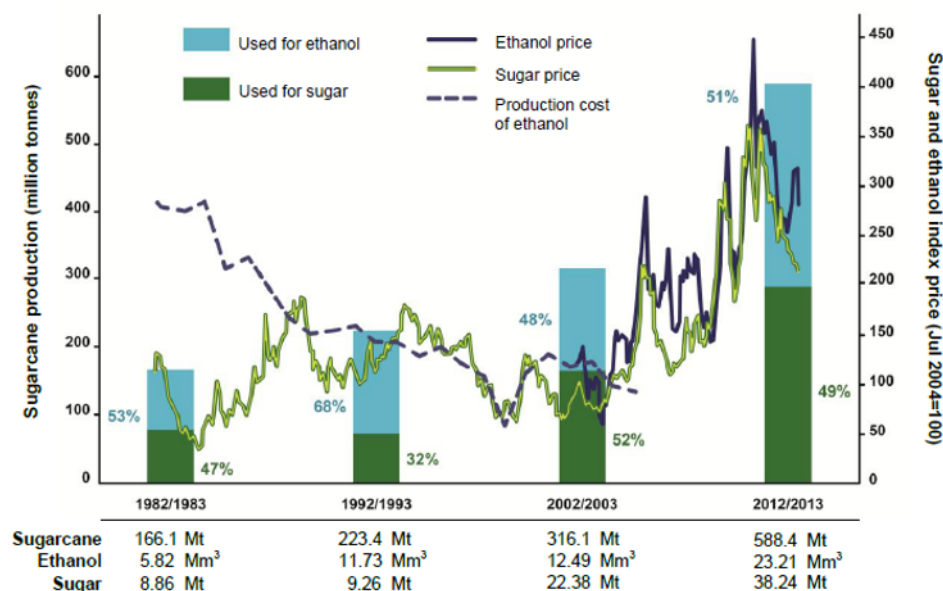
L'un des effets négatifs de la production des biocarburants sur la sécurité alimentaire résulte de l'utilisation de certaines denrées alimentaires comme matières premières. En effet, l'utilisation des denrées tels le maïs, la canne à sucre ou l'huile de palme peut contribuer à une diminution de leur disponibilité pour la consommation humaine. Dans la mesure où la baisse de la consommation de ces denrées affectera principalement des personnes pauvres et vulnérables, la production des biocarburants augmentera la faim et la malnutrition. Cette situation pourrait également favoriser l'accroissement des prix.

Rajagopal et al. (2007) et Zilberman et al. (2013b) montrent que l'introduction des biocarburants a été responsable d'un quart de l'inflation des prix alimentaires dans le monde en 2007 et 2008. Se focalisant sur la production de bioéthanol à partir de la canne à sucre, la figure 1.5 nous donne, d'une part, l'évolution de la production de canne à sucre et du bioéthanol, et, d'autre part, les indices de prix associés au sucre et au bioéthanol. Il apparaît que de 1983 à 2013, plus la part de canne à sucre associée à la production d'éthanol était importante, plus le prix du sucre augmentait. La sécurité alimentaire peut donc être mise en péril principalement dans les pays en développement importateurs nets de denrées alimentaires (Chauvin et al., 2012).

Dans la plupart de ces pays en développement, le taux de pauvreté est très élevé. Étant donné que les pauvres consacrent environ deux tiers de leurs revenus à l'alimentation, une variation à la hausse des prix des aliments impliquerait une variation de leur revenu réel et donc de l'accessibilité à ces aliments. Dans de nombreux pays d'Amérique latine, les hausses de prix de 2007-2008 ont entraîné des réductions significatives de l'apport calorique, tant au niveau national qu'au niveau des ménages, principalement pour les enfants de moins de deux ans des ménages pauvres (Robles et al., 2010). En outre, le sens de l'évolution du revenu réel dépend de la position commerciale du ménage. D'une part, les vendeurs nets de denrées alimentaires bénéficieraient des hausses de prix, tandis que les acheteurs

nets verraient leur revenu réel diminuer à court terme. D'autre part, des prix alimentaires bas peuvent négativement affecter les vendeurs ou les producteurs de denrées alimentaires. C'est l'essence même du dilemme des prix alimentaires (Timmer et al., 1983).

Par ailleurs, certaines études montrent que la production de biocarburants induit un changement direct ou indirect de l'utilisation des terres. Les terres supplémentaires nécessaires à la production de biocarburants s'étendent vers les zones forestières entraînant une déforestation (de Carvalho et al., 2015; Choumert et al., 2017).



Source : MAPA (2013) pour la production de canne à sucre, d'éthanol et de sucre ; Meyer et al. (2012) pour les coûts de production de l'éthanol, sur la base de Goldemberg (2007). Le prix mondial du sucre est une approximation très proche du prix du sucre brésilien disponible sur www.cepea.esalq.usp.br. Mt = Million de tonnes, Mm3 = Million de mètres cubes

Figure 1.5: Brésil : production de canne à sucre et du bioéthanol, et indice du prix du sucre et du bioéthanol

Cependant, selon Ewing and Msangi (2009), il existe des possibilités pour que la production de biocarburants crée des emplois et augmente localement l'offre d'énergie, fournisse des avantages aux personnes vulnérables tout en améliorant la sécurité alimentaire. En effet, la chaîne de production du bioéthanol est plus intensive en main-d'œuvre que la chaîne de production du pétrole, ce qui peut favoriser l'emploi et l'amélioration des revenus dans les zones rurales. Ceci est cohérent avec l'idée que l'expansion des biocarburants peut générer des revenus supplémentaires dans le secteur agricole. En Ethiopie, la production de ricin pour les biocarburants a permis aux agriculteurs d'améliorer leur sécurité alimentaire. En effet, la vente des graines de ricin a contribué à générer des revenus aux agriculteurs leur permettant par la

suite d'acheter et de stocker des denrées alimentaires (Negash and Swinnen, 2013).

De même, les programmes de production des biocarburants favoriseraient également les sources d'énergie alternatives pour les usages domestiques et contribueraient à améliorer la productivité et les revenus des femmes. Un exemple de l'impact des biocarburants sur les revenus des femmes a été observé en Inde. À l'initiative de l'Institut international de recherche sur les cultures des zones tropicales semi-arides (ICRISAT) en 2007, un projet d'huile de pongamia mené par des femmes a été mis en œuvre pour faire fonctionner de petits générateurs produisant de l'électricité. Ce projet a également permis aux femmes d'être plus indépendantes financièrement.

Ainsi, le développement responsable et durable des biocarburants peut contribuer à améliorer le développement rural, à réduire la pauvreté dans de nombreux pays en développement tout en améliorant la sécurité alimentaire (Arndt et al., 2012).

1.3.2 Effets liés aux politiques de soutien aux biocarburants

Les politiques de soutien aux biocarburants visent à promouvoir l'utilisation de carburants issus de la biomasse et d'autres carburants renouvelables dans les transports. Les crédits d'impôts, exonérations fiscales, mandats de mélange ou d'utilisation et les restrictions commerciales sont considérés comme les mécanismes les plus courants expliquant l'expansion des biocarburants (Blanco Fonseca et al., 2010; Sorda et al., 2010). Ces politiques tendent à stabiliser les prix des biocarburants car elles induisent un certain niveau de consommation et de production (Beckman et al., 2015).

Selon Durham et al. (2012), ces politiques visant à promouvoir la production de biocarburants ont pour effet d'augmenter le prix de certains produits agricoles de base. La conséquence est une réduction de la consommation et du bien-être nutritionnel des consommateurs (Afiff et al., 2013). Toutefois, Choumert et al. (2018) à travers une méta-analyse de la littérature sur les modèles d'équilibre général calculable, ont constaté que les politiques de soutien aux biocarburants généraient des impacts significatifs sur le produit intérieur brut (PIB) et les revenus des ménages.

Enciso et al. (2016) notent que la suppression des politiques de soutien aux biocarburants aurait un effet significatif sur la variabilité des prix des biocarburants, mais seulement un impact marginal sur la variabilité des prix des produits agricoles de base. Sans politique en matière de biocarburants, la demande mondiale de biocarburants diminuerait de 25% pour le bioéthanol et de 32% pour le biodiesel. Toutefois, les prix ne diminueraient que modérément pour les produits de base du bioéthanol, comme le blé et les céréales secondaires, tandis que les prix des produits

de base du biodiesel, notamment des huiles végétales, seraient plus affectés.

Par conséquent, la baisse des prix et la diminution de l'utilisation des cultures à des fins de production de biocarburants pourraient se traduire par une alimentation plus abordable pour la population et par un renforcement de la sécurité alimentaire. Cependant, l'abolition des politiques en matière de biocarburants ne conduirait pas nécessairement à une augmentation de la sécurité alimentaire mondiale. En effet, les cultures pourraient être réaffectées à des utilisations concurrentes telles que l'alimentation animale ou des usages industriels.

1.4 Contribution de la thèse

Cette thèse contribue à la littérature sur le dilemme "nourriture contre carburant" en étudiant l'impact de la production des biocarburants sur la sécurité alimentaire. Elle concentre son analyse sur les effets attendus à court et long terme, et propose des solutions qui permettraient de favoriser à la fois la production des biocarburants et la sécurité alimentaire. Elle se focalise sur les impacts des biocarburants sur la disponibilité alimentaire, les prix des denrées alimentaires, le déficit alimentaire, et vérifie si la production des biocarburants fait partie des principaux déterminants de long terme de l'insécurité alimentaire.

Plus spécifiquement, le chapitre 2 considère les effets de la production de biocarburants sur la sécurité alimentaire. L'analyse porte sur l'Indonésie et le Mexique et utilise la méthode de contrôle synthétique. L'Indonésie est l'un des grands producteurs mondiaux de biodiesel, tandis que le Mexique est spécialisé dans le maïs et l'éthanol. Les résultats montrent que la production de biodiesel affecte positivement la sécurité alimentaire grâce à une augmentation de la consommation énergétique quotidienne par habitant et de la production alimentaire. Toutefois, l'effet inverse est obtenu pour le bioéthanol. Ces résultats peuvent s'expliquer de la façon suivante. La production de biodiesel en Indonésie utilise des matières premières qui n'entrent pas dans la consommation humaine comme le jatropha. Par ailleurs, les exportations de biodiesel génèrent des revenus qui peuvent être alloués aux importations alimentaires. Au Mexique, la production de bioéthanol réduit la sécurité alimentaire parce qu'elle repose sur l'utilisation de maïs, aliment de base de nombreux Mexicains. En outre, les exportations mexicaines d'éthanol rivalisent avec celles des États-Unis. Par conséquent, l'analyse du lien entre sécurité alimentaire et biocarburants diffère selon les modalités de production de ces derniers.

Le chapitre 3 considère la question importante du possible lien entre la production de biocarburants et l'augmentation des prix des denrées alimentaires. Plus précisément, il analyse la transmission dynamique des chocs des prix mondiaux du bioéthanol aux prix alimentaires, en particulier les prix du maïs. La méthode des projections locales permet d'estimer les réponses dynamiques à chaque période prise en considération. Les résultats montrent qu'il y a une réponse positive des prix du maïs aux chocs de prix du bioéthanol qui s'estompent en moyenne au bout de trois ans. Par ailleurs, en moyenne, l'asymétrie par rapport à la direction des chocs révèle un effet net nul, suggérant que la production du bioéthanol n'affecte pas la sécurité alimentaire. Cependant, une analyse désagrégée de l'intensité des impacts révèle une hétérogénéité importante.

En dépit des nombreux programmes visant à éradiquer la faim dans le monde, des millions de personnes font encore face à l'insécurité alimentaire. Le chapitre 4 vise à tester l'existence d'une trappe inconditionnelle de la faim et à déterminer si la production de biocarburants fait partie des déterminants de long terme de l'insécurité alimentaire. Le calcul des probabilités de passage d'un état d'insécurité alimentaire à l'aide de la matrice de transition de Markov et la distribution ergodique servent à tester l'hypothèse d'une trappe inconditionnelle de la faim. Ensuite, l'estimation d'un arbre de régression d'inférence conditionnelle permet d'identifier les principaux moteurs de l'insécurité alimentaire. Les résultats indiquent que les pays en développement ne sont pas pris dans une trappe inconditionnelle de la faim. Le résultat de la matrice de transition montre que tous les pays ayant des niveaux élevés d'insécurité alimentaire ont une probabilité non nulle de passer à un niveau faible dans un temps limité. De plus, compte tenu des caractéristiques des pays, les résultats de l'arbre de régression d'inférence conditionnelle montrent que la variable la plus importante est le PIB par habitant et que la production de biocarburants ne fait pas partie des déterminants de long terme de l'insécurité alimentaire. Nos résultats suggèrent que la production de biocarburants peut être un moyen de lutte contre le changement climatique sans pénaliser la sécurité alimentaire.

CHAPTER 2

Biofuels and food security: evidence from Indonesia and Mexico

This chapter is joint work with Mohamed Boly (The World Bank) and has been published in Energy Policy.

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.

Keywords : Food security · Biofuels · Impact assessment

2.1 Introduction

Fossil fuels account for about 80% of global energy consumption, 57% of which is due to the transport sector (Publishing et al., 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 2013¹. 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 increase government revenue, which supports public spending and improves food security.

¹FAO database

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 2.3 presents our data and the empirical method we use to answer the research questions posed in this study. Section 2.4 presents the main results of our analysis. Section 2.5 shows the findings of the robustness check before concluding in Section 2.6.

2.2 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.

2.2.1 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% to 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).

2.2.2 Indonesian context

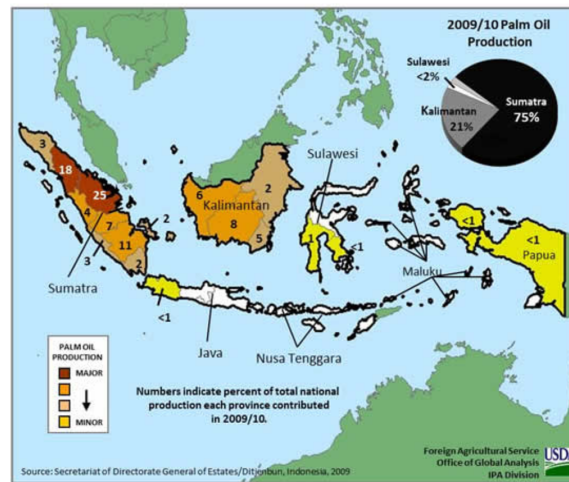
Indonesia is a Southeast Asian country consisting of 17,504 tropical islands with over 20 million hectares of arable land. It is the leading CPO producer globally (McCarthy et al., 2012), providing around half of the world's palm oil (Colbran and Eide, 2008). To stay the largest CPO producer, in 2008, 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 Figure 2.1 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 hectares, Papua more than 40,000 hectares, and Java, primarily Jakarta, more than 20,000 hectares. This contributed to increasing palm oil production, as we can see in figure 2.12, 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 six hours per day (Sumatra and Kalimantan), is suitable for palm oil production. Moreover, these lands are also suitable for producing other crops.



Source: USDA, Foreign Agricultural Service, Commodities Intelligence Report

Figure 2.1: Main areas of palm oil and biofuel production in Indonesia

Indonesian biofuel is mainly constituted by biodiesel. As shown in Figure 2.2, 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 \$1,250. The levy on palm oil exports is a tax collected 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

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

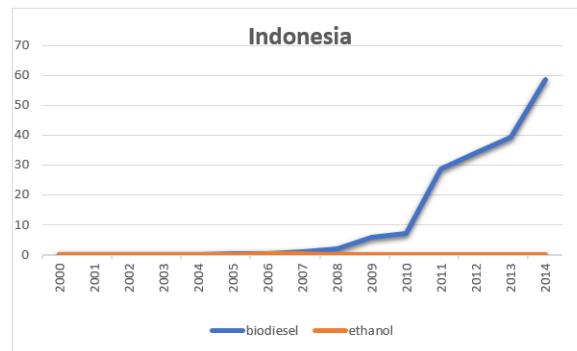


Figure 2.2: Indonesia biofuel production in 1000 barrels/day

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 CO_2 emissions per year.

2.2.3 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 Figure 2.3.

Because it is one of the largest maize producers, its bioethanol is mostly based on maize. As shown in Figure 2.4, 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

³FAO database.

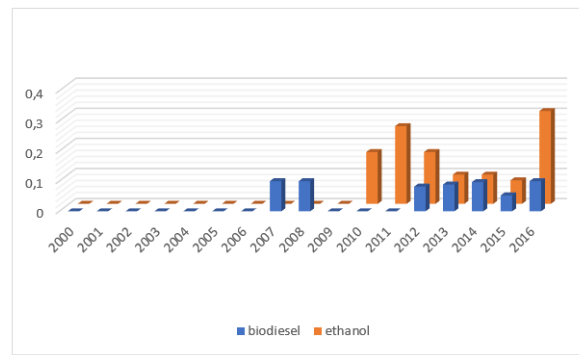
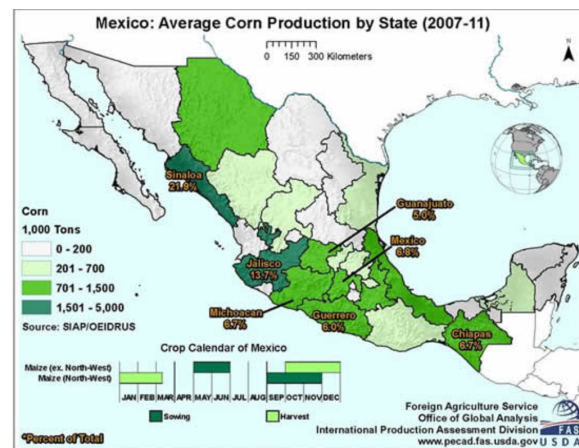


Figure 2.3: Mexico biofuel production in 1000 barrels/day



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

Figure 2.4: Main areas of maize and biofuel production in Mexico

on the international market. Indeed, in 2007, Mexico enacted a law to promote bioenergy development, but not legislation to 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).

2.3 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 method sheds light on the similarities between the treated country and its synthetic control regarding preintervention outcomes and other predictors of postintervention 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.

2.3.1 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 Mexico⁴ 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

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

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

$$\lambda_{it} = Y_{it}^B - Y_{it}^N \quad (2.1)$$

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

$$Y_{it} = Y_{it}^N + \lambda_{it}B_{it} \quad (2.2)$$

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:

$$Y_{it}^N = \alpha_t + \beta_t X_{it} + \delta_t \mu_i + \varepsilon_{it} \quad (2.3)$$

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} .

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, \hat{W} that minimizes the size of this difference or the vector \hat{W} that minimizes the distance:

$$\|Z_1 - Z_0W\|$$

The outcome value for each synthetic control indexed by W is

$$\sum_{p=2}^{P+1} w_p Y_{pt} = \alpha_t + \beta_t \sum_{p=2}^{P+1} w_p X_p + \delta_t \sum_{p=2}^{P+1} w_p \mu_p + \sum_{p=2}^{P+1} w_j \varepsilon_{it} \quad (2.4)$$

with $0 \leq w_p \leq 1$.

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

$$\begin{aligned} \sum_{p=2}^{P+1} \hat{w}_p Y_{p1} = Y_{11}, & \quad \sum_{p=2}^{P+1} \hat{w}_p Y_{p2} = Y_{12} \quad , \dots, \\ \sum_{p=2}^{P+1} \hat{w}_p Y_{pT_0} = Y_{1T_0}, & \quad \text{and} \quad \sum_{p=2}^{P+1} \hat{w}_p X_p = X_1 \end{aligned} \quad (2.5)$$

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 2.5 is found exactly in the data. Therefore, the synthetic control region is selected so that Equation 2.5

⁵For this country, $p = 1$.

holds approximately. Thus, a synthetic control such as

$$\sum_{p=2}^{P+1} \hat{w}_p X_p = X_1 \quad \text{and} \quad \sum_{p=2}^{P+1} \hat{w}_p \mu_p = \mu_1 \quad (2.6)$$

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.

2.3.2 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.

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](#)).

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 [Esmaeili and Shokoohi \(2011\)](#). The food production index also enables us to measure human carrying capacity values, defined

⁶One barrel is equivalent to 159 liters.

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.

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 (2000a), 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 2.1 provides the descriptive statistics of all the variables.

Table 2.1: 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
GDP 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 Celsius)	378	22.38	6.92	-0.69	29.24
Biofuel (thousand barrels per day)	378	0.37	3.60	0	48.25

2.4 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.

2.4.1 The case of Indonesia

Table 2.2 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 2.6 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 2.9) 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).

Tables 2.3 and 2.7 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.

Figure 2.5 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

⁷Such 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 2.2: 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		

Table 2.3: 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

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 country's biodiesel competitiveness in the international market ([McCarthy et al., 2012](#)); indeed, in 2013, it exported 1,942

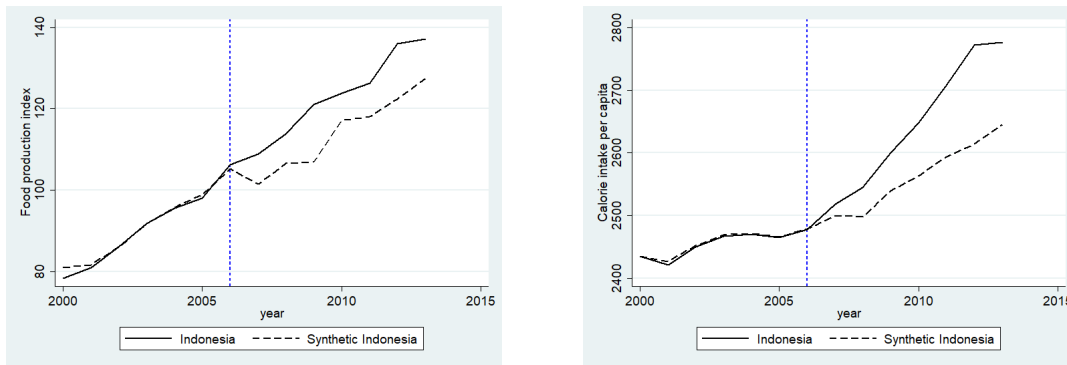


Figure 2.5: Trends in food security: Indonesia vs. synthetic Indonesia

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 2.11 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.

2.4.2 The case of Mexico

Table 2.4 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 2.9, 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 2.8, Albania, Gabon, Morocco, and Tunisia provide a good synthetic Mexico.

Table 2.4: 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		

We test the trustworthiness of the counterfactual. As shown in Table 2.5 and 2.9, 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 Figure 2.6, 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 (Figure 2.3). 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

Table 2.5: 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

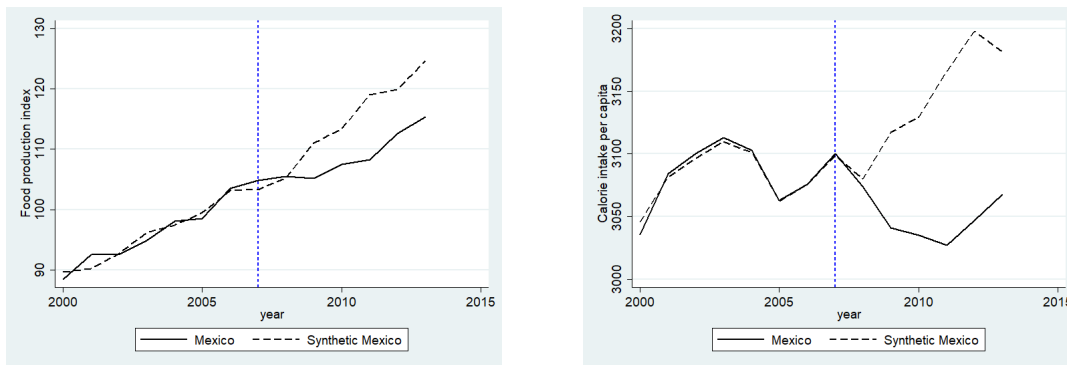


Figure 2.6: Trends in food security: Mexico vs. synthetic Mexico

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 increases and declines since 2007 (the year of biofuel adoption) (see figure 2.11). 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 2.13), which increased maize import cost for Mexico ⁸ 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,

⁸Mexico 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.

and explains in part the increase in maize imports, and therefore a decline in profits for local producers and food insecurity.

2.5 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 pool⁹.

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:

$$t_i^{ratio} = \frac{\frac{1}{T-T_0} \sum_{t=T_0+1}^T [Y_{it} - \sum_{i \neq j} \hat{w}_i^j Y_{jt}]^2}{\frac{1}{T_0} \sum_{t=1}^{T_0} [Y_{it} - \sum_{i \neq j} \hat{w}_i^j Y_{jt}]^2} \quad (2.7)$$

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

2.5.1 Placebo test for Indonesia

Figure 2.7 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 ($1/26 \approx 0.038$).

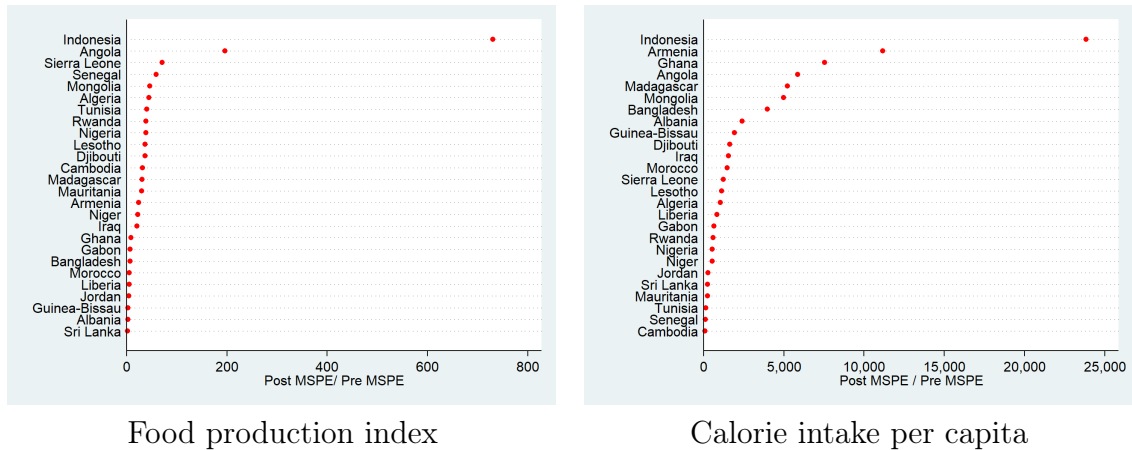


Figure 2.7: Placebo test for Indonesia

2.5.2 Placebo test for Mexico

Figure 2.8 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 ($1/26 \approx 0.038$).

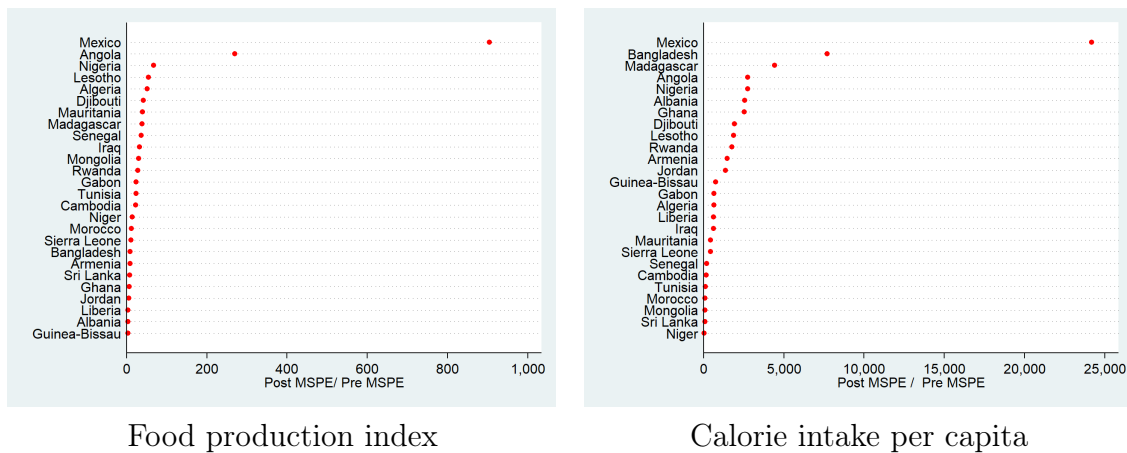


Figure 2.8: Placebo test for Mexico

2.6 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 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.

2.7 Appendices of Chapter 2

Table 2.6: 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 2.7: 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 2.8: 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 2.9: 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

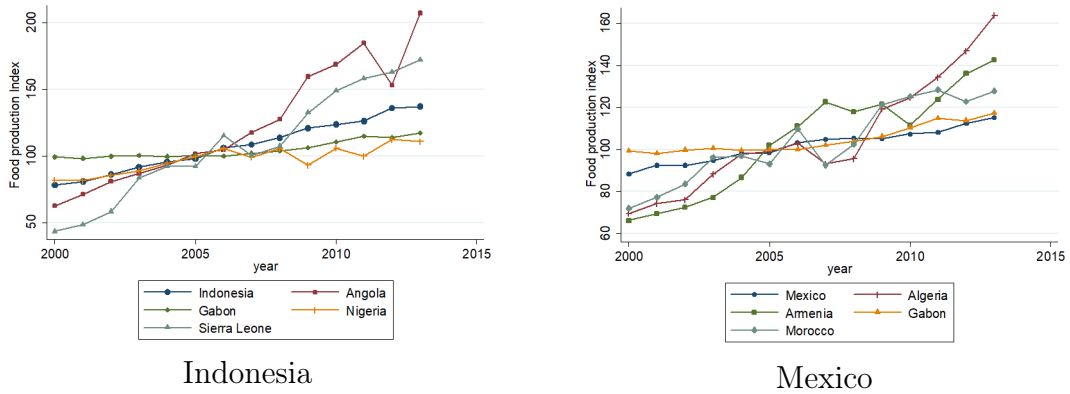


Figure 2.9: Food production index for Indonesia, Mexico and countries entering in their synthetic construction

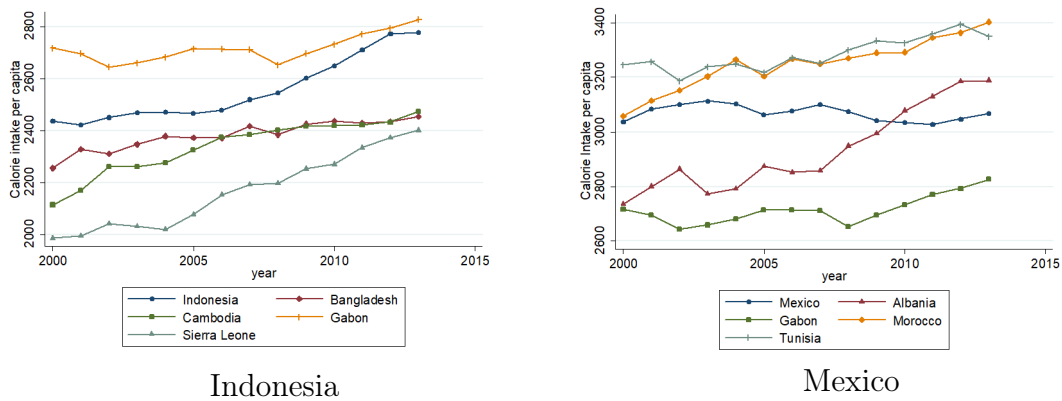


Figure 2.10: Calorie intake per capita for Indonesia, Mexico and countries entering in their synthetic construction

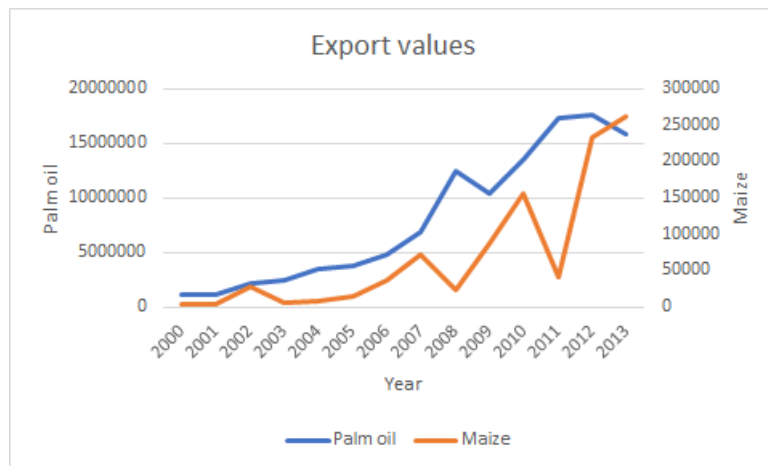


Figure 2.11: Export values (1000\$) of Indonesian palm oil and Mexican maize



Figure 2.12: Palm oil quantity and price



Figure 2.13: Maize quantity and price

CHAPTER 3

Dynamic bioethanol price pass-through : implication for food security

This chapter is joint work with Mohamed Boly (The World Bank).

This paper analyzes the pass-through dynamics of world bioethanol price shocks to food prices, particularly maize prices, for a set of developing and developed countries, over the period 2000-2014. Using local projections, a method robust to the risk of misspecification that allows us to generate multi-step predictions, we estimate the dynamic responses at each period of interest. Our results show that there is a positive response of maize prices to bioethanol price shocks. On the whole sample, the impulse response function displays that a one percent increase in bioethanol prices per liter contributes to around 50 percent rise in maize price two years after the shock. Besides, on average, the asymmetry concerning the magnitude of shocks indicates that high magnitude shocks impact is more important than low magnitude shocks; however, asymmetry with respect to shocks direction reveals a nil net effect, suggesting that bioethanol is not harmful to food security. Finally, the intensity of these impacts is subject to heterogeneity related to many factors: income level, trade openness, exchange rate regime, maize production, net maize trade, or the role of public policies.

Keywords : Maize price · Bioethanol price · Pass-through · Food security · Local projections

3.1 Introduction

High commodity prices affect consumers of both developing and developed countries by transmitting disruptions in the business cycle and creating inflationary pressures (Hochman et al., 2010). People from developing countries are more affected by food price shocks because many people live on the margins of adequate nutrition. Thereby, high food prices lead to the reduction of food access and consumption. Moreover, changes in food prices impair farmers' incomes and future production, especially in the case of downward variations. They also contribute to raising their incomes when there are positive price shocks. Based on these findings, food price shocks could result in broader social risks in terms of food security and human development and political stability.

Food price variations can be explained by some factors such as energy production, primarily biofuels. As they use crops as feedstocks, the increase in the global maize price since 2004 has been explained by the fact that ethanol production has tripled 15 to 50 billion liters over the period 2004–2010 (Chen and Khanna, 2012). This significant growth is caused by the rise in biofuel demand and price, as well as high oil prices. Indeed, ethanol policies (subsidies and restrictions on imports) in the U.S, combined with high oil prices, led to the use of around 5 percent of the world's caloric production of maize, soybeans, wheat, and rice (Roberts and Schlenker, 2013).

The assumption that high world prices translate into high domestic prices is ultimately an empirical question. The central objective of this paper is to empirically examine the extent to which global bioethanol prices go/pass through domestic consumer prices, which is a good measure of food access. In developing countries, the government often subsidizes the cost of basic necessities; that means consumers are not always confronted with the market price of these products. Given that public subsidies distort food prices, consumer prices may therefore not be fully adjusted to higher world prices. In addition, data on consumers prices are hardly available. They are however, linked to producer prices, allowing to use these latter as a proxy for food access.

Constrained by data availability, we focus on maize, one of the primary feedstocks for bioethanol production in many countries¹, and data availability; thereby, the change in bioethanol prices could enhance some variations in maize producer price.

¹According to the Department for Environment, Food and Rural Affairs (DEFRA), the share of world bioethanol production by maize was 49% in 2008 that of sugarcane was 33% .

We analyze the static and dynamic responses of maize prices to bioethanol price shocks by using the local projection. This method is robust to misspecifications and allows generating multi-steps predictions through the re-estimation of the direct forecasting models for each forecast horizon. Moreover, local projections take into account asymmetric effects and non-linearities, which are mainly relevant in this study.

While most of the studies are country-specific and in particular focus on the U.S. market (Zhang et al., 2009) and other advanced economies in Europe (Busse et al., 2012; Abdelradi and Serra, 2015), this paper can be an important contribution to the literature on biofuels and food security, by assessing the dynamic response in a large sample of advanced, emerging, and low-income countries over the period 2000-2014. Moreover, it evaluates the asymmetry in the effects with respect to bioethanol world price shocks direction, as well as shocks magnitude, and analyses the impact according to some heterogeneities.

The remainder of this paper is structured as follows. Section 3.2 reviews the main ideas behind the link between energy and food prices. Then, section 3.3 presents data sources and the empirical method. Section 3.4 analyses in the whole sample how maize prices have answered to change in world bioethanol prices, and section 3.5 focuses on the robustness check. Finally, in section 3.6, we analyze some heterogeneities before concluding in section 3.7.

3.2 Background

Despite the efforts of governments and international organizations, the number of food-insecure people remains high. Indeed, around 780 million people are undernourished, and two billion are malnourished (McGuire, 2015). There is a list of causal determinants of food insecurity that matter for individuals' well-being and health. These determinants could be the lack of food supply and food access at the household and country level. The lack of food supply is often linked to the decrease in food production, due to climatic extreme events or crises that reduce a government's ability to import food. However, nowadays, the lack of food supply is also attributed to renewable energy production, specifically biofuels. The lack of food access, primarily due to high food prices, could also be attributed to various factors such as rapid population growth in developing countries, low inventory levels, loose monetary and expansionary fiscal policies, depreciation in the U.S. dollar, and diversion of food crops into biofuel production (Baffes, 2011).

There is a negative correlation between food supply and food prices. Low food availability could involve high prices, which could severely affect food security in the short-run. Therefore, the decrease in food supply related to biofuel production leads to an increase in food prices. Focusing on bioethanol real world price and some main crops used as feedstocks such as maize, we can see in figure 3.1 that bioethanol price rise is followed by an increase in maize producer price. Indeed, from 2002 to 2008, the growth rate of ethanol price was approximately 74% and that of maize price 98%. Likewise, a decrease in bioethanol price is followed by a decline in maize price.

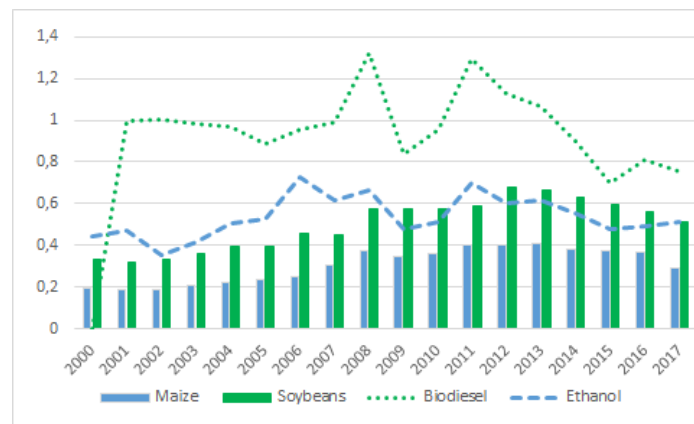


Figure 3.1: Trends in biofuels and some agricultural feedstocks prices

Bioethanol price variations can be attributed to some factors. [Zilberman et al. \(2013a\)](#) find two possible reasons for changes in bioethanol prices. Firstly, it could be attributed to a change in bioethanol demand due to a gasoline price rise. The second reason is a change in bioethanol supply resulting from a variation in the refining capacity. Moreover, when bioethanol is considered as a substitute to energy, its price would reflect the difference in energy content. However, if it is used as an additive for the improvement of gasoline chemistry, bioethanol price can be above the energy equivalent price. Hence, the effect of a variation in biofuel prices on food prices can be predicted when the cause of the change in biofuel prices is specified. The reduction in the price of bioethanol could reduce its production and raises food availability for human consumption, so that the price of food goes down and vice versa. Second, if the change in biofuel price is created by a fluctuation in the price of gasoline, the direction of the change in food prices and that of biofuels will be the same. Finally, if the fluctuation in biofuel price is caused by an increase in refining capacity, the sense of the change in food prices will go into the opposite direction to the price of biofuels.

The amplitude of the relation between biofuels and food prices can differ according

to geographic areas. Figure 3.2 shows us that maize prices are higher in countries of the Middle East and North Africa, Latin America and the Caribbean, and South Saharan Africa than that of other regions, meaning that they could be more affected by the rise in bioethanol price.

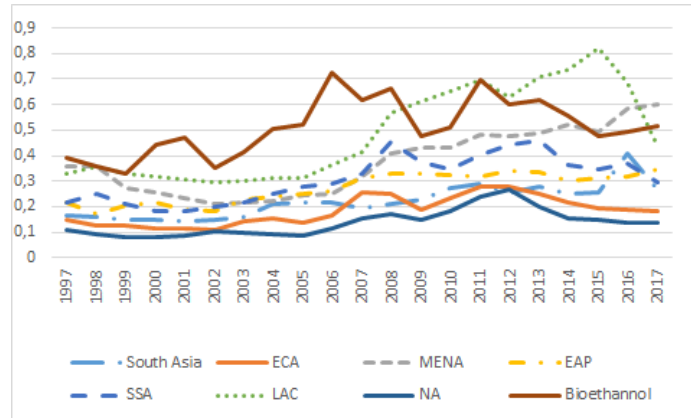


Figure 3.2: Trends in bioethanol and maize prices by region

Given that biofuels are produced from food crops, one of the determinants of food price volatility is biofuel price shocks. Recent energy policies which favor biofuel production, help to creating a large and persistent demand for maize. According to Robles et al. (2010), the raise in food prices from 2007 to 2008 reveals important reductions in calorie intake in several Latin American countries primarily for children. Likewise, higher food prices enhanced the number of underweight children in many African countries such as Mozambique, Zambia and Zimbabwe (Arndt et al., 2016; De Brauw, 2011; Hoddinott and Kinsey, 2001). However, the role of biofuels on high agricultural commodity prices in both 2007-2008 and 2011 is controversial. Since the 2007-08 food crisis, some authors have imputed the level and volatility of commodity prices to the increase in biofuel demand. While, for others the common factors across commodities are more important than biofuel shocks because biofuel would mostly affect maize (Abbott et al., 2008; Gilbert, 2010). In addition, some studies provide evidence on the link between food and energy showing that price transmission mechanisms are generally non-linear. For example, Busse et al. (2012) use a Markov-switching Vector Error Correction Model (VECM) to examine the link between biodiesel, diesel, rapeseed oil and soybean oil price levels in Germany. They show that there is a co-integration between biofuels and agricultural commodities. Another study has been made in Brazil and indicates a positive and non-linear link between ethanol prices, sugar and oil prices (Balcombe and Rapsomanikis, 2008).

3.3 Empirical method

3.3.1 Model specification

In this subsection, we explain the method used to analyze the role of bioethanol world price shocks in clarifying trends in some food prices. Firstly, we do a static analysis by computing the pass-through coefficients as follows:

$$PT^i = 100 \times \frac{P_t^i - P_{t-1}^i}{P_t' - P_{t-1}'} \times \frac{P_{t-1}'}{P_{t-1}^i} \quad (3.1)$$

Where the pass-through (PT) is considered as the ratio between the relative change of food price (P_t^i) and the relative change in bioethanol prices (P_t'), both expressed in US dollars. i is an index for the food product or agricultural commodity considered. In our study, we just have maize as agricultural product; so, P_t^i represents maize producer price at time t .

As maize is used to bioethanol production, the link between these two commodities price goes through exports channel. Therefore, pass-through coefficient could be considered as a proxy of export policies. We assume transportation costs and margins that determine the price structure are stable; hence, any variation in supply cost is likely to be driven by some modifications in export barriers. If for a positive change in the world bioethanol prices, the pass-through coefficient is lower than 100 percent, this could mean there is low export barriers or high export subsidies. Inversely, a coefficient of more than 100 percent would imply a strong export barriers or low export subsidies.

On the one hand, a high pass-through could indicate it is less competitive than other countries with low pass-through. Maize will be more available at country level because its exports will be less important than that of other countries. Hence, even if there is an increase in maize price, its magnitude will be lower than the case of low pass-through. On the other hand, a country with low pass-through could mean low export barriers which favor maize exports contribute to reducing its availability in the local market and lead to high maize producer prices. In this case, countries are competitive and there is a greater impact of world prices on local prices. Furthermore, pass-through coefficient can be negative when prices registered opposite direction. This effect can be explained by the role of monetary authorities in inflation targeting policies, exchange rate movement, trade openness or the decline in the share of bioethanol consumption in economy.

Secondly, we analyze the dynamic response of food prices to world biofuel price shocks. In the literature, many authors used Vector Autoregressive models (VAR) (Steinsson, 2008; Benati and Surico, 2009; Kristoufek et al., 2012; McPhail, 2011) which suppose that data are generated by a VAR model that coincides with the data generating process. However, this model can introduce misspecifications in the impulse response functions when data are not generated by a VAR model (Jordá, 2005). Another method widely used is the Vector Error Correction Model (VECM) (Kurmman and Mertens, 2014; Mallory et al., 2012), but this method can suffer from low power of cointegration tests. For these reasons we choose the local projection approach developed by Jordá (2005) because contrary to VAR models, the main idea of this method is to estimate local projections at each period of interest. Moreover, impulse responses are considered as predictive functions with ever-larger horizons. Therefore, a VAR model whose forecast errors are repeated and correlated, cannot give a good approximation, unlike the local projection that minimizes forecast errors at each horizon. In addition, we can estimate local projection by simple regression techniques and there are no misspecification problems because they are more robust. Likewise, they allow easy experimentation with highly non-linear and flexible specifications that could be impractical in a multivariate context.

The impulse response is usually estimated by the Wold decomposition of a linear multivariate Markov model and could be considered as the difference between two forecasts (Hamilton, 1994; Koop et al., 1996).

$$IR(t, h, d_i) = E(y_{t+h}|v_t = d_i; Y_t) - E(y_{t+h}|v_t = \lambda; Y_t) \quad h = 0, 1, 2, 3 \quad (3.2)$$

Where y_t is a random vector; $E(.|.)$ is the best mean squared error predictor; λ dimension is $n \times 1$; v_t is the reduced-form disturbances vector; columns d_i of $n \times n$ matrix D give the relevant experimental shocks; and Y_t which is equivalent to $(y_{t-1}, y_{t-2}, \dots)$.

Local projection leads to computing the decomposition of the forecast-error variance. The following expression determines the error in forecasting y_{t+h} :

$$y_{t+h} - E(y_{t+h}|X_t) = \mu_{t+h}^h \quad (3.3)$$

Where the residual μ_{t+h}^h is the forecast errors average moving from time t to $t + h$ and therefore uncorrelated with the dependent variable that is explained by its

lagged values (y_{t-1}, y_{t-2}, \dots). h represents the number of horizon considered. Here we analyze the dynamic response until three years after the shocks because after these years the effect returns to its initial value and becomes subsequently insignificant.

As well as being robust to misspecification, this method allows generating multi-step predictions by re-estimating the direct forecast models for each forecast horizon (Koop et al., 1996; Jordá, 2005). Moreover, local projection takes into account net effects and non-linearities which are mainly relevant in this study. We implement this method, in our case, through the following equation:

$$\begin{aligned} \Delta FP_{i,t+h} = \alpha_\rho \sum_{\rho=0}^{\varrho} (\Delta FP_{i,t-\rho}) + \beta_1 \Delta Biofuel_t + \gamma_\rho \sum_{\rho=1}^{\varrho} (\Delta Biofuel_{t-\rho}) \\ + \lambda_\rho X_{it} + \tau + \zeta_i + \epsilon_{it} \quad h = 0, \dots, 3. \end{aligned} \quad (3.4)$$

Where $\Delta FP_{i,t+h} = FP_{i,t+h} - FP_{i,t-1}$ ², with FP the annual price of agricultural feedstocks considered, here maize; $Biofuel$ is the annual bioethanol prices; τ defines a time trend; ζ gives country specific effects; error term is ϵ_{it} ; h refers to the number of horizons; X_{it} predictor variables and ρ indicates the number of lags³

This baseline model assumes that a positive shock leads to raising maize price; while a negative shock contribute to decreasing maize price. However, we have to consider the two shocks in order to determine what effect is the most important. To take into account the possibility of getting asymmetry in the effects, we add to equation 3.4 the variable $Biofuel$ divided into two censored variables specified as follows:

$$Biofuel_t^- = \begin{cases} \Delta Biofuel_t & \text{if } \Delta Biofuel_t < 0 \\ 0 & \text{if } \Delta Biofuel_t \geq 0 \end{cases} \quad (3.5)$$

$$Biofuel_t^+ = \begin{cases} \Delta Biofuel_t & \text{if } \Delta Biofuel_t > 0 \\ 0 & \text{if } \Delta Biofuel_t \leq 0 \end{cases} \quad (3.6)$$

²Variables have been taken in first-difference, hence, even if they were I(1), they become stationary in first-difference. These results have also been verified by Fisher-Augmented Dickey-fuller unit root test.

³Here the optimal number of lags is two. Moreover, standard errors have been clustered by country because treatment is repeated in all countries.

With $Biofuel_t^+$ and $Biofuel_t^-$, respectively the positive and negative biofuel price shocks.

$$\Delta FP_{i,t+h} = \alpha_\rho \sum_{\rho=0}^{\varrho} (\Delta FP_{i,t-\rho}) + \theta_1 Biofuel_t^+ + \theta_2 Biofuel_t^- + \gamma_\rho \sum_{\rho=1}^{\varrho} (Biofuel_{t-\rho}^+) + \omega_\rho \sum_{\rho=1}^{\varrho} (Biofuel_{t-\rho}^-) + \lambda_\rho X_{it} + \tau + \zeta_i + \epsilon_{it} \quad h = 0, \dots, 3. \quad (3.7)$$

As it is presented by equation 3.7, the net effect will be the sum of these two coefficients ($\theta_1 + \theta_2$). If it is positive, it will mean that the impact of positive shocks is greater than that of negative shocks. In this context, we could conclude that bioethanol is on average harmful for consumers but favourable for producers. While, if the net effect is negative, it will indicate that negative shocks impact is higher than that of positive shocks. This finding might suggest that bioethanol is on average disadvantageous for maize producers, but advantageous for consumers. A nil net effect will show that positive shocks impact is as high as that of negative shocks. In this case, we could deduce that there is a compensation between these two effects; thereby, bioethanol would not be a threat to food security.

Another type of asymmetry will consist in testing price shocks effect according to their magnitude. Therefore, as shown in the Equations 3.8 and 3.9, we consider the absolute value of bioethanol price variation and then define two variables that contain low and high shocks, as follows:

$$Biofuel_t^L = \begin{cases} |\Delta Biofuel_t| & \text{if } |\Delta Biofuel_t| < M \\ 0 & \text{if } |\Delta Biofuel_t| \geq M \end{cases} \quad (3.8)$$

$$Biofuel_t^H = \begin{cases} |\Delta Biofuel_t| & \text{if } |\Delta Biofuel_t| > M \\ 0 & \text{if } |\Delta Biofuel_t| \leq M \end{cases} \quad (3.9)$$

With $Biofuel_t^H$ and $Biofuel_t^L$, respectively high and low bioethanol price shocks; M represents the median value.

$$\Delta FP_{i,t+h} = \alpha_{\rho} \sum_{\rho=0}^{\rho} (\Delta FP_{i,t-\rho}) + \theta_1 Biofuel_t^H + \theta_2 Biofuel_t^L + \gamma_{\rho} \sum_{\rho=1}^{\rho} (Biofuel_{t-\rho}^H) + \omega_{\rho} \sum_{\rho=1}^{\rho} (Biofuel_{t-\rho}^L) + \lambda_{\rho} X_{it} + \tau + \zeta_i + \epsilon_{it} \quad h = 0, \dots, 3. \quad (3.10)$$

We also consider the value of parameters θ_1 and θ_2 , however, the net effect between high and low shocks magnitude will be obtained by $(\theta_1 - \theta_2)$. If this difference is positive, it will mean that on average, the impact of high magnitude shock on maize price is more important than that of low magnitude shock. Conversely, if the net effect is negative, it will indicate that high shocks effects are not entirely transmitted to maize price that could be due to public interventions. No net effect will signal a compensation between these two impacts.

3.3.2 Data

Our sample is constituted by 77 developed and developing countries from 2000 to 2014. Most of the data come from the World Development Indicators (WDI), Food and Agriculture Organization (FAO), International Energy Agency (IEA), International Monetary fund (IMF) and the Organisation for Economic Co-operation and Development (OECD) statistics. As dependent variable, we use maize price to assess bioethanol world price shocks effects. This choice is due to the availability of data, but also because it is one of the main bioethanol feedstocks⁴.

Our variable of interest is bioethanol real price, which has been taken to assess biofuel price shocks. This variable is expected to create positive dynamic responses of maize price. Then, biofuel and maize production have been chosen as predictor variables because they affect the level of prices through the mechanism of demand. Moreover, exchange rate variation can affect bioethanol price and its pass-through into maize producer price. The US dollar weakness reduces the domestic-currency price of bioethanol and maize, and inversely because they are denominated in dollar. In addition, we insert trade openness and inflation rate. These variables impact both bioethanol and maize price because they influence biofuel trade, production and prices. They are supposed to have a positive impact on maize price. Furthermore,

⁴In addition, Zhang et al. (2009) find a relationship between the volatility of world prices of maize and ethanol, as well as gasoline and oil.

some studies focus on the link between oil price and biofuel, find that oil price also affect biofuel production and its price. Finally, following these studies, we add the crude oil world price among predictors in the robustness check but also the world price of other cereals because there is a correlation among them. Table 3.1 gives a summary and descriptive statistics of all data used.

Table 3.1: Descriptive Statistics

Variable	Obs	Mean	Std.	Min	Max
Maize price	1,149	267.69	289.84	34.80	3206.10
Maize production	1,155	9375603	3.83e+07	39	3.61e+08
Ethanol real price	1,155	.55	.10	.35	.73
Inflation rate	1,114	6.69	9.69	-8.24	168.62
Exchange rate	660	96.61	16.69	54.06	296.33
Trade openness	1,129	79.75	42.86	20.96	382.29
Biofuel production	1,147	14.94	84.42	0	1056.69
High shocks	1,078	0.07	0.08	0	0.20
Low shocks	1,078	0.02	0.02	0	0.06
Negative shocks	1,078	-0.40	0.06	-0.19	0
Positive shocks	1,078	0.05	0.07	0	0.20
Crude oil price	1,155	0.48	0.19	0.21	0.75
Rice price	1,155	149.77	58.25	72.92	266.58
Barley price	1,155	185.37	67.94	100.99	289.58
Wheat price	1,155	192.07	65.98	100.74	292.97

3.4 Results

3.4.1 Static analysis

Figure 3.3 shows bioethanol world price fluctuations between 2000 and 2014 which allowed us to identify 5 sub-periods. Indeed, between 2000 and 2002, there was a slight rise and then a significant drop in the world price of about 0.45 to around 0.35 USD per litre. From 2002 to 2006, the world price experienced a strong growth until reaching its peak in 2006 with an estimated price of around 0.7 USD per litre. The strong growth observed from 2002 to 2006 preceded an incremental decline in

prices until 2009 before growing again between 2009 and 2011. Finally, in the last sub-period identified from 2011 to 2014, there was a slight decrease in prices.

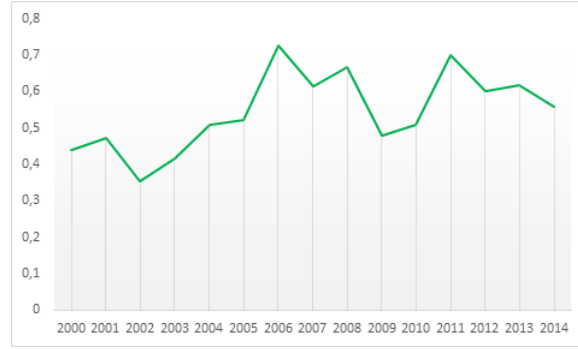


Figure 3.3: Trends in ethanol real prices (US dollars per liter)

Table 3.2: Median pass-through coefficients by country groups

Median pass-through coefficients					
	[2000-2002]	[2002-2006]	[2006-2009]	[2009-2011]	[2011-2014]
All countries	-9.71	34.65	6.18	75.26	-1.02
Developing Asia	-33.43	28.63	-7.05	51.57	-23.27
Sub-saharan Africa	-38.66	47.39	36.89	15.68	-11.71
MENA	28.75	39.95	3.93	26.53	-47.09
Emerging Europe	21.95	38.75	-31.52	109.96	11.76
Latin America	1.60	10.11	40.19	101.22	38.33
Advanced Economies	-17.43	31.35	-42.78	118.49	-6.94
commonwealth	32.70	88.70	-11.82	44.40	10.28

Table 3.2 presents the median pass-through for different country groups in all sub-periods considered. We can remark that there is a great heterogeneity of coefficients, but also some symmetries between them and bioethanol price changes described in figure 3.3. Positive variations in bioethanol world prices are followed by an increase in coefficients, and negative variation in world prices, by a decline in coefficients. In addition, in all the study period, pass-through coefficients are on average positive and high in Latin America compared to other countries, which could display that bioethanol and maize price have moved in the same direction.

In Sub-Saharan Africa countries, we note a decline in pass-through coefficient from 2009 to 2011, although bioethanol world prices have increased. The same

result applies to Latin America and the Caribbean countries between 2006-2009; pass-through coefficient was significantly higher than the previous period although bioethanol world prices have fallen on average.

3.4.2 Dynamic Responses

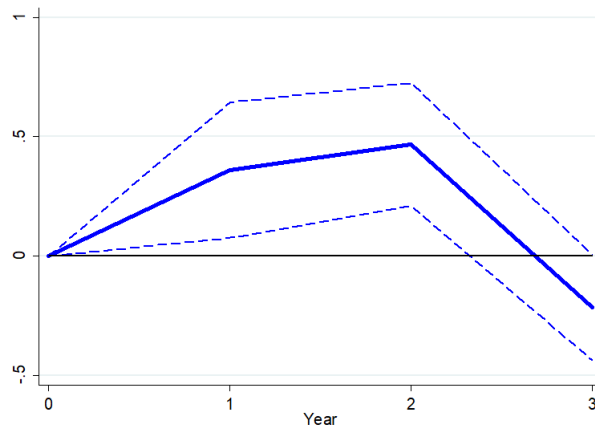
As previously mentioned in the methodology, after presenting static analysis result, we examine the dynamic response of maize through local projection. Thereby, Figure 3.4 indicates how a transitory shock in bioethanol prices reverberates to maize producer prices for all countries in our sample. Finding allows us to conclude that in the short run, there is a significant and positive effect of ethanol price shocks. The magnitude implies that 1 cent per litre raise in bioethanol price favors the increase in maize price of 40 cents at the peak level which appears 2 years after the shock. After this peak, the effect drops, becomes negative and not significant. This result is in line with Zhang et al. (2009, 2010) who find that the enhance in bioethanol prices have short-run, but not long-run effects on agricultural commodity prices. The increase in maize price effect during the first two years could be due to the increase in bioethanol demand or consumption (figure 3.34) and production, which have helped to rise maize demand and therefore its price. Otherwise, the decline after two years could be attributed to farmers adaptation. Indeed, as we can see in many countries when the price of a product steps up in the market, people seek opportunities to profit by increasing production, which in turn could lead prices down (Isik, 2002). Hence, the decrease in price might be due to an increase in maize production after the second year, which can, therefore, correspond to the farmers' response to this shock.

Asymmetry

We decide to study the asymmetric effects of pass through due to some results of the static analysis and the fact that biofuels is an oligopolistic market. Therefore, the lack of competition, production and research costs could cause oligopolistic seller to maintain a prior price in response to a negative price shock until biofuel demand change. In addition, according to Borenstein et al. (1997), price asymmetry can be expensive for final consumers, highlighting the importance of appreciating, identifying sources and taking appropriate actions.

- **Asymmetry with respect to shocks direction.**

The net effect shows, in general, there is a compensation between positive and



Dashed lines represent the 95 percent confidence intervals.

Figure 3.4: Dynamic responses of Maize

negative price shocks. As indicated by the previous results, a positive shock to the world price of bioethanol would have the effect of contributing to the raise in maize producer price. Furthermore, negative shocks contribute to the decline in maize price. Thereby, this net effect could suggest that producing bioethanol would not have a negative effect on maize consumer and producer and therefore on food security.



Dashed lines represent the 95 percent confidence intervals.

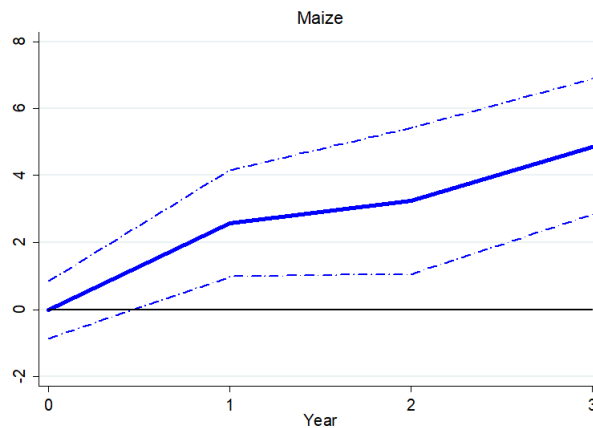
Figure 3.5: Asymmetry in shocks direction

Asymmetric results presented suggest that on average bioethanol is not harmful to food security. Indeed, since 2000, there have been positive and negative change in bioethanol world price. But we note that these shocks, on average did not penalise

maize producers income and consumers food access in the short-run. According to the conventional wisdom, when there is no public intervention producer prices lead consumer prices ([Tiwari et al., 2014](#)). Hence, we can say that the effect observe in producer prices is imputed to consumer prices, because a variation in producer prices create a change in consumer prices.

- **Asymmetry with respect to shocks magnitude**

After displaying the asymmetry with respect to shocks direction, we test the shock magnitude effects. Using the absolute value of bioethanol variations, we have categorized shocks to low and high, according to whether they are lower or higher than the median value. Figure 3.6 allows concluding that the impact of high shocks is more important than that of low shocks. Indeed, the net effect between high and low magnitude shocks is positive, suggesting that the impact of high shocks on maize price is larger than low shocks.



Dashed lines represent the 95 percent confidence intervals.

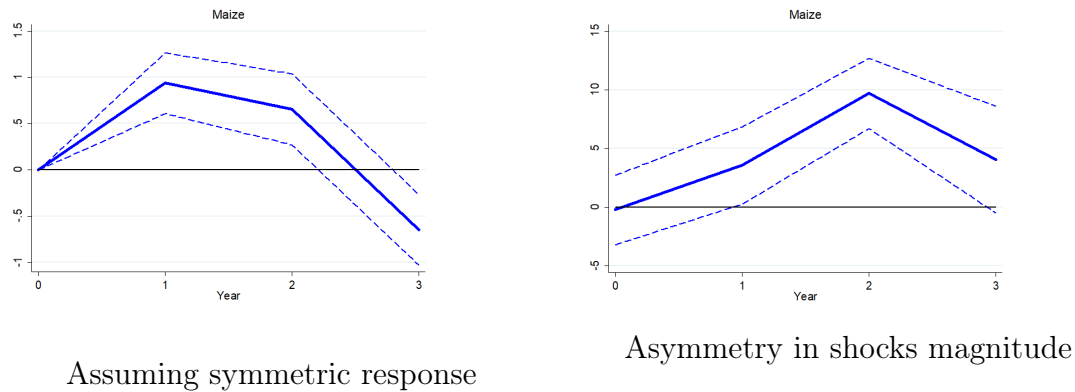
Figure 3.6: Asymmetry in shocks magnitude

3.5 Robustness check

3.5.1 Effect before financial crisis

Financial crisis contributes to increasing international food prices that have reached between 2007-2008 their highest levels in 30 years, threatening food security for the world's poor (FAO, 2009; Lee et al., 2017). Hence, in order to see if the observed effect is not only due to the financial crisis, we test the dynamic response of maize during the period prior to 2007. Figure 3.7 indicates that the impact is not due to the financial crisis effect. As in the whole sample, during the period prior to the financial crisis, a positive shock in the world bioethanol price contributes to increasing the maize producer price until attaining its peak one year after the shock before declining. In addition, we can notice that on average the impact of high magnitude shocks is higher than low magnitude shocks; this is in line with Figure 3.6 and shows that our findings are robust. Furthermore, we do not make a

representation of the asymmetry with respect to shocks direction because there was only one negative bioethanol price shock during the period prior to the financial crisis.



Dashed lines represent the 95 percent confidence intervals.

Figure 3.7: Maize price response before financial crisis

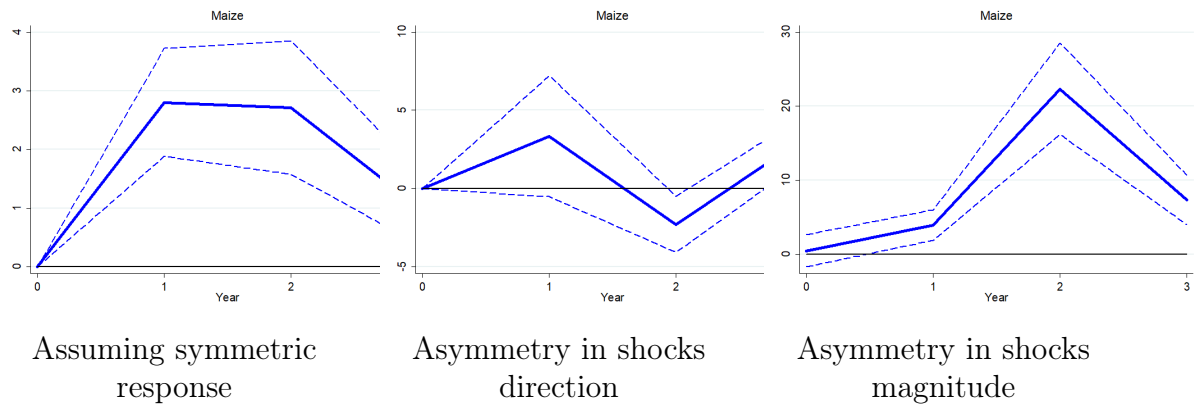
3.5.2 Additional predictors

Bioethanol world price can also be correlated to the world crude oil that could influence bioethanol production cost and price; as a result, it could affect maize price through transport costs (Zhang et al., 2009; Vacha et al., 2013). Moreover, there is a correlation between cereal prices and some of them are also used for bioethanol production such as wheat. Hence, we assume that other cereals world prices could assign bioethanol price and maize price. For this reason, and according to the availability of data, we add among predictors the world price of crude oil other cereals such as wheat, rice and barley. We remark in Figure 3.8 that the impact of bioethanol does not change. As in Figure 3.4 there is an increase in maize producer price until reaching its peak two years after the shock before decreasing. A positive shock of bioethanol world price leads to raising maize price.

Similarly to findings obtained in the asymmetry subsection, by adding these additional predictors there is on average a nil effect according to the asymmetry with respect to shocks direction. Moreover, in the short-run, the asymmetry with respect to shocks magnitude is positive, meaning that high shocks result exceeds low shocks.

3.5.3 Consumer Price Index (CPI) as dependent variable

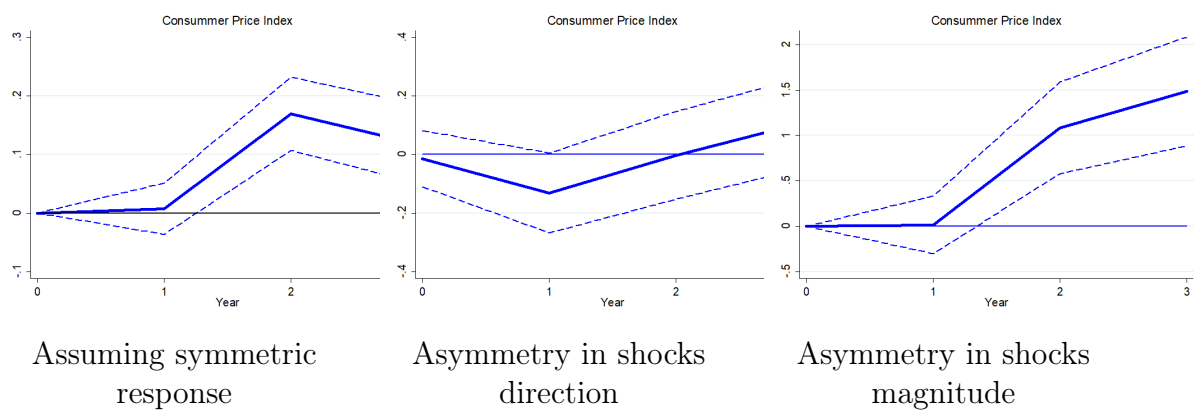
Consumer price index can be defined as a measure that assess the weighted average of a basket of consumer goods and services prices (Burns et al., 2008). Hence, due to



Dashed lines represent the 95 percent confidence intervals.

Figure 3.8: Maize price response with additional predictor variables

the lack of data on maize consumer price, we choose the CPI as dependent variable, in order to see what will be its impulse response to a bioethanol world price shock. Figure 3.9 displays that a positive bioethanol price shock has no effect on CPI one year after the shock, but leads to raising CPI after the first year until attaining its peak two years after the shock before decreasing. In addition, there is also a compensation between positive and negative shocks impact and we can remark that the effect of high magnitude shocks is more important than low magnitude.



Dashed lines represent the 95 percent confidence intervals.

Figure 3.9: Dynamic response of consumer price index

3.6 Some heterogeneities

Previous findings were observed in the whole sample. However, static analysis allows us to think that these results could differ according to country groups. Hence, we will see in the following subsection what could be the impulse response of maize price to bioethanol price shocks according to country groups, as well as a country level of income, maize production, exchange rate regime, trade openness, public policies and net trade of maize.

3.6.1 Income group

Income level is one of the main determinants of the level of poverty and food insecurity in a country (Smith et al., 2016). People from low-income countries are more exposed to hunger and undernourishment. Thereby, policy makers and international organizations adopt some measures to allow people to be less sensitive to price shocks, precisely positive shocks. Thus, we assume that bioethanol price shocks impacts on maize price can differ according to the level of income.

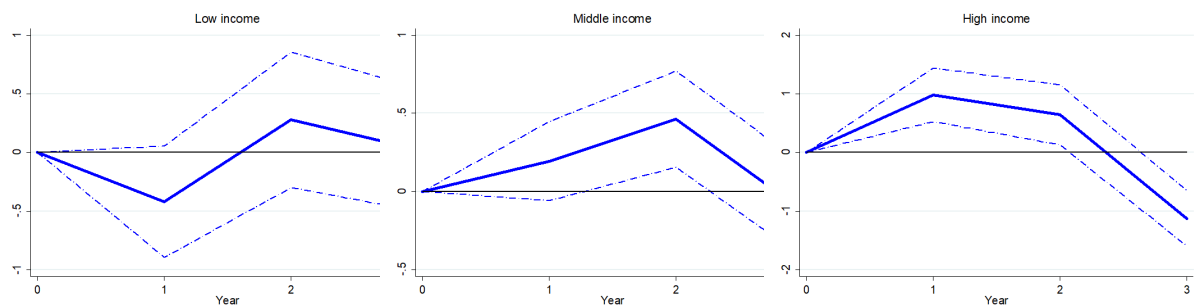
Symmetric effects

Assuming a symmetric response, Figure 3.10 shows that the effect of bioethanol price shocks on food prices differs under income level. Indeed, there is no significant effect for low-income countries over the period, however, it is positive and significant for high-income countries. For middle-income countries, the impact of bioethanol price shocks is significant only 2 years after the shock, causing the enhance in maize price by around 50 cents when the world price rises by 1 cent. In addition, the effect quickly fades because we notice a rapid decline in the effect after the second year.

The effect obtained for low- and middle-income countries could be explained for a variety of reasons. One is that many of these countries are African countries facing food insecurity. As a result, governments are putting in place grants and subsidies to farmers to reduce production costs and their impacts on producer and consumer prices. In many of these countries, such as Ethiopia, South Africa and Kenya, farmers have joined together in cooperatives to gain technical and financial support. Moreover, in other countries such as Malawi, the government takes some measures to restrict exports when international food prices are high (Chalmin et al., 2019). As mentioned in the empirical method, the amplitude of pass-through tends to be low in the presence of strong export barriers. Another cause would be trade openness; these low-income and middle-income countries are less open because they

are often less competitive in the international market. Thus, they are less affected by a global price shock.

Contrary to the effect observed for low-income countries, a 1-cent increase in the world price of biofuels would enhance corn prices by about 100 cents a year after the shock. This finding is the same as [Chiou-Wei et al. \(2019\)](#); they display there is a positive feedback effect of maize price to bioethanol price shocks. Then, the effect gradually declines until becoming not significant and negative at the end of the third year. This effect can be explained by the fact that in most of these countries, product prices are liberalized ([Kpodar and Abdallah, 2017](#)). Thus, fluctuation intensity of bioethanol price, will have more consequences than low-income countries; in addition, these countries have also a high level of trade openness.



Dashed lines represent the 95 percent confidence intervals.

Figure 3.10: Dynamic responses of Maize according to the level of income

Asymmetric effects

As for the whole sample, we note a compensation between negative and positive shocks impact mainly for low-income countries ([Figure 3.17](#)). However, for middle-income countries, there is a peak after two years which shows that positive shocks effect is lower than negative shocks. The same impact applies for high income countries, on average the net effect between positive and negative shocks is nil until the middle of the second year where the effect of negative shock becomes higher than that of positive shock. Thus, we could say bioethanol production is not harmful to food security mainly in low- and middle-income. Moreover, we can notice an increase in maize access for consumers after two years.

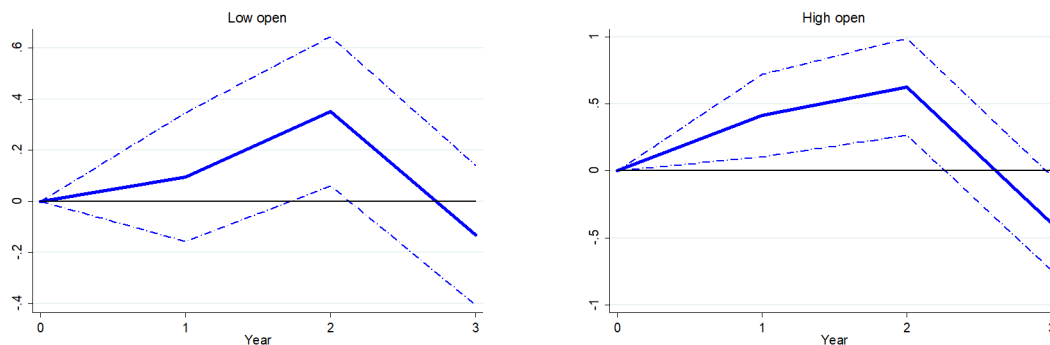
[Figure 3.24](#) indicates the asymmetry in shocks magnitude according to the level of income. We can observe on average a nil effect for high income countries; for low- and middle-income countries, the impact is also nil until becoming positive after

two years.

3.6.2 Trade openness

Symmetric effects

Opening countries to international trade can be beneficial for both the producer and consumer (Javorcik et al., 2006). From this statement, and as mentioned above, we note that positive bioethanol price shock effect on maize production price is significant and larger in countries with a high degree of trade openness. This is because trade openness facilitates the increase in market size (Brühlhart, 2011). However, the raise in bioethanol price is particularly related to the enhance in its demand. As a result, trade openness provides a significant market and demand for already competitive countries and raises maize producer prices. This effect starts immediately after the shock and up to 2 years when it reaches its peak, causing maize prices to rise by about 60 cents before falling and becoming insignificant by the end of the third year.



Dashed lines represent the 95 percent confidence intervals.

Figure 3.11: Dynamic responses of Maize according to the level trade openness

Asymmetric effects

Figure 3.18 states the asymmetry in shocks direction and allow concluding that on average, the response effect of domestic maize price during negative world price shocks is higher than those of positive price shocks. However, as for the full sample, the asymmetry with respect to shocks magnitude (Figure 3.25) displays a positive net effect, indicating that high magnitude impact is the most important.

3.6.3 Maize production

Commodities prices vary among countries according to the level of their production. Indeed a country specialised in the production of a commodity can apply low prices, due to economies of scale or, conversely, apply high price mainly in a monopoly situation (Joskow, 2007). Hence, we assume that the impact can also differ according to the level of maize production. In order to analyze this heterogeneity, we categorize countries in our sample into high and low producer according to the median value of maize production.

Symmetric effects

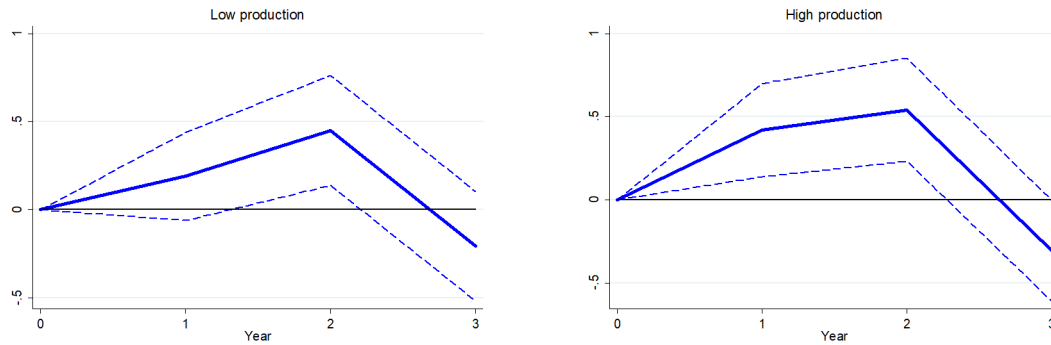
Figure 3.12 presents the impact that a global positive shock of bioethanol prices would have on maize price in the large or small producing countries of this cereal. We note that price response is higher in the major maize producing countries. Indeed, an increase in world prices of 1 cent would cause a raise in the producer price of about 50 cents two years after the shock before fading.

Because the curves look similar to those obtained in Figure 3.11, we tested the dynamic of maize price response according to the level of trade openness and maize production. We find that the impact is greater in the major maize producing countries which have a high degree of trade openness. These results allow us to confirm those obtained in Figure 3.11 and especially to explain our new results, by the fact that the major maize producing countries are for the most of them, countries with a significant degree of trade openness. As a result, in a situation of positive shocks linked to an increase in demand, the only ones able to meet this demand are the leaders in maize production, that favors the rise in producer price. This is why we notice an increase in price from the beginning of the shock up to 2 years after it for countries with high level of maize production and trade openness (Figure 3.32).

Asymmetric effects

According to the level of maize production, the net effect reveals that the response to a positive shock is lower than that of the negative shocks for low maize producer's countries, while for high maize producer countries, the same effect is observed but after one year (Figure 3.19).

Similarly to the whole sample, the asymmetry in shocks magnitude (Figure 3.27 shows on average a positive net effect for high maize producer countries; while, for countries with a low level of maize production, this net effect is nil until becoming



Dashed lines represent the 95 percent confidence intervals.

Figure 3.12: Dynamic responses of Maize according to the level maize production

positive from the second year.

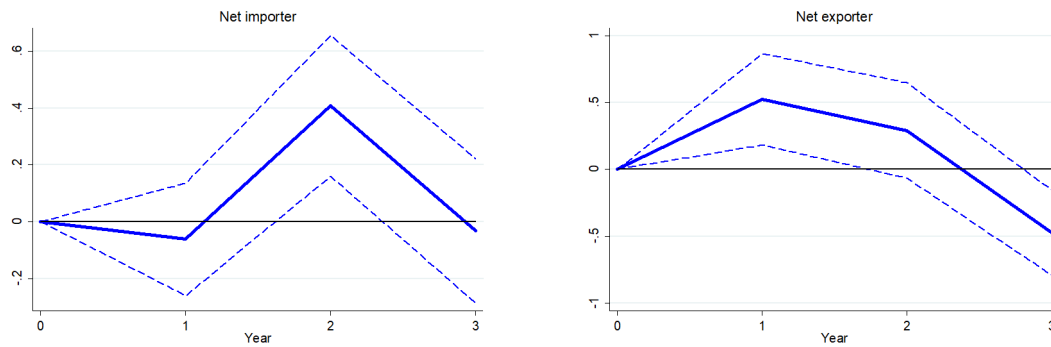
3.6.4 Net maize trade

Symmetric effects

We can have different effects in maize price according to the net trade of maize. Figure 3.13 allows us to show that the dynamic response of maize is more important in net maize exporting countries rather than net importers. Indeed, we remark that the effect is significant after the shock until reaching its peak one year after it, before declining. While it is only significant two years after the shock for net importers before decreasing. This result is in line with pass-through coefficient and static analysis interpretation. We assume that net maize exporting countries are the most competitive in maize market. Hence, a positive shock in bioethanol price could lead to a rise in its feedstocks demand such as maize. As a result, net maize exporter countries would take advantage of this increase by raising maize price. Moreover, the impact is similar to that obtained according to the level of maize production, suggesting that these findings are robust as on average, net importers have a low level of maize production than net exporters.

Asymmetric effects

Figure 3.20 presents the asymmetry in shocks direction according to the net maize trade. We remark a nil net effect for net importer countries, while the effect is positive before becoming negative after two years for net exporter countries. After shocks direction, the analysis of asymmetry with respect to shocks magnitude (Figure



Dashed lines represent the 95 percent confidence intervals.

Figure 3.13: Dynamic response based on net maize trade

3.29 reveals a compensation between the impact of high and low magnitude shocks for net exporter countries. However, the result obtained for net importers allows concluding that high shocks magnitude impact are on average more important than low magnitude.

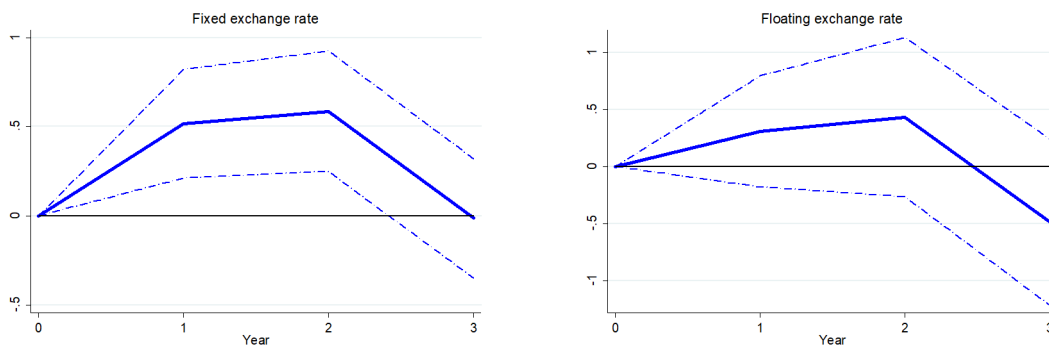
3.6.5 Exchange rate regime

Traded commodities price is influenced by exchange rates that have strong repercussions on their exports and imports (Harri et al., 2009; Kwon and Koo, 2009). There are different effects of bioethanol price shocks depending on the type of exchange rate regime.

Symmetric effects

A positive price shock has a positive and significant impact on the price of maize for countries with a fixed exchange rate regime. While it has no effect in countries with floating exchange rate. One of the advantages of a floating regime is that the exchange rate can vary according to the terms-of-trade shocks: the currency depreciates automatically when the world prices of the imported product increase, and it also automatically depreciates when the world prices of the exported product fall (Broda, 2001). Since bioethanol price is global and expressed in dollars per litre, the result obtained for countries with a fixed exchange rate can be explained by the fact that the currency of these countries is backed by the dollar or the euro, contrary to floating exchange rate. So, if the dollar price of a good raises, the same good local currency price will be multiplied by the dollar price value growth; While when the

dollar goes down, commodity prices will be cheaper (McCalla, 2009). In a floating exchange rate regime, the price of a country’s currency is set by the foreign exchange market on the basis of supply and demand relative to other currencies. This is contrary to the fixed exchange rate regime concept (Reinhart and Rogoff, 2004), in which the government wholly determines the rate. As a result, an increase in the price of bioethanol will seem more expensive in countries with a fixed exchange rate regime than those with a floating rate. Likewise, this result is in line with those obtained in Figure 3.31. There is a positive and significant impact for countries which are net maize importer with fixed exchange rate regime.



Dashed lines represent the 95 percent confidence intervals.

Figure 3.14: Dynamic responses of Maize according to the exchange rate regime

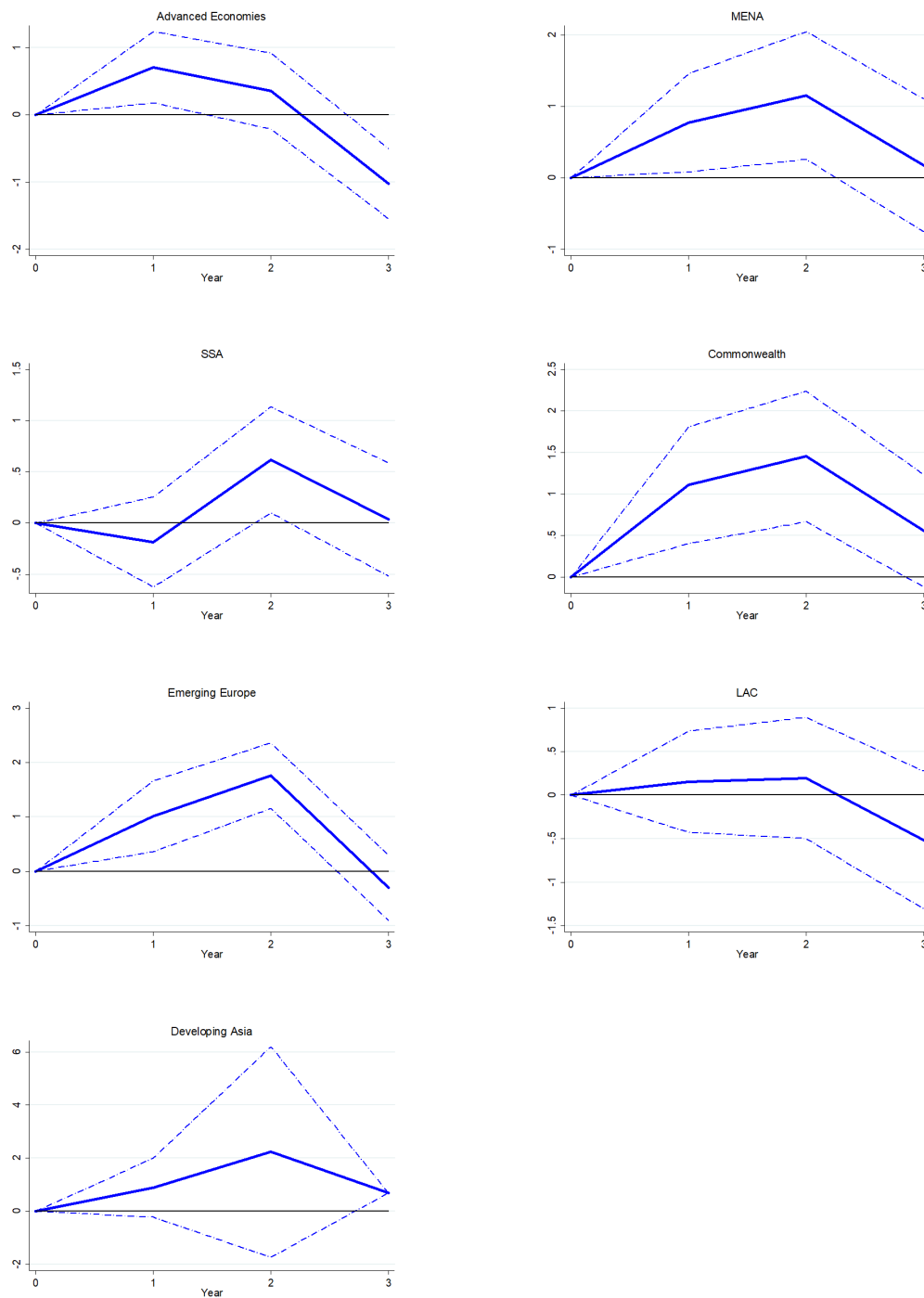
Asymmetric effects

As we can see in Figure 3.21, on average and according to exchange rate regime, there is no significant effect suggesting a compensation between positive and negative shocks impacts. Results are similar to the asymmetry with respect to shocks magnitude (Figure 3.28). We also notice that low magnitude shocks effects are as important as high magnitude. Furthermore, due to symmetric result, we can note that floating exchange rate regime will be more advantageous because it does not lead to the reduction in maize producers incomes or consumers power purchase.

3.6.6 Country groups

Symmetric effects

In order to verify our results, we also test the dynamic response of maize producer price to a positive bioethanol price shocks according to country group. As previously assumed, the results indicate a non-significant effect in Sub-Saharan Africa and



Dashed lines represent the 95 percent confidence intervals.

Figure 3.15: Dynamic responses of Maize according to country group

Middle East North Africa. We note that these results are consistent with those observed in low- and middle-income countries, as most of these countries are clustered in these two groups of income.

Furthermore, responses in Emerging Europe and Advanced Economies are similar to those in high-income countries. These results are therefore fair because most of them are high-income countries whose prices are liberalized relative to those in sub-Saharan Africa or Middle East North Africa.

On the other hand, we have no effect for countries belonging to the group of Latin America and the Caribbean and Developing Asia. As mentioned in the static analysis, the effect observed in Developing Asia is linked to food export barriers implemented by the governments of these countries as most of them depend on imported food. As a result, an increase in the world price of bioethanol does not have the same magnitude in these countries compared to the Emerging countries of Europe or Advanced Economies.

Asymmetric effects

For most of the countries groups (Figure 3.22) the asymmetry results in shock direction are not significant. This finding precisely concerns the Sub-Saharan Africa, Latin America and the Caribbean and Middle East and North Africa, and are comparable to asymmetry in shocks direction obtained for low- and middle-countries (Figure 3.17). The same result applies for Emerging Europe, while in Advanced Economies the effect becomes negative and significant from the third year. For Developing Asia and Commonwealth, the impact is negative and significant until two years before becoming not significant.

The asymmetry in shock magnitude (Figure 3.26) shows a compensation between high and low magnitude shocks impacts for Advance economies, Sub-Saharan Africa, Latin America and the Caribbean and Middle East and North Africa. However, for Emerging Europe and Developing Asia, the impact becomes positive and significant respectively after one and two years. Otherwise, in the Commonwealth, there is on average positive and significant effect until the third year where it is not significant.

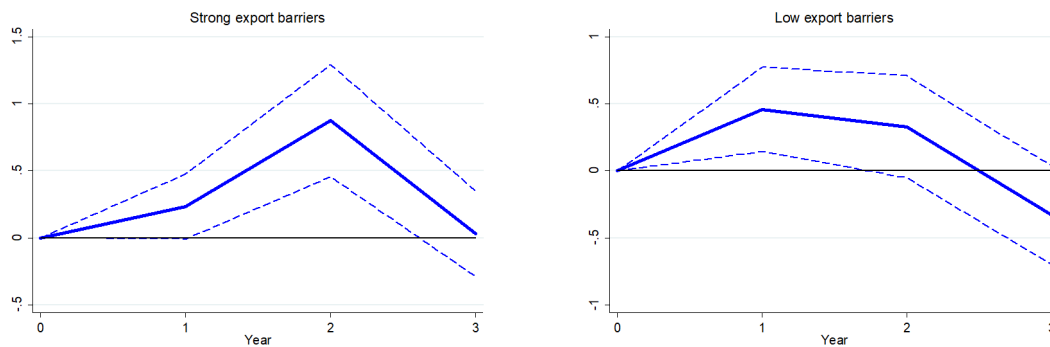
3.6.7 The role of public policies

Depending on public policy, bioethanol world price shocks may have different impacts on maize producer price; it may be totally, partially or not at all reflected on price. Thereby, the impulse response of maize can differ according to the kind of

policies implemented in a country that could influence the dynamic bioethanol price pass-through on maize producer price (Zhang et al., 2010; Ivanic et al., 2012).

Symmetric effects

As mentioned in the empirical method, we could consider pass-through coefficients as a proxy of public policies precisely export policies. Hence, we categorize countries according to the level of pass-through computed at the beginning of our study period⁵. Countries are, then, classified into high and low level of pass-through, by comparing the coefficient obtained in 2001 to the median value obtained by considering the full study period. Figure 3.16 shows that for countries with a low level of pass-through, which means that export barriers are low, there is a positive and significant effect which happens one year after the shock; while for countries with a high level of pass-through, due to strong export barriers, the effect of bioethanol price shocks is not significant one year after the shock. However, we observe a positive and significant effect only at the second year before becoming non-significant. These results are similar to that obtained according to the level of maize production or trade openness.



Dashed lines represent the 95 percent confidence intervals.

Figure 3.16: Dynamic responses of Maize according to public policies

⁵We consider the beginning of our study period rather than the average of pass-through coefficients computed during the full study period because government can take some measures to adapt to the shocks. Therefore, by focusing on 2001, we can rest assured that even if a measure had been taken as a result of the change observed between 2000-2001, it would be less important than which could have been taken over the entire study period.

Asymmetric effects

Figure 3.23 represents the asymmetry in shocks direction according to the role of public policies. Thus, results display that for countries with low export barriers, the effect is not significant the first year, but from the second year it becomes negative and significant. However, in countries with strong export barriers, the net effect is nil, meaning that these countries are more resilient to shocks effect. Hence, we could conclude that on average there is no impact on food security due to the compensation between positive and negative shocks effects.

Furthermore, the analysis of asymmetry with respect to shocks magnitude (Figure 3.30) shows on average a positive and significant impact from the first year in countries with low export barriers, as well as countries with strong barriers. However, the effect intensity is more important in countries with low barriers than that with strong barriers.

According to symmetry and asymmetry results, export barriers seem to be more advantageous for consumers through the increase in maize access. As this measure can not succeed in the long-run, to reach food security goal, we need to find the optimal level of export barriers in order to increase consumers power purchase without reducing producers income.

3.7 Concluding remarks

In a context of food energy deficiency, it is important to find some alternative sources of energies. Among these alternative sources we can use biofuels. However, they are produced with agricultural crops, which according to some studies could lead to high food prices and high food insecurity.

Following these studies, this paper aims at assessing the dynamic responses of food prices mainly maize price to the world bioethanol price shocks, through local projection. Before proceeding to the dynamic analysis, the static analysis displays that the episodes of increase in bioethanol world price were accompanied by a raise in the pass-through coefficients. These results have been corroborated by those of the dynamic analysis, showing us, in general, an increase in the world price of bioethanol also leads to a raise in maize producer price. However, this impact disappears three years after the shock and its intensity varies according to the level of income, trade openness, maize production, country groups, exchange rate regime net trade of maize, or public policies. Thus, due to some government policies, the

effect is higher in high-income countries or those with high levels of trade openness compared to those with low levels of trade openness or low-income.

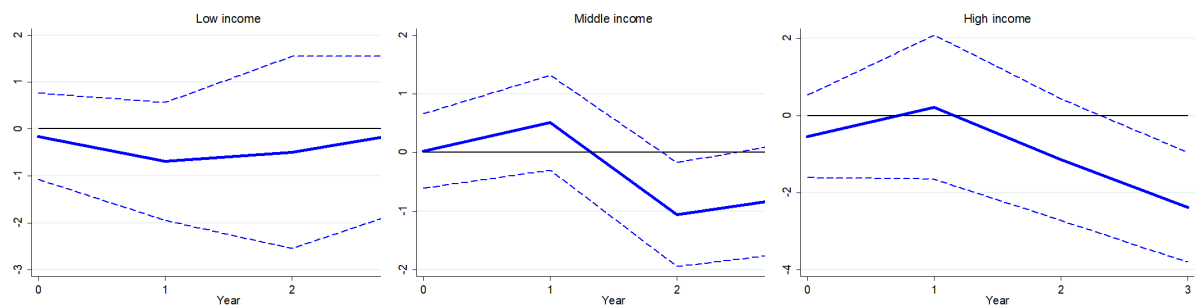
Due to some results found during the static analysis and the fact that biofuel market is oligopolistic, we analyze the asymmetry with respect to shocks direction and shocks magnitude. Findings indicate a compensation between positive and negative shocks effects, suggesting that there is no negative effect on food security, more precisely on food access. However, the impact of high shocks magnitude tends to be greater than that of low shocks magnitude.

As robustness checks, we add additional predictors variable such as the world crude oil price and other world cereal prices, we also only consider the period prior to 2007-2008 crisis and the consumer price index as dependent variable. We find similar results are those obtained in the result section, displaying that findings are robust.

We can conclude that bioethanol could be promoted in both developing and developed countries in order to reach the goal of energy security, because in the short-run, bioethanol does not assign food access to consumers and does not penalize producer income. Otherwise, this paper can be extended by using a set of commodities entering in bioethanol production and by using consumer prices when data will become easily available.

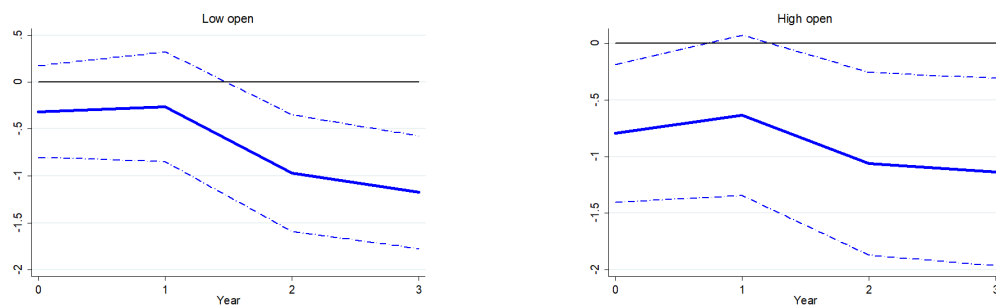
3.8 Appendices of Chapter 3

Appendix A. Asymmetry with respect to shocks direction: some heterogeneities



Dashed lines represent the 95 percent confidence intervals.

Figure 3.17: Asymmetry in shocks direction according to the level of income

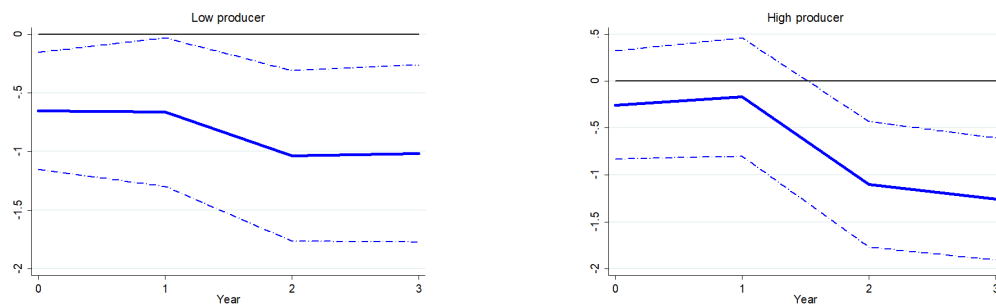


Dashed lines represent the 95 percent confidence intervals.

Figure 3.18: Asymmetry in shocks direction according to the level of trade openness

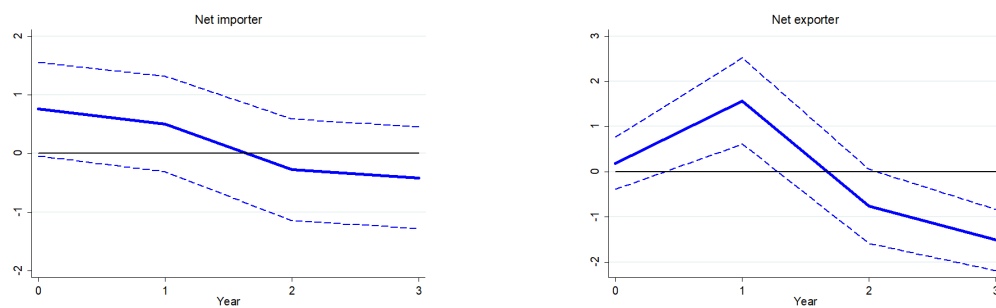
Appendix B. Asymmetry with respect to shocks magnitude: some heterogeneities

Appendix C. Supplementary graphs and tables



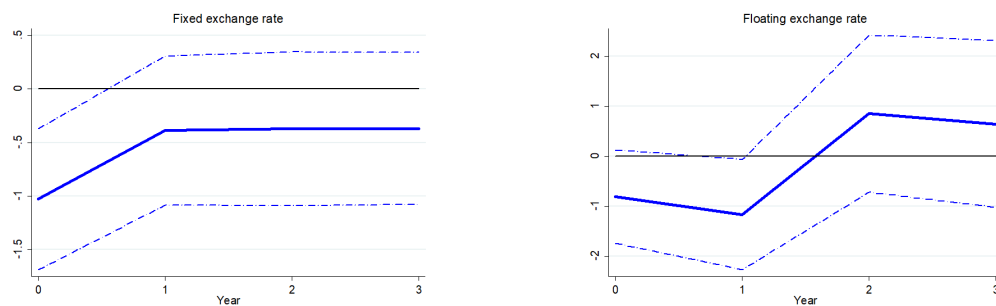
Dashed lines represent the 95 percent confidence intervals.

Figure 3.19: Asymmetry in shocks direction according to the level of maize production



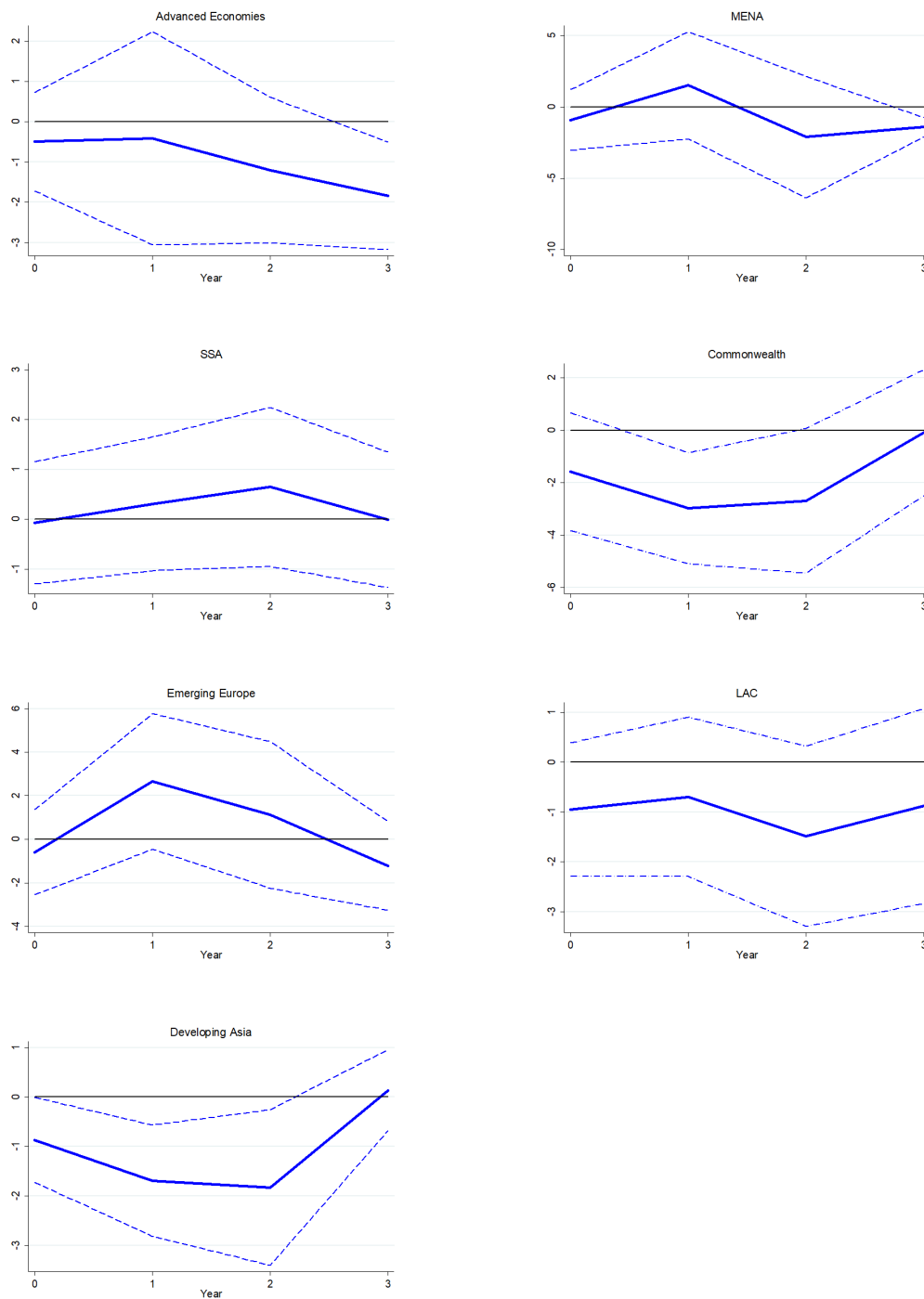
Dashed lines represent the 95 percent confidence intervals.

Figure 3.20: Asymmetry in shocks direction based on net maize trade



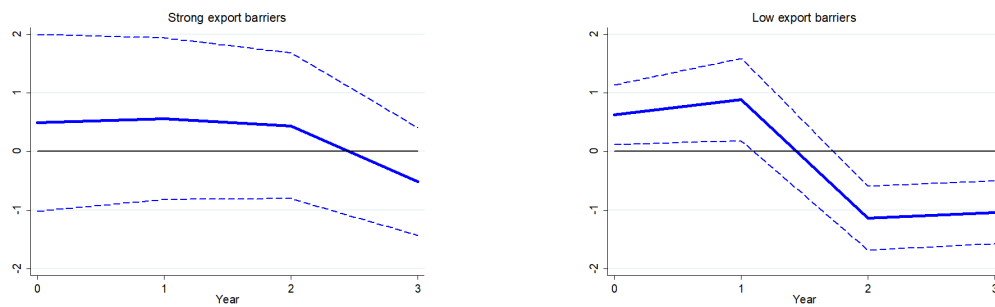
Dashed lines represent the 95 percent confidence intervals.

Figure 3.21: Asymmetry in shocks direction according to the level of exchange rate regime



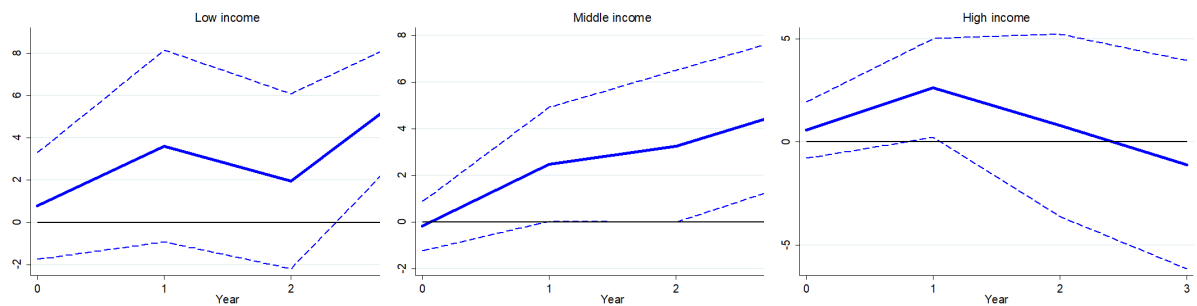
Dashed lines represent the 95 percent confidence intervals.

Figure 3.22: Asymmetry in shocks direction according to country groups



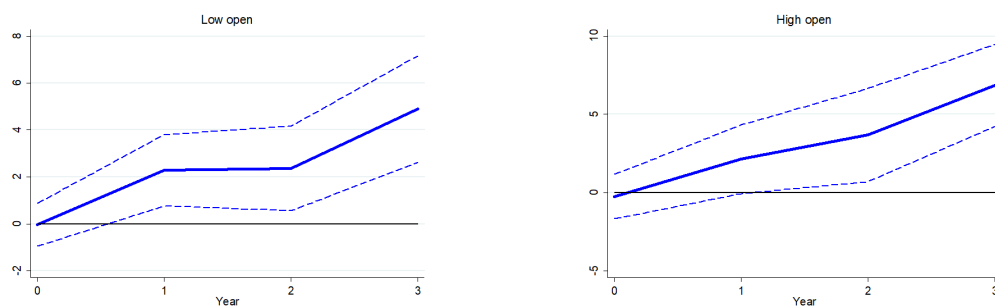
Dashed lines represent the 95 percent confidence intervals.

Figure 3.23: Asymmetry in shocks direction according to public policies



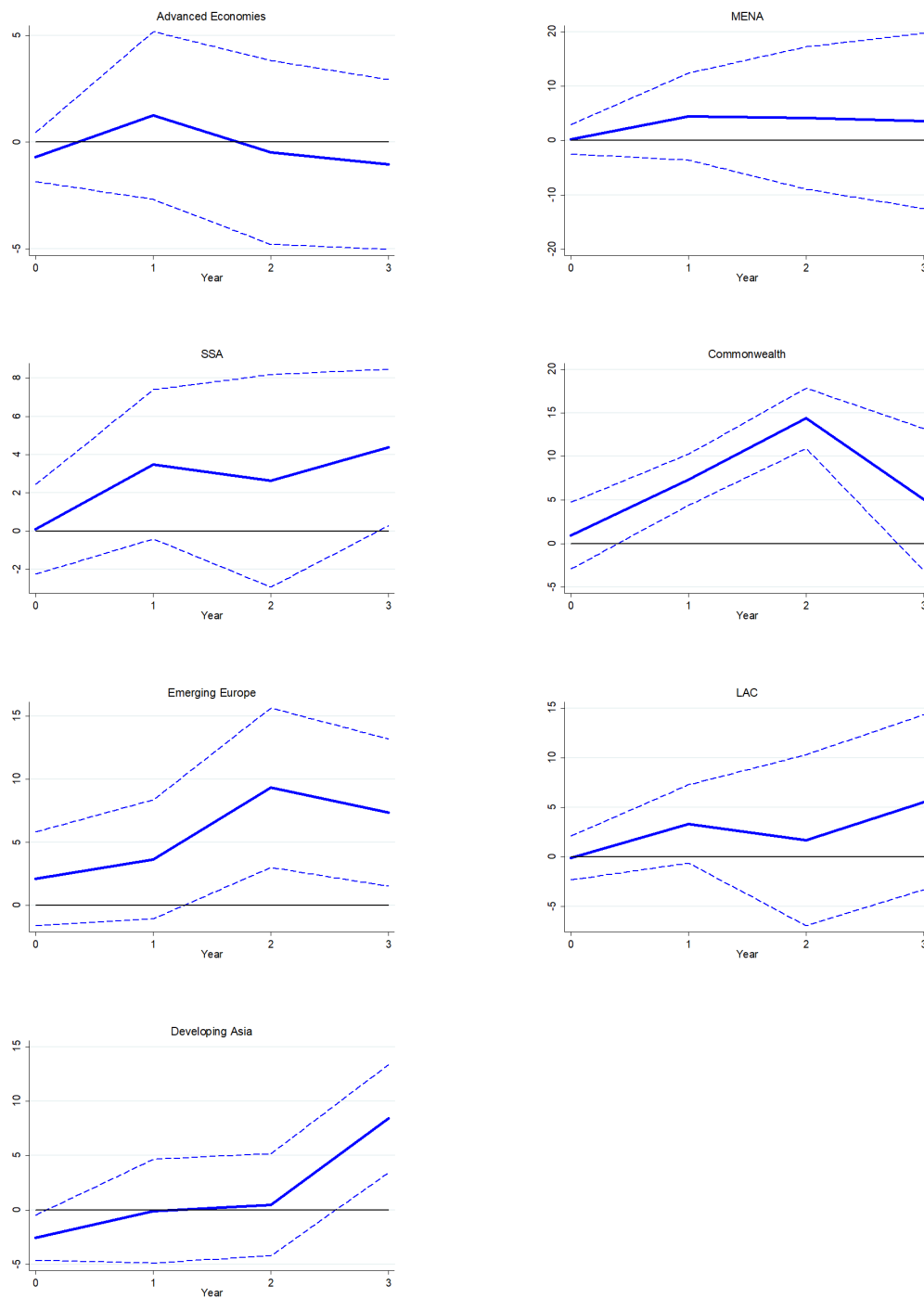
Dashed lines represent the 95 percent confidence intervals.

Figure 3.24: Asymmetry in shocks magnitude according to the level of income



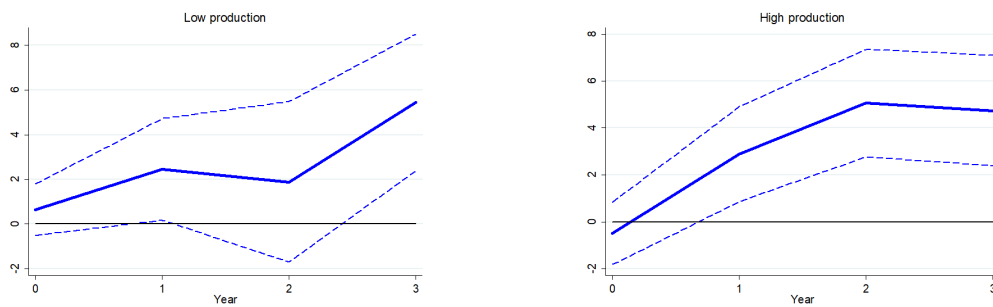
Dashed lines represent the 95 percent confidence intervals.

Figure 3.25: Asymmetry in shocks magnitude according to the level of trade openness



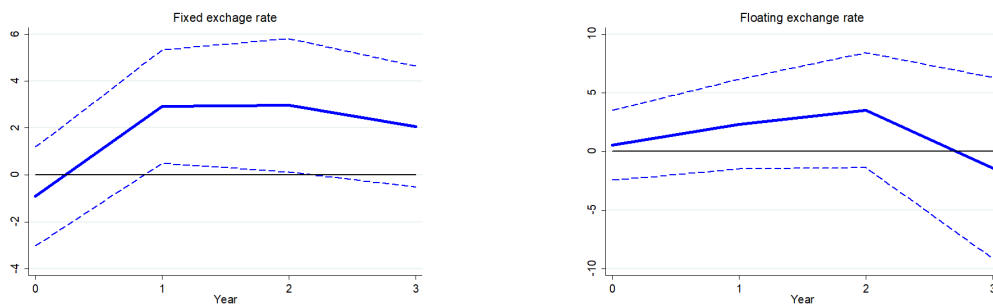
Dashed lines represent the 95 percent confidence intervals.

Figure 3.26: Asymmetry in shocks magnitude according to country groups



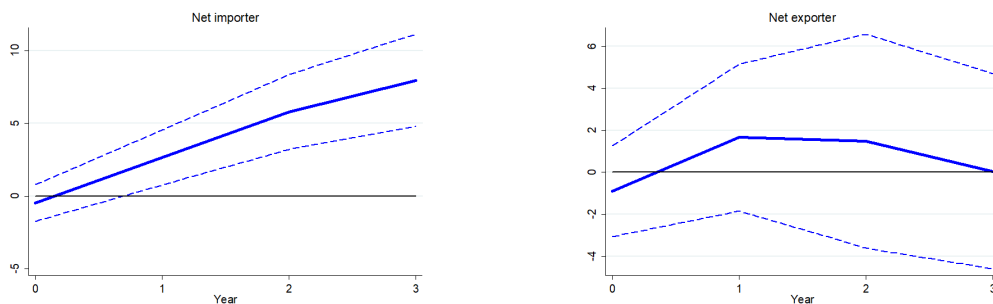
Dashed lines represent the 95 percent confidence intervals.

Figure 3.27: Asymmetry in shocks magnitude according to the level of maize production



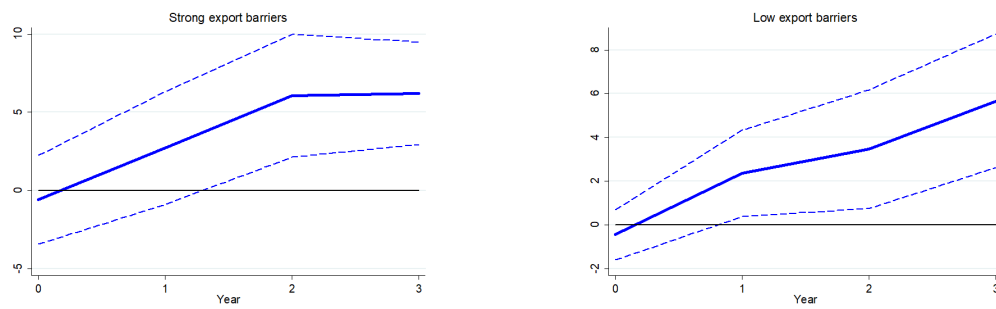
Dashed lines represent the 95 percent confidence intervals.

Figure 3.28: Asymmetry in shocks magnitude according to the level of exchange rate regime



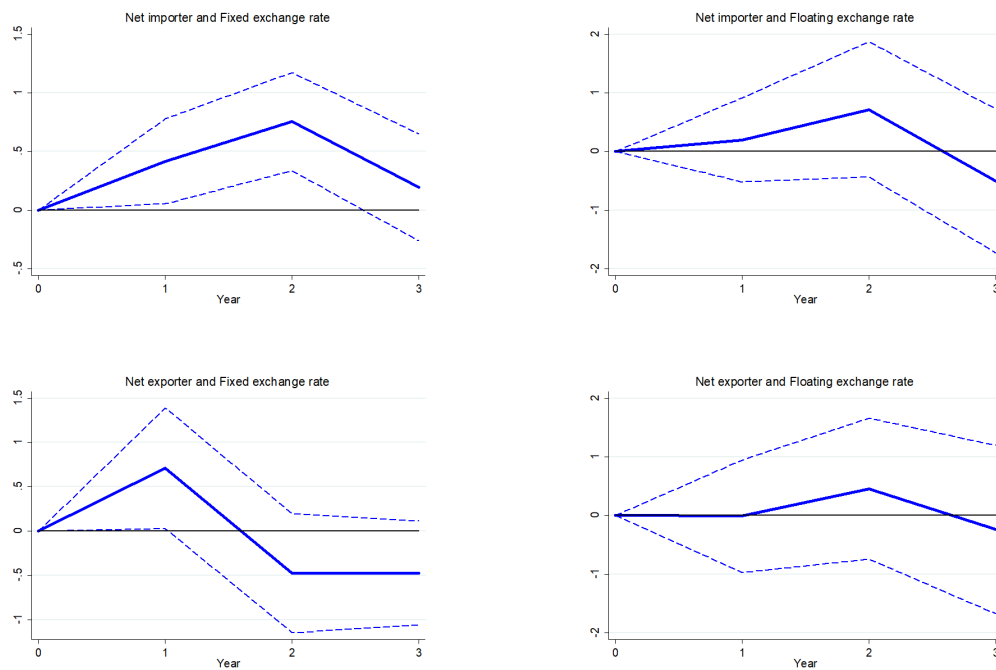
Dashed lines represent the 95 percent confidence intervals.

Figure 3.29: Asymmetry in shocks magnitude based on net maize trade



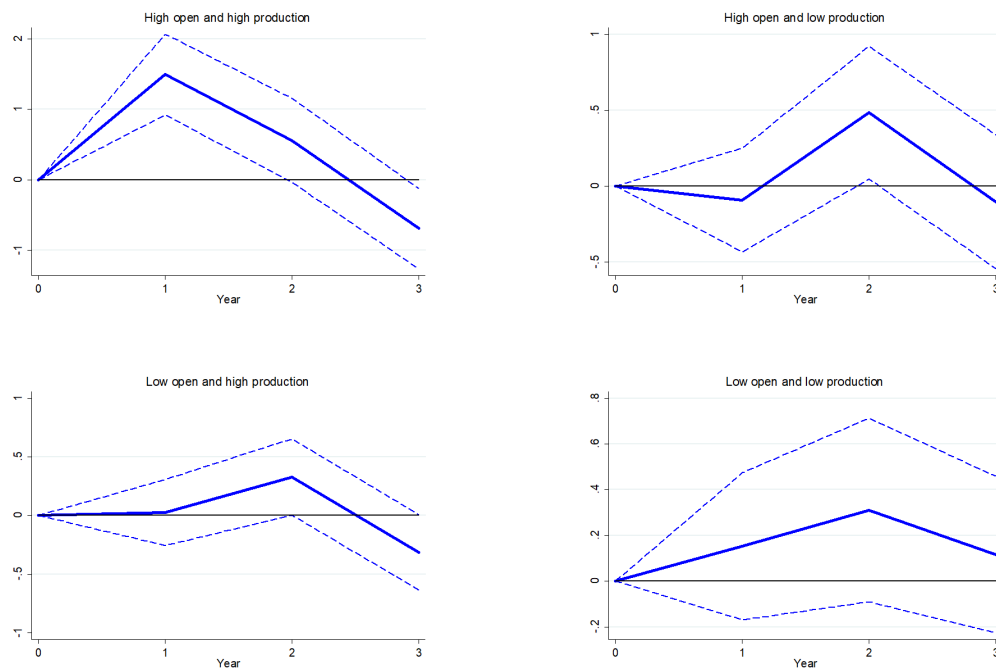
Dashed lines represent the 95 percent confidence intervals.

Figure 3.30: Asymmetry in shocks magnitude according to public policies



Dashed lines represent the 95 percent confidence intervals.

Figure 3.31: Dynamic response of maize price by the level of net maize trade and exchange rate regime



Dashed lines represent the 95 percent confidence intervals.

Figure 3.32: Dynamic response of maize price according to the level of maize production and trade openness

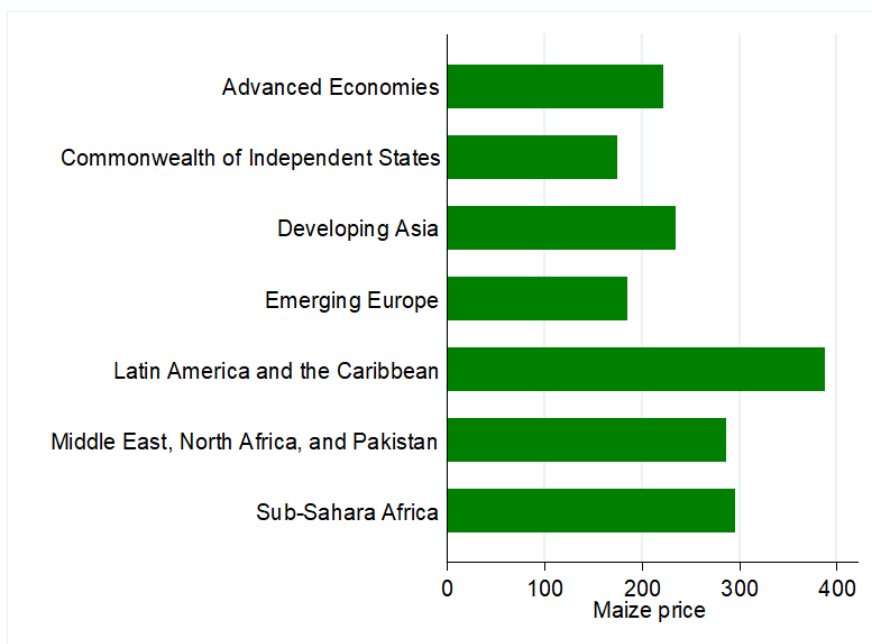


Figure 3.33: Average maize price (US dollars per tonne)

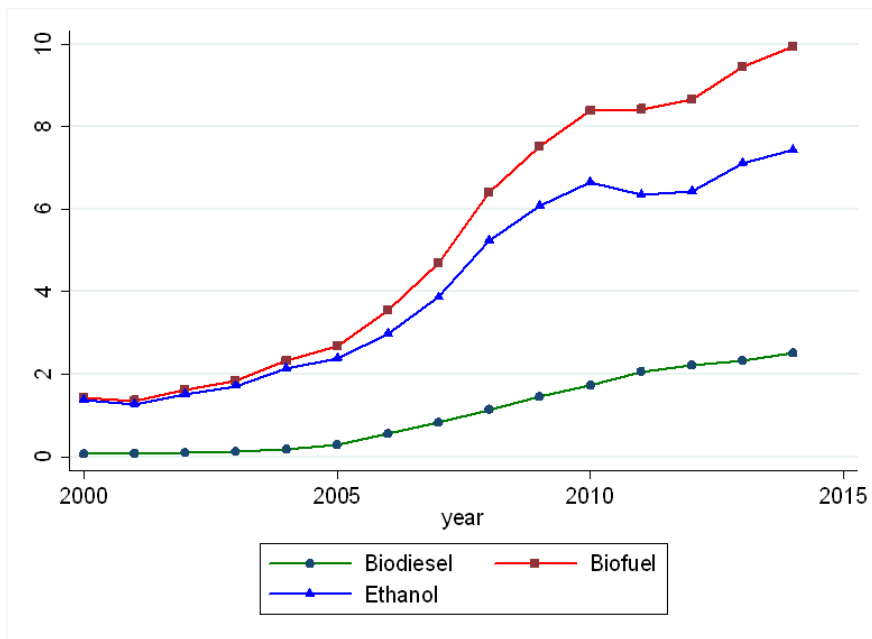


Figure 3.34: Biofuel consumption

Table 3.3: Countries

Argentina	Ecuador	Lithuania	Senegal
Australia	Egypt, Arab Rep.	Luxembourg	Serbia
Austria	Ethiopia	Malawi	Slovak Republic
Azerbaijan	Fiji	Mali	Slovenia
Belarus	France	Mexico	South Africa
Bolivia	Gambia, The	Moldova	Spain
Botswana	Germany	Morocco	Sri Lanka
Brazil	Greece	Mozambique	Switzerland
Bulgaria	Hungary	Nepal	Tanzania
Burundi	Indonesia	New Zealand	Thailand
Canada	Iran, Islamic Rep.	Nigeria	Togo
Cape Verde	Israel	Panama	Turkey
Chile	Italy	Paraguay	United States
China	Jamaica	Peru	Uruguay
Colombia	Jordan	Philippines	Venezuela, RB
Congo, Rep.	Kazakhstan	Poland	Vietnam
Costa Rica	Kenya	Portugal	Yemen, Rep.
Croatia	Kyrgyz Republic	Romania	
Czech Republic	Lao PDR	Russian Federation	
Dominican Republic	Lebanon	Rwanda	

Table 3.4: Variables descriptions and sources

Variable	Description	Source
Maize price (log)	Maize producer price in USD per tonne	Food and Agriculture Organization (FAO)
Maize production (log)	Maize production in tonne	Food and Agriculture Organization (FAO)
Ethanol real price	Ethanol real price in USD per litre	OECD
Inflation rate	Inflation measured by the consumer price index (annual %)	World Development Indicators (WDI)
Trade openness	Sum of export and import as a share of GDP	World Development Indicators (WDI)
Biofuel production (log)	Biofuel production in thousand barrels per day	International Energy Agency (IEA)
High shocks	High changes in bioethanol world prices	International Energy Agency (IEA)
Low shocks	Low changes in bioethanol world prices	International Energy Agency (IEA)
Negative shocks	Negative changes in bioethanol world prices	International Energy Agency (IEA)
Positive shocks	Positive changes in bioethanol world prices	International Energy Agency (IEA)
Real effective exchange rate	Real effective exchange rate index (2010=100)	International Monetary fund (IMF)
Exchange rate regime	Exchange rate regime, IMF classification	Reinhart and Rogoff (2004)
Crude oil price	Crude oil world real prices in USD dollar per barrels	International Energy Agency (IEA)
Rice price (log)	Rice world real prices in USD per tonne	World Development Indicators (WDI)
Barley price (log)	Barley world real prices in USD per tonne	World Development Indicators (WDI)
Wheat price (log)	Wheat world real prices in USD per tonne	World Development Indicators (WDI)

CHAPTER 4

Are some developing countries caught in a hunger trap?

This paper aims to test the existence of an unconditional hunger trap and to determine whether biofuel production is among the key long-term determinants of food insecurity. Therefore, we consider the Markov transition matrix and ergodic distribution to test the hypothesis of an unconditional hunger trap and then the conditional inference regression tree to identify the key drivers of food insecurity. We find that developing countries are not caught in a hunger trap. The result of the transition matrix shows that all countries with high levels of food insecurity can move to a lower level. Furthermore, given the characteristics of the countries, the conditional inference regression tree results show that the most important variable is gross domestic product (GDP) per capita. However, in addition to this variable, we need to include the level of age dependency ratio, precipitation, socioeconomic conditions, and corruption index for countries with high levels of food insecurity. Considering the overall sample and sub-samples of low and high food insecure countries, biofuel production is not part of the long-term determinants. The results of the boosting model and panel data quantile regression reveal that the influence of biofuels seems very weak, meaning that they can be a way to fight climate change without penalizing food security.

Keywords : Food security · Long-run determinants · Hunger trap · Biofuels · Conditional Inference Regression tree · Transition matrix

4.1 Introduction

Although more than enough food is produced to feed the global population, the level of food insecurity remains high in the world. It was estimated that 690 million people were considered as undernourished in 2019, representing 8.9 percent of the world's population, an increase of 10 million people in one year and nearly 60 million in five years. In addition, about one in 10 people worldwide were exposed to severe levels of food insecurity, and the number of stunted children was 144 million (FAO, 2020). Otherwise, around two billion people suffered from mineral and vitamin deficiencies (FAO, 2019). While there is food insecurity even in developed countries, most food insecure people come from developing countries. The majority of food insecure people in 2019 lived in Africa (20%), Asia (11%), and Latin America and the Caribbean (7%). In high-income countries, 8% of the population in North America and Europe is considered to be at moderate levels of food insecurity (FAO, 2019).

According to the World Food Summit in 1996, food security describes a situation that prevails when all people have physical and economic access to sufficient, safe and nutritious food, at all times, that meets their dietary needs and food preferences for an active and healthy life. It is a multidimensional concept including food availability, access, utilization and stability (Shaw, 2007). While food security refers to adequate access to enough food at all times, food insecurity primarily measures hunger. Therefore, hunger can be linked to one or all of the dimensions of food security. Factors that can lead to hunger include food unavailability, lack of access, misuse and instability over a given period. The hunger trap can be defined as a situation that forces people to remain in their food insecurity situation. It is so constraining that it is difficult to escape, especially for vulnerable people. In 2019 about 40% and 54% of stunted children lived in Africa and Asia, respectively, or nine out of ten children. These children were caught in the hunger trap, so-called to emphasize the intergenerational nature of the problem (Bratspies, 2014). The

effects of the hunger trap not only affect the individuals involved but also impose significant economic losses due to illness, deaths, school repetitions, school dropouts and reduction in adults physical capacity. According to the Cost of Hunger in Africa (COHA) team, Malawi's economy loses nearly \$600 million every year due to the effects of child undernutrition. Some studies on the hunger trap, focus on a specific country or aspect. [Chinkin and Wright \(1993\)](#), by analyzing the hunger trap, examine women's role in reducing food insecurity, and [McNamee \(2007\)](#) assesses the hunger trap through the effects of Ganyu labor on maize output in Malawi.

Several programs and policies have been implemented worldwide by some institutions, such as the Food and Agriculture Organization ([FAO, 2018](#)) to improve the level of food security, mainly in developing countries. Among others, these programs aim to improve their food security through rapid increases in productivity and food production on an economically and environmentally sustainable basis, the reduction of agricultural production variability from year to year by the promotion of climate-smart agriculture techniques, the improvement of food access. However, despite food programs and projects implemented in many countries and the improvement of agricultural practices, food insecurity is still high worldwide. Does this reflect the existence of an unconditional hunger trap?

According to the literature, food insecurity can be due to many factors that exacerbate the problem of food availability or food access. According to [Jenkins and Scanlan \(2001\)](#), inequalities, militarism, population pressure, and low economic growth are the main culprits. [Smith et al. \(2000\)](#) and [Barrett \(2008\)](#) analysis reveal that poverty is the most common cause of food insecurity. The group of countries with the greatest severity of food insecurity are those with a high poverty rate. Other authors think about high food price ([Gregory and Coleman-Jensen, 2013](#); [Grace et al., 2014](#); [Verpoorten et al., 2013](#)) because it leads many households to reduce both the quantity and quality of food consumption. Furthermore, climate change

and extreme events (Gregory et al., 2005; Devereux and Edwards, 2004), and civil unrest (Bode, 2018) can negatively impact people's food security mainly through their effect on food production and access. Therefore, what are the key determinants of food insecurity?

Due to the significant increase in fuel production from raw materials grown on agricultural land, the debate between food and fuel has engaged many actors since the 2000s. On average, the evidence so far has highlighted important trade-offs between biofuel production and food security (Rosegrant and Msangi, 2014). Some studies (Zilberman et al., 2013b; Beckman et al., 2012; Afiff et al., 2013) revealed that biofuel production hurt food security because they contribute to reducing food availability by using food crops as feedstock and to decreasing food access by increasing food price. Therefore, given the growing interest in biofuels as an alternative energy source to fossil fuels and the literature on their negative impacts on food security, are they among the key determinants of food insecurity?

In this paper, we try to identify the conditions under which some countries could be caught in a hunger trap through a sample of 110 countries from 1992 to 2016. However, before defining the key determinants of the hunger trap, we first test the unconditional hunger trap hypothesis through the Markov transition matrix and ergodic distribution. Rejecting this hypothesis allows us to ensure that there are indeed conditions under which a country can be caught in a hunger trap and thus identify these factors. We, therefore, consider the depth of the food deficit in kilocalories per capita as our food insecurity indicator and five-year periods. Then, we classify countries into four levels of food insecurity (severe, high, moderate, and low) based on their level at the beginning of the period. We determine through the transition matrix the probability of moving from one level of food insecurity to another. We also assess if a country from any level could end up in the low level of food insecurity with the ergodic distribution and the expected time it takes. Hence,

in this paper, we consider countries to be in a hunger trap if there is more than a 50% chance that their situation will not improve, and if the transition matrix and ergodic distribution show that, on average, countries with a severe, high or moderate level of food insecurity will not move to a lower level.

To identify conditions under which a country can be caught in a hunger trap or the key determinants of food insecurity, we grouped countries with severe, high, and moderate levels of food insecurity, which we named high food insecurity, and used the conditional inference regression tree analysis. This non-parametric classification technique is robust to outliers, missing data, and allowed us to classify and find the most relevant determinants for each level of food insecurity (high and low). It does not directly determine causal effects, but it is a step toward identifying causal variables. Specifically, it is a classification exercise that looks for combinations of policy and fundamental variables that separate countries with low levels of food insecurity from those with high levels. Thus, if a variable is not considered by the regression tree method to be a predictor of food insecurity, it is unlikely to be a cause. Robustness was verified using the boosting method, other indicators of food insecurity such as the global hunger index and the prevalence of underweight (% of children under 5), additional predictors and with a panel data quantile regression method.

This paper contributes to the existing literature on five essential points. First, instead of just pointing out the unconditional transitions of a country's level of food insecurity, we examine which combinations of fundamentals and policies can distinguish countries with low levels of food insecurity from those with high levels of food insecurity. Second, we highlight an unconditional or absolute convergence, through the Markov transition matrix and ergodic distribution. Our results assume that all the countries concerned have the same steady-state, so that convergence will lead all countries to a low level of food insecurity. Third, to our knowledge, this

is the first attempt to use a non-parametric classification scheme, the conditional inference regression tree, in the analysis of the determinants of food security. The technique allows for the flexible discovery of possible interaction effects between potential determinants. Forth, the regression tree technique can easily handle many potential determinants which is important in this analysis, tolerate the uneven presence of missing data across variables, countries, and time periods, and not have to make assumptions about the distribution random shocks. Five, we perform this analysis in a set of countries instead of a specific country as many papers analyzing the determinant of food security have done ([Arene and Anyaeji, 2010](#); [Beyene and Muche, 2010](#); [Rammohan and Pritchard, 2014](#)).

Our results demonstrated the non-existence of an unconditional hunger trap. The only unconditional trap that may exist is food security. Furthermore, food insecurity determinants seem closer to the capability approach developed by [Dreze and Sen \(1990\)](#) than to the malthusian approach. The key determinants of food insecurity are related to the country economic structure. Contrary to some studies on the high negative effect of biofuel production on food security, our results revealed that biofuels are not among the long-run key determinant of food insecurity. To achieve the 13th objective of Sustainable Development Goals (Climate Action) without reducing food security, biofuel production can be a solution.

The remainder of this paper is structured as follows. The following section provides an overview of food security in developing countries and reviews its main constraints. Then, Section [4.3](#) presents our data and the methodology we use to answer the research questions posed in this study. Section [4.4](#) presents the main results of our analysis. Section [4.5](#) shows the findings of the robustness check before concluding in Section [4.6](#).

4.2 Background

Although governments have signed numerous treaties and made many commitments since the 1990s to eradicate hunger in the world, the numbers remain alarming. Indeed, at the World Food Summit in Rome in 1996, and then in target 3 of the first Millennium Development Goal, governments pledged to reduce hunger in the world by half by 2015. Then, the second target of the Sustainable Development Goals aims to eliminate hunger by 2030. However, the latest FAO State of Food Security and Nutrition report (FAO, 2020) indicates that the world is not on track to achieve zero hunger by 2030. One of the main indicators measuring success or failure in progress toward this goal is the depth of the food deficit (DFD). This section provides an overview of the context of food insecurity in developing countries through this indicator, followed by the main determinants of food insecurity according to the literature.

4.2.1 Overview of food insecurity in developing countries

The DFD in kilocalories per person per day gives an estimation of the intensity of undernourishment in the population of a country and thus, indicates the average severity of undernourishment. It is calculated by considering the difference between the average energy requirement and average caloric consumption of the undernourished population. This difference gives the food deficit multiplied by the number of undernourished people and divided by the total population; thereby, the lower the DFD value, the better their level of food security. The prevalence of undernourishment is also considered as one of the main hunger indicators according to the UN's Food and Agriculture Organization. This indicator measures the share of the population with a dietary energy intake insufficient to meet the minimum energy requirements necessary for a given population. However, the proportion of undernourished people does not measure the average severity of undernourish-

ment and does not tell us the extent to which people live below minimum energy requirements.

Following the DFD data, the maps below show that many developing countries reduced their level of DFD from 1992 to 2016. Indeed, we can see a reduction in the number of countries with a DFD higher than 400 kilocalories between 1992 and 2016. In addition, in 2016, many countries had a food deficit level below 200 kilocalories per person per day; however, some countries, mainly in Sub-Saharan Africa, had a deficit above 200 and between 300 and 500 kilocalories per capita per day.

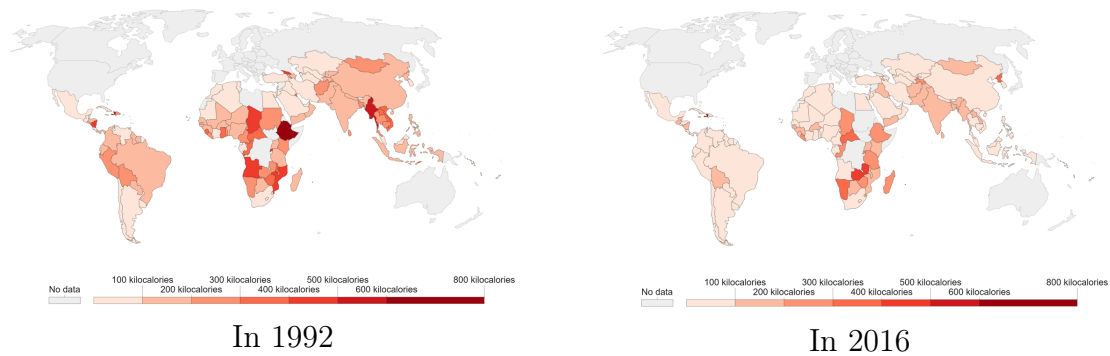


Figure 4.1: Depth of food deficit in kilocalories per person per day

Figure 4.2 shows us the food insecurity transition from 1992 to 2016 through the DFD. On average, we can see an improvement¹ of countries level of DFD from 1992 to 2016 as most of them are under the first bisector. This means a decrease in the severity of undernourishment. However, we could notice an increase in the severity of undernourishment in countries above the first bisector, such as Haiti, Zimbabwe, Central African Republic, Cote d’Ivoire, Liberia, Tanzania. Table 4.6 displays the level of DFD in 1992 and 2016 and its rate of variation from 1992 to 2016; unlike the other countries in our database, these countries had a positive growth rate indicating a deterioration in the level of food security.

Following the FAO food deprivation groups¹ and the maps above, we categorize our

¹According to FAO (2001), a DFD of 300 kilocalories is the threshold. A country with a level

sample in four groups: low food insecurity when the level of DFD is lower or equal to 100 kilocalories (e.g., Tunisia and Argentina); moderate food insecurity when the level of DFD is between 100 and 300 kilocalories (e.g., Kenya and India); high food insecurity when the level of DFD is between 300 and 500 kilocalories (e.g., Rwanda and Ghana); severe food insecurity when the level of DFD is higher or equal to 500 kilocalories (e.g.: Haiti and Ethiopia).

4.2.2 Determinants of food insecurity in developing countries

Based on the food security definition, food insecurity or hunger can be defined as a situation when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development, and active and healthy life. As it is one of the critical challenges worldwide, several studies have been done on food security concepts, definition, and determinants ([Barrett, 2002, 2010](#); [Pinstrup-Andersen, 2009](#)), or focused on factors affecting food security for a specific country ([Von Braun et al., 2003](#); [Misselhorn, 2005](#); [Eilerts and Vhurumuku, 1997](#)). This subsection presents the key drivers of food insecurity in developing countries and highlights the impact of biofuel production.

Hunger is linked to poverty as people living in poverty often face food insecurity. This is due to inappropriate care practices, unsafe environments, low access to or availability of health services and education, which contribute to hunger. Moreover, [Sen \(1981\)](#) shows that famine is not necessarily due to food availability, but rather to the ability of people to order food through legal means available in society such as the use of production possibilities, market opportunities, entitlements to the state, etc. Hence, higher economic growth and lower wealth and income inequalities

above 300 is considered highly food insecure, while a country with a level below 300 kilocalories is classified as low food insecure.

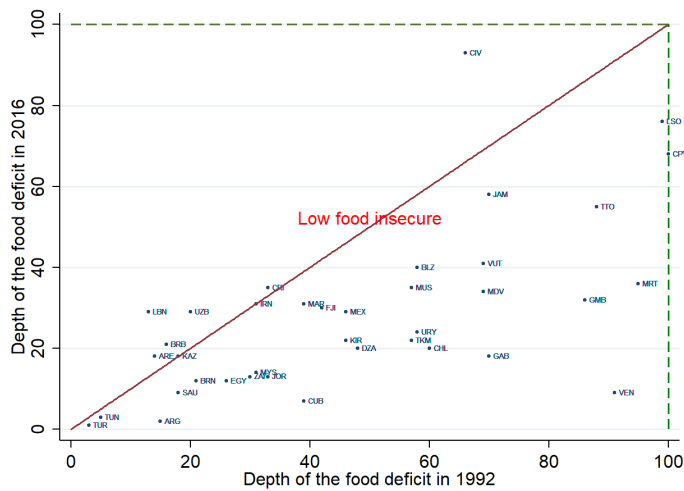
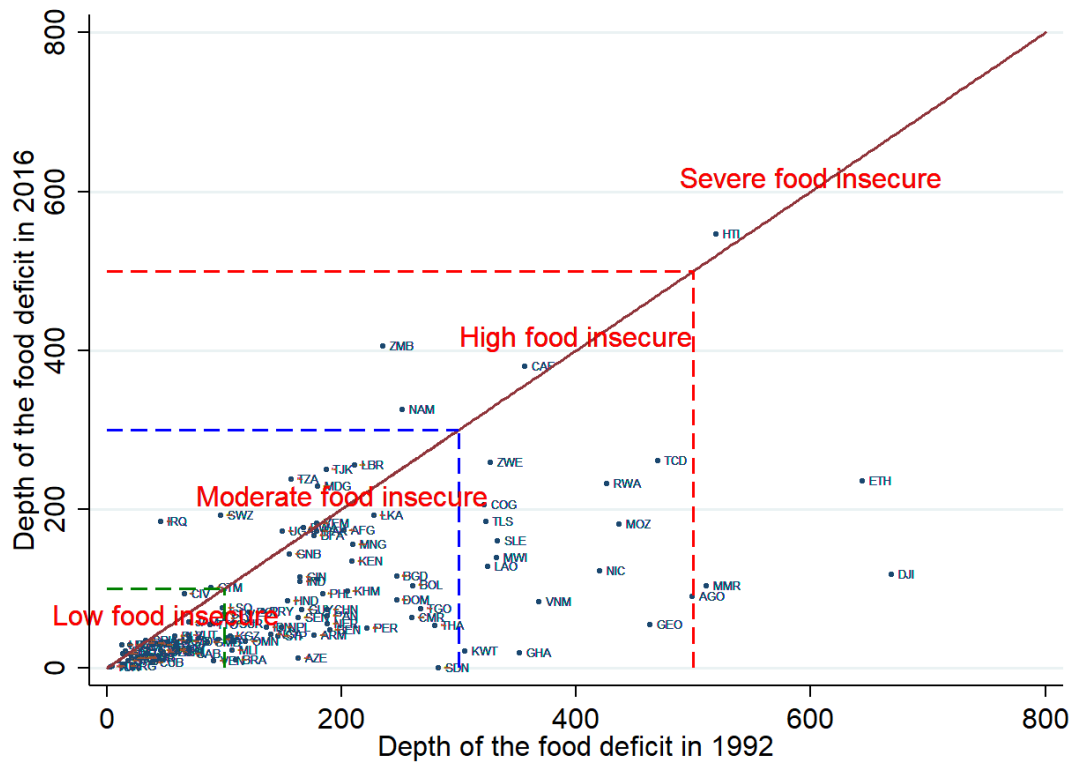


Figure 4.2: Food insecurity transition from 1992 to 2016

decrease food insecurity (Timmer, 2004). Specifically, based on an instrumental variables probit model, Babatunde and Qaim (2010) analysis in Nigeria revealed that economic growth and reduced wealth and income inequality contribute to improved

food security by increasing food access and production, and then farmers' income from food sales. Thus, among the measures aiming to ensure food security, economic growth rate and distribution, also known as pro-poor growth, seems very important. Therefore, efficient economic growth can reduce famine, undernourishment and favor food security, mainly in dry-land developing countries (Manap and Ismail, 2019). Likewise, countries' economic downturn negatively impact food availability and reduce people's ability to access food (Timmer, 2000a).

As seen in the previous paragraph, increasing farmers' income helps reduce food insecurity. This rise in income can be attributed to the increase in food and cash crop production, or to biofuel production (Negash and Swinnen, 2013). However, according to some studies, this renewable energy production is considered as an essential determinant of food prices variation and food insecurity. Biofuel production can rise food price volatility due to food supply variability (Beckman et al., 2012). In addition, biofuel subsidies contribute to driving up food prices, reducing net buyer's consumption and nutritional well-being (Afiff et al., 2013). For Ewing and Msangi (2009), though, there are possibilities for biofuel production to create jobs and local energy options, to provide benefits for the poor, food security, and offset the risks to their welfare. Through a meta-analysis, Choumert et al. (2018) also show that the promotion of biofuels leads to an improvement in income but also the level of GDP. Likewise, Boly and Sanou (2022) used a synthetic control method and showed that biodiesel production positively impacted Indonesia food security. Biodiesel export generated revenue that could be allocated to food import. In addition to biofuels, other factors can affect food security.

Food prices which are also related to food access, have a negative impact on food security, mainly for net consumers, because when they are high, they reduce their capabilities to get food (Timmer, 2000b). Since the poor spend about two-thirds of their income on food, a change in food prices implies a change in food access. Some

studies used a three-level hierarchical logit model to assess the Spatio-temporal dynamics of the food price shock observed in 2007-2009 ([Akter and Basher, 2014](#)) and found a negative impact on food access, mainly for net buyers and vulnerable people.

The food security threat posed by climate change is significant in developing countries and mainly in Africa, where agricultural yields and food production per capita have been steadily declining ([Masipa, 2017](#)). High rainfall intensity and temperature harm agricultural yields and food security ([Rosegrant and Cline, 2003](#)). [Wossen et al. \(2018\)](#) analysis in Ethiopia and Ghana showed through an Agent-Based Modelling that climate variability reduces both food security and household income. Likewise, extreme events such as drought or flood negatively affect food production by decreasing crop yields ([Wheeler and Von Braun, 2013](#)).

Most countries with the highest number of undernourished people also have high fertility rates and population growth. The production of food depends on croplands and water supply, which are under strain as population increases. Likewise, population growth often implies the destruction of vital forest resources or overexploitation of arable land to meet the population's needs. Therefore, population pressure jeopardizes food availability and access ([Jenkins and Scanlan, 2001](#)).

Armed conflicts and events reduce food access and food availability through declining food production and supply. Conflict is also a key driver of severe food crises, including famine ([Bode, 2018](#)). Indeed, of the 144 million stunted children, 85% live in countries affected by conflict. Using a difference-in-differences approach, [Martin-Shields and Stojetz \(2019\)](#) displayed that children under age five born in areas affected by civil war violence have a significantly lower weight than those born in other areas. Hunger and undernutrition are worse when prolonged conflicts and institutions are weak. In addition to civil unrest, countries' institutional quality may affect food security. Corruption, government instability, religious tension, and

poor socioeconomic condition could erode food security by mainly reducing food production and food access.

Although many studies analyze the determinants of food security, few of them focus on the analysis of the hunger trap and the absolute and or conditional convergence of countries towards a specific level of food security, which are the added values of this paper. Therefore, the following section will present the methodology used to assess the existence of a hunger trap and the associated results.

4.3 Methodology

This paper aims to assess whether some developing countries may be caught in a hunger trap. Specifically, we test the hypothesis of an unconditional hunger trap and then the the combination of fundamentals and factors that may affect food insecurity. To that end, we use the Markov transition matrix and the ergodic distribution to test the unconditional hunger trap, and the conditional inference regression tree analysis to assess the key determinants of food insecurity. Thus, in this section, we first describe the Markov transition matrix and the ergodic distribution, and then conditional inference regression tree. We conclude by presenting the data used.

4.3.1 Markov transition matrix and ergodic distribution

In this subsection, we focus on the transition probabilities of different levels of food insecurity by using the Markov transition matrix and ergodic distribution (Quah et al., 1992). This allows us to see where the distribution is headed if the current dynamics hold. Therefore, this distribution approach allows one to check what happens to the entire shape of the distribution, instead of only showing what happens to its mean as in β -convergence studies (Abreu et al., 2005), and dispersion as in σ -convergence studies (Furceri, 2005).

A transition matrix is defined as a square matrix that describes the transition probabilities from one state to another. In our case, it means the probabilities of moving from one group or one level of food insecurity to another and from one period to the next.

Let P_t be a $(n * 1)$ vector of the number of DFD levels distinguished to represent the distribution at time t . We have:

$$P_{t+1} = F * P_t \tag{4.1}$$

Where F is the transition Matrix allowing P_t transformation into P_{t+1} , the distribution for $t + 1$. Four levels of food insecurity gives the following form for our matrix:

$$F = \begin{pmatrix} l_{11} & l_{12} & l_{13} & l_{14} \\ l_{21} & l_{22} & l_{23} & l_{24} \\ l_{31} & l_{32} & l_{33} & l_{34} \\ l_{41} & l_{42} & l_{43} & l_{44} \end{pmatrix} \tag{4.2}$$

Each element l_{ij} of F provides the probability of moving from level i during the initial period to level j during the next. Specifically, l_{11} gives the probability to remain in the first level of food insecurity, in our case in the severe food insecurity level over a period, while l_{12} provides the probability of moving from level 1 (severe food insecurity level) to level 2 (high food insecurity level). To analyze this transition matrix, we also assume that on average the probabilities of switching to another group are similar for all countries in a given category of food insecurity.

$$P_{t+d} = (F^d) * P_t \xrightarrow{d \rightarrow \infty} \bar{P} \quad (4.3)$$

Following the transition matrix results, we can easily assess the probability of switching from one food insecurity level to another. Now, through the ergodic distribution, we will see whether countries in any group could end up in a low level of food insecurity.

If this matrix remains the same over time, the distribution after d periods could be obtained by repeating equation 4.1 d number of times.

$$P_{t+d} = (F^d)(P_t) \quad (4.4)$$

When d^2 goes to infinity, the distribution converges to an ergodic distribution or steady-state distribution \bar{P} .

The equation below allows us to get the expected time for a country belonging to other levels of food insecurity to move to the steady-state (low food insecurity).

$$t(i, j) = 1 + \sum_{k \neq j} l_{i,k} \times t(k, j) \quad (4.5)$$

Where $t(i, j)$ is the expected time to move from level i to the steady-state j , and $l_{i,k}$, the probability to move from level i to k . k represents each intermediate level between i and j .

The transition matrix results and ergodic distribution allow us to test whether an unconditional hunger trap exist. A country with a severe, high or moderate levels of food insecurity that grows at the average or median rate of the group will not become a low food insecure country. Suppose the results allow us to reject the

²In this analysis, d was equal to 1000.

hypothesis of unconditional hunger trap. In that case, we will then perform the conditional inference regression tree analysis to identify the key determinants of food insecurity.

4.3.2 Conditional inference regression tree analysis

Several methods have been used to assess the determinants of food security and their impacts. These methods include scenario simulations, panel probit or logit model, local projection approach, synthetic control, etc. However, these methods present some limits. The probit model requires a normal distribution for all unobserved components, while a logit model needs a logistic distribution. These parametric methods assume that the population can be adequately modeled by a probability distribution that has a fixed set of parameters which may lead to the transformation of data. In addition, they are sensitive to outliers, missing values, and cannot be performed with too many variables. The synthetic control method is mostly used for comparison purposes and therefore focuses on the effect of an event or policy. Therefore, to identify the key determinants of food insecurity we consider in this paper, the conditional regression tree method, a non-parametric method. Contrary to a parametric method, a non-parametric method does not need any assumption regarding the data generation process. Moreover, it is robust to outliers, missing data, and can be performed with many variables³ which is advantageous for our study, as there are many factors that could affect food insecurity.

The regression tree method ([Breiman et al., 2017](#)) is a machine learning method that can be explained following two processes. Firstly, the algorithm looks for the split point of the predictor that best predicts food security, then this particular predictor and splitting point makes two children's branches grow from the parent node. Secondly, the algorithm divides each of the child nodes until further division

³It can be performed with more than 20 variables.

does not improve predictability. In the final tree, each observation will result in one of the end nodes. The expected level for each end node is simply the average of the countries belonging to that node. Therefore, for prediction purposes, we first determine the final node of a country based on the values of its fundamentals. Then the food security level of that final node will be assigned to the expected level for that country. So, this method will allow us to find which proposed determinants of food security are the most relevant. Moreover, by using this method, we can manipulate many variables without making assumptions about the distribution of the random shocks. Likewise, trees can be graphically displayed and are easier to explain than linear regression. Finally, compared to linear regression analysis, this technique does not require any transformation of variables. It is robust to outliers and has a greater tolerance of missing data without having to impute values. However, the regression tree analysis results are potentially sensitive to changes in the sample.

Specifically, we use the conditional inference regression tree ([Hothorn et al., 2006](#)) a non-parametric classification technique. It corresponds to a refinement of the regression tree analysis that brings a tested hypothesis in the decision of each split. A split is performed if the null hypothesis that the proposed split does not improve the predictive power can be rejected. Because it makes splitting a predictor conditional on other correlated predictors, it pulls through the criticisms of traditional regression tree analysis that favors choosing correlated predictors to perform the splitting method.

This method separately searches for the best predictor to perform the split and the search for the optimal split value. First, based on the linear statistics ([Strasser and Weber, 1999](#)), the relationship between a variable and the response evaluated by the permutation tests follows a χ^2 distribution. The null hypothesis is no association between a predictor and the response. With a smaller p-value, the probability of falsely rejecting the null hypothesis is lower. Therefore, the variable with the smallest

p-value is chosen to perform the split in the first step. The best cut-off point for the most significant variable chosen in the first step is determined in the second step. For each of the two branches associated with the first split, another variable with the strongest association with the response is sought among all the variables. The other branches of the tree will grow in the same way. Thus, the conditional inference regression tree allows classifying and finding the most relevant determinants for each level of food insecurity. It does not directly determine causal effects, but it is a step toward identifying causal variables. Specifically, it is a classification exercise that looks for combinations of policy and fundamental variables that separate countries with low levels of food insecurity from those with high levels. Thus, if a variable is not considered by the regression tree method to be a predictor of food insecurity, it is unlikely to be a cause.

We can find a relationship between the regression tree and the linear Bayesian Model Averaging (BMA) approach ([Hinne et al., 2020](#)). The linear BMA approach imposes a linear relationship between food security and potential correlates. However, the regression tree approach allows for all deviations from linearity in a very flexible manner, and the existence of any non-linearity is subject to statistical testing. A variable that is robust in the linear BMA may not be robust in the regression tree. Similarly, a variable that is not robust in the linear BMA may be relevant in some combination with other variables in a regression tree.

4.3.3 Data

We perform these analyses by using 110 developing countries from 1992 to 2016 and several variables. As a dependent variable, we use the depth of food deficit. Following the determinants of food security mentioned above, we considered variables related to the population structure, economic structure, renewable energy production, weather and climate change, and conflicts and institutional conditions.

Population structure

Predictors related to population structure are the annual population growth (%) and age dependency ratio (% of working-age population). According to the literature (Jenkins and Scanlan, 2001; Tilman et al., 2001), the larger and younger the population, the greater the negative impact on food security because this situation could increase food demand and reduce food access. However, other studies suggest that this could be beneficial to food security in the sense that more people mean a larger labor force for food production. We, therefore, expect our results to indicate a threshold below and above which their effect on food security could vary.

Economic structure

Those linked to the country's economic structure include the gross domestic product (GDP) per capita (constant 2010 US\$), trade openness, socioeconomic conditions index, investment profile index, government stability index, wage and salaried workers (% of female employment), wage and salaried workers (% of male employment), contributing family workers(% of total employment), manufacturing value-added, access to electricity (% pf population), food net export, agricultural land and employment in agriculture. We assume that for these variables the higher they are, the better for food security (Barrett, 2002; Devereux et al., 1993; Magrini et al., 2017). We also include total of unemployment (% of total labor force), corruption index, and the total external debt stocks (% of GDP). We suppose that for these variables the lower they are, the better for food security. Moreover, we consider natural resource rent and extractive dependence index. Following the dutch disease theory, we suppose that these variables can have a positive or negative impact on food security under some specific conditions. Natural resource rent could lead to an appreciation of national currency, which would benefit net food-importing countries (Comunale, 2017; Huchet-Bourdon et al., 2013). Thus, our result will provide a

threshold below and above which natural resources rent impact on food security could differ.

Renewable energy production

As renewable energy production variable, we choose biofuel production (1000 barrels per day). Based on the literature, we assume that under some conditions, biofuel production can positively or negatively affect food security ([Ewing and Msangi, 2009](#); [Zilberman et al., 2013b](#)). Therefore, we suppose that a threshold exist, below and above which Biofuel production can favor food security or it increase hunger.

Weather and climate change

We consider temperature, precipitation, evapotranspiration, the occurrence of extreme weather events, and natural shock index, to assess weather conditions and extreme weather events. Further to the literature, we can suspect there is a line below and above which the impact of precipitation, temperature, and evapotranspiration on food security can differ. Indeed, several studies point out that too much rain harms food production while others suggest that too low rain also hurts food production. The same applies for temperature and evapotranspiration. Furthermore, the occurrence of extreme weather events and natural shock index negatively impact food production and access ([Harvey, 2011](#); [Schwab and Sala-i Martin, 2015](#)).

Conflicts and institutional conditions

To assess the effects of armed conflicts and events, the following predictors were added: internal conflict index, external conflict index, military in politics, number of battles, explosions, riots, violence against civils and religious tensions. These variables negatively affect food security ([Martin-Shields and Stojetz, 2019](#); [Bode, 2018](#)) through the negative effect they can have on each dimension of food security mainly availability and access.

Other predictors

Furthermore, we take into account the shock sub-index and the exposure sub-index. The shock sub-index can be defined as the weighted average of 3 indexes (the victims of natural disasters, the instability in the export of goods and services, and the instability in agricultural production). Therefore, this predictor can be linked to those related to economic structure, and extreme weather events. This variable has a negative impact on food security as when the victim of natural disasters is important this may reduce food production, access and food security. The same goes for instability in the export of goods and agricultural. The exposure sub-index is the weighted average of 5 indexes such as population size, remoteness from the world market, exports concentration, the share of agriculture, forestry and fishery in the GDP, and the share of population living in the low elevated coastal zone. Thus, it can be associated with the predictors of economic and population structure. Each of these variables affects at least one of the dimensions of food security (availability, access, utilization, and stability). We assume that the lower it is, the better for food security. The table 4.5 provides the descriptive statistics and table 4.8 the source of each variable.

4.4 Results

For our analyses, we computed five-year periods and considered the value at the beginning of each period and the thresholds previously defined to categorize countries in a level of food insecurity. This section presents the results of the transition matrix and the ergodic distribution. Then, based on their results, we also performed the conditional inference regression tree.

4.4.1 Markov transition matrix and ergodic distribution

The table below displays the results of the transition matrix⁴. Specifically, the first cell shows that a country classified as severely food insecure has a 50.00% probability of staying in the same level. The second cell indicates that the probability of moving to the level of high food insecurity is 50.00%. The remaining cells in the first row allow concluding there is zero probability of becoming moderate or low food insecure. The same explanation applies to other rows. For a country that started as low food insecure, the probability of remaining in the same level is 92.7%, while the probability of getting back to a level of moderate food insecurity is 7.30%. These results highlight the fact that the probability of obtaining an improvement in the food security situation is higher than the opposite.

Table 4.1: Average transition matrix (in %)

	Severe FI	High FI	Moderate FI	Low FI
Severe food insecurity	50.00	50.00	0.00	0.00
High food insecurity	2.17	43.48	52.17	2.18
Moderate food insecurity	0.00	3.90	78.54	17.56
Low food insecurity	0.00	0.00	7.30	92.70
Ergodic distribution	0.00	0.00	0.00	100.00
Average expected time to move to Low FI(years)	9	8	5.3	
Expected time for 50% of observations (years)	6.7	6.7	5	
Expected time for 75% of observations (years)	9.3	7.5	5.2	

Given the ergodic distribution result, we can be ensured that in the long run, all countries of our sample belonging to the severe (, high, and moderate level of food insecurity will end up at the low level. In addition, on average, a country in a situation of severe (Ethiopia, Djibouti or Haiti), high (Mozambique, Central African Republic or Sierra Leone) or moderate (Bolivia, Cambodia or Cameroun) levels of food insecurity has more than 50% chance of having a negative growth rate of

⁴These probabilities have been calculated over the whole period, and the sum per row is 100%.

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the DFD (table 4.5) which means an improvement of their level of food security. Thus, all the countries considered in this analysis, are always expected to move to the low level of food insecurity. Since the thresholds used to categorize the level of food insecurity are exogenous, we modified their values to see if this could have a significant impact on the unconditional hunger trap hypothesis we are testing. The results indicate some small variations of the probabilities, however, the ergodic distribution findings remain the same; which enable us to be confident that in the long run, all states will converge to the low level of food insecurity.

We might then ask how long does it take for a set of countries at one level (severe, high, or moderate) to move to low food insecurity? According to the transition matrix results, it will take an average of 9 years⁵ for a severe food insecure country (Ethiopia or Haiti) to move to the low level. Similarly, it will take 8 and 5.3 years, for a high (Mozambique or Cameroon) and moderate food-insecure country (Cambodia) to reach the low level. Furthermore, to take into account the distribution of countries, we considered in each group of food insecurity, the country-period having a level of the depth of the food deficit below the median (50%) and the third quartile (75%) value. We found that countries classified as severe food insecure and whose food deficit depth value is below the median value (Haiti), will take about 6.7 years to reach the low level. Severe food insecure countries below the third quartile (75%) value include Ethiopia and Djibouti. Considering these countries, the transition time increases to 9.3 years.

As the results allow us to reject the unconditional "hunger trap" hypothesis, and given that each country presents specific contexts and characteristics, it is essential to check the conditional hunger trap or determine the conditions under which a country could find itself in a high level of food insecurity. In other words, it is necessary to

⁵The results give us 1.8 periods, and as mentioned above (see data section), we considered periods of five years; therefore, $1.8 \times 5 = 9$. Furthermore, it will take an average of 1.6 and 1.06 periods for high and moderate food-insecure countries, respectively.

identify the key determinants of food insecurity or the combinations of fundamentals that can distinguish countries with low levels of food insecurity from those with high levels of food insecurity. Thus, the non-parametric method, conditional inference regression tree, described above will provide the main conditions and variables for which a country could be at a low or high level of food insecurity.

4.4.2 Conditional inference regression tree analysis

This section is divided into three subsections. First, we present the result of the conditional inference regression tree performed in the overall sample and then the results in the sub-sample of low and high food insecure countries.

Overall sample

Figure 4.3 shows the conditional inference regression trees for the overall sample with the variables used for each split and the associated p-values. For each division, the right branch displays the result when the values of the division variable are above a threshold value of the parent node, while the left branch shows the result when the values are below or equal to the threshold. The final nodes indicate the number of observations and the predicted value of the depth of food deficit obtained with the relevant combination of the preceding variable values. The predicted value of the depth of food deficit corresponds to the median values over 5 years. The results indicate that among all the variables considered for this analysis, the most critical variables for their level of food deficit are: GDP per capita, evapotranspiration, natural shock index, employment in agriculture, socioeconomic condition index, access to electricity (% of the population), exposure sub-index, age dependency ratio, and food net export. However, biofuel production does not appear in the tree. The variable considered most relevant to determine the depth of the food deficit is GDP per capita. This variable competed with all other variables in explaining

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the level of the food deficit and was found to have the highest explanatory power. Thus, any country-period whose GDP per capita (log) exceeds 7.77 (2368.47\$US per capita ⁶ such as Argentina Turkey, Brazil, Mexico and Ecuador), is classified in the right-hand branch group and the others (Ethiopia, Mozambique, Djibouti, Cambodia, Cameroon and Haiti) in the left one. After the first split, all variables compete to perform the next split until the regression tree attains the stopping criterion. Thus, for countries with a GDP per capita value (log), less than or equal to 8.783 (6522.42 \$US per capita), the depth of the food deficit will also depend on the percent of the population having access to electricity. If this percent is less than or equal to 97.195, the predicted average value of the log of our dependent variable will be 4.5, or about 90.017 kilocalories per person per day⁷. Some of the country-periods in node 17 include Ecuador in 2012 and Brazil in 2002. By doing this systematically, all observations classified into the same final nodes share the same range of explanatory variables and have similar food deficit depth values. The regression tree technique allows threshold and interactive effects to be handled flexibly. It favors one variable to contribute to our food security variable only after another variable has reached certain levels. For example, does a low exposure index contribute to food security? The regression tree results indicate that this is correct, but it also requires a high level of GDP per capita.

High food insecurity

Since we assume that all countries in our sample aim to become low food insecure and then achieve food security, we group severe, high, and moderate food insecure countries together. Thus, figure 4.4 provides the conditional inference regression tree result in the countries labelled as highly food insecure. Of all the variables considered for this analysis, the relevant variables for categorizing their level of the

⁶ $e^{7.77} = 2368.47$

⁷ $e^{4.5} = 90.017$

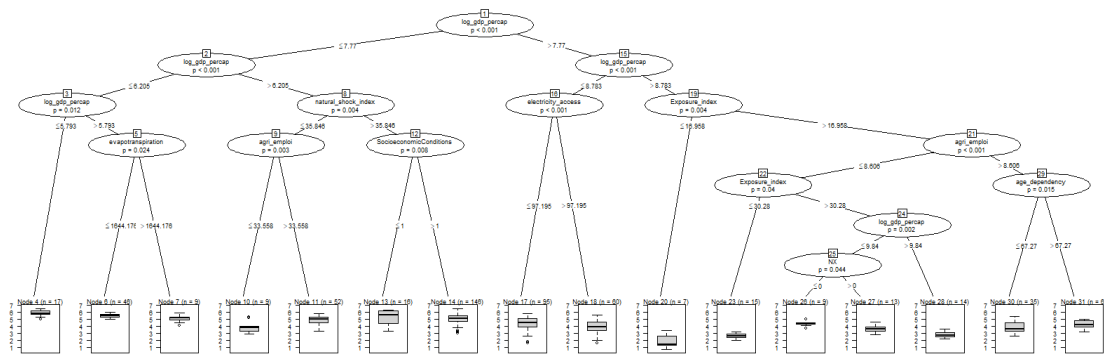


Figure 4.3: Conditional inference regression tree in the overall sample

depth of the food deficit are the level of GDP per capita, age dependency ratio, precipitation, socioeconomic conditions, and corruption index. The most important variable is GDP per capita, and biofuel production is not among the determinants revealed by the tree as with the overall sample. A low level of GDP per capita favors food insecurity; indeed, country-periods with a GDP per capita (log) less than or equal to 5.462 will have the highest depth of food deficit. As we can see in figure 4.4, this characteristic leads to node 3, and some of the country-periods involved are Mozambique in 1992 and Ethiopia in 1997 (see table 4.2). Then, for those with a GDP per capita (log) greater than 6.077, their level of the depth of the food deficit will also depend on the socioeconomic conditions. If the socioeconomic condition index is less than or equal to 1, the average predicted value of the log of our dependent variable would be 6.05 or about 424.11 kilocalories per person per day. However, suppose the level of the index is higher than or equal to 1, and the level of annual precipitation is higher than 1738.988 mm, as we can see in figure 4.4. In that case, the country-period in node 15 will have the lowest median value of the depth of the food deficit. Some of the country-periods concerned are Cambodia and Cameroon in 2007 (see table 4.2). The predicted value of DFD is 4.90 or about 134.3 kilocalories per person per day, and the associated predicted error is low, attesting to a good prediction of the DFD by this method.

Even if they did not specify a threshold, several studies assess the role of GDP per capita on food security. Baer-Nawrocka and Sadowski (2019) analysis displays that countries with the lowest GDP per capita, mainly from Sub-Saharan Africa and Central Asia, presented the lowest energy supply per capita; while countries with the highest GDP per capita presented the largest energy supply per capita. They also indicated that worldwide, general economic growth contributes to reducing famine. Additionally, Luan et al. (2013) showed that a seriously unbalanced domestic economy but also large disparities between rich and poor determine low food self-sufficiency. Moreover, for Smith et al. (2017), low socioeconomic conditions through low levels of education, poorly developed social networks and low social capital make food insecurity a much more likely experience.

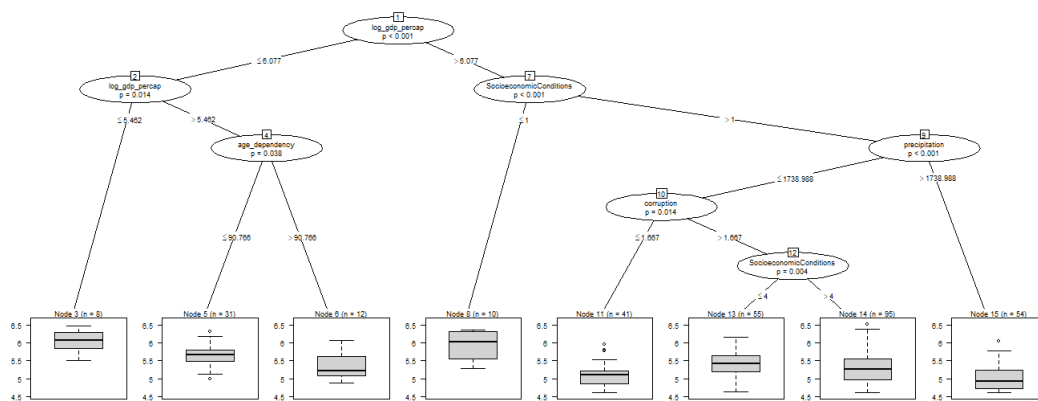


Figure 4.4: Conditional inference regression tree in high food-insecure countries

Low food insecurity

Figure 4.5 shows the conditional inference regression tree results for low food-insecure countries. As for the overall sample and high food-insecure countries, the most important determinant of the depth of the food deficit is the GDP per capita. Otherwise, among all the variables used to perform the analysis, the relevant variables to categorize the level of the depth of the food deficit include GDP per capita, precipitation, exposure sub-index, and conflict events such as explosions. Biofuel production again does not appear in figure 4.5. These results still highlight

the importance of high GDP per capita for food security. Indeed, the low predicted values of the depth of the food deficit appear for country-period with a GDP per capita (log) higher than 8.783 (6522.42 \$US per capita). Then, country-period with a level of exposure sub-index less than or equal to 16.95 will end in node 12 with a median predicted value of the depth of the food deficit (log) of around 1.5 or 4.48 kilocalories per capita per day. Countries of node 12 include Turkey and Mexico. Table 4.3 and 4.2 provide some examples of country-period per final node with the absolute value of the predicted error⁸. We notice that the predicted errors are pretty low, indicating a good prediction of the outcome and the relevance of the identified determinants.

As presented in the data section, exposure sub-index is the weighted average of indexes including population size and remoteness from the world market; therefore, The lower its value, the better for food security. This finding is in line with [Jenkins and Scanlan \(2001\)](#), who displayed that population pressure hurts food security and that most of the countries with the highest number of undernourished people also have high fertility rates and population growth. Moreover, high remoteness from the world market can jeopardize food security as trade between regions favors movement from food-surplus areas to food-deficit areas ([Katengeza et al., 2011](#)). Furthermore, [Bode \(2018\)](#) indicated that conflict events are among the key drivers of food crisis and famine as they lead to decrease food access and availability.

These results indicate that the understanding of food insecurity in developing countries is closer to the theory of the capability approach developed by [Dreze and Sen \(1990\)](#) and later extended by [Burchi and De Muro \(2016\)](#) than the malthusian approach focused on food availability and more specifically on food supply failure. Indeed, the key determinants are mainly related to the economic structure, climate

⁸The predicted error is the absolute value of the difference between the real and the predicted value of the DFD.

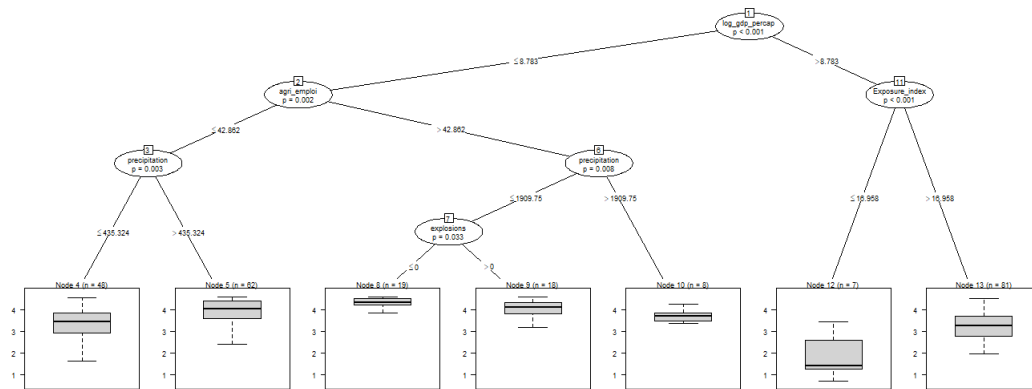


Figure 4.5: Conditional inference regression tree in low food-insecure countries

change, institutional factors and armed conflicts.

4.5 Robustness check

Although the regression tree analysis has many advantages, its results are sensitive to variations in the sample (Shmueli et al., 2007). Therefore, to check the robustness of our results, we consider another nonparametric method, the boosted random forest. We also perform the conditional inference regression tree on the overall sample with other dependent variables (prevalence of underweight (% of children under 5) and the global hunger index), and with additional predictors (Official development assistance and real exchange rate). A parametric method, the panel data quantile regression, has been also used.

4.5.1 Boosted Random forests

The random forest technique considers and examines sensitivity to each sub-samples (Breiman, 2001; Hapfelmeier, 2012). This is a combination of trees, each constructed based on an independently drawn random sub-sample. This method construct a forest of decision trees on bootstrapped training samples. Whenever a split in a tree

is considered, a random sample of X predictors is chosen as split candidates from the full set of p predictors. The number of predictors at each split is approximately one-third of the total number of predictors.

$$X = \frac{p}{3} \tag{4.6}$$

Random forests solve the problem of heteroscedasticity that may occur by considering only a subset of the predictors for each division. However, it requires many decision trees because fewer decision trees reduce performance. Therefore, when applied on a small scale, it cannot retain its generality. This is why boosting is introduced in the random forest ([Mishina et al., 2015](#)).

Boosting is a general approach that aims at improving the predictions resulting from the decision tree, and can be applied to statistical learning methods for regression or classification ([James et al., 2013](#)). With this method, trees are grown sequentially by using information from previously grown trees. Specifically, the boosting combines many decision trees⁹ $\hat{f}^1, \dots, \hat{f}^B$. In contrast to fitting a single large decision tree to the data, which would mean strictly fitting the data and potentially overfitting it, the boosting approach learns slowly. It fits a decision tree to the residuals in the model. In other words, the procedure is to fit a tree using the current residuals, rather than the Y result, as the answer. Then we add this new regression tree to the fitted function to update the residuals. Each of these trees can be quite small, with only a few terminal nodes determined by the parameter d of the algorithm. Boosting results allow us to get the relative influence of each variable on the outcome and thereby check if they are in line with the conditional inference regression tree results.

The boosting has three settings. First, the number B of trees selected with cross-validation. Second, the shrinkage parameter ρ whose typical values are 0.01 or 0.001

⁹In this study, the number of decision trees was 5000.

controls the boosting learns rate. A very small ρ may require using a huge value of B to achieve good performance.

The boosting results in figure 4.10 show us the relative influence of each variable on our food security indicator in the overall sample. Hence, giving the results, we can be ensured that, like in the conditional inference regression tree, the most important determinant is the level of GDP per capita, then the employment in agriculture (% of total employment) and exposure sub-index. Although biofuel production appears among the variables that could influence food security in the long run, its influence is very low around 0.01%. These results can allow us to think that biofuels' long-run effects on food security can be negligible. The other key determinants revealed by the boosting results include the level of wage and salaried workers (% of female employment), precipitation, evapotranspiration, agricultural land, age dependency ratio, external debt, contributing family workers (% of total employment), socioeconomic conditions, access to electricity, food net export, shock sub-index, climate events occurrence, government stability, external conflict, corruption, conflict events such as explosions and protests.

We also run this model on the sample of high and low food-insecure countries (see figure 4.13 and 4.5); the results reveal that GDP per capita is among the three main determinants. However, it seems that employment in agriculture and exposure sub-index are respectively the most relevant for high and low food insecure countries. Furthermore, the biofuel production effect appears again negligible. Its relative influence on the outcome compared to the other variables is 0.12% in the high level sample and 0.66% for the sample of low food insecure countries.

To assess the model accuracy, we also compute the mean squared error (MSE) through the equation below:

$$MSE = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{f}(x_i))^2 \quad (4.7)$$

Where $\hat{f}(x_i)$ gives the prediction for the i th observation and y_i the real value of the depth of the food deficit for the i th observation. Therefore, the MSE allows quantification of the extent to which the predicted value for an observation is close to its true response value. The lower the MSE, the better the prediction. Since, on average, we are primarily interested in the accuracy of the predictions we obtain by applying our method to unseen test data rather than the effectiveness of the method on the training data, we divided our dataset into two, training and a test dataset. Specifically, we want to know if the predictive value of the depth of the food deficit is very close to its real value for an unseen test observation. For the overall sample, the results of the MSE computed on the test and training dataset respectively show 0.47 and 0.22. For the sample of high food insecurity, the results of the MSE computed on the test and training dataset respectively give 0.14 and 0.06. In the low food insecurity sample, we get 0.43 and 0.13 for the MSE computed on the test and training dataset. As the MSE value in the test and the training data is very low, we can be ensured on the model's prediction quality and robustness.

4.5.2 Other dependent variables: prevalence of underweight (% of children under 5) and the global hunger index

In addition to the depth of the food deficit, the prevalence of underweight as a percentage of children under 5 and the global hunger index are two other main indicators of hunger.

- Prevalence of underweight

The prevalence of underweight measures the share of children under 5 who are underweight over a long period of time. It can include children who are stunted, wasted, or suffering from insufficient energy intake. It is one of the two indicators used to monitor the hunger target of the Millennium Development Goals (MDGs) ([Hickel, 2016](#)). Figure 4.16 draw through data coming from the World Development

Indicators database the evolution of the underweight children from 2000 to 2020. We can notice worldwide a decrease in the prevalence of underweight, however, it is still high in Sub-Saharan Africa and low and middle-income groups. This points out the fact that food insecurity is a crucial challenge mainly for the developing world.

Considering this indicator as our dependent variable, we performed the conditional inference regression tree in the overall sample. As for the previous results, we can see that the most important variable to predict the level of the prevalence of underweight is the GDP per capita; While biofuel production does not appear. Hence, the higher the level of GDP per capita, the lower the level of food insecurity. Figure 4.6 also shows other key determinants to food insecurity such as agricultural land, the occurrence of extreme weather events, female wage, food net export, evapotranspiration, access to electricity, precipitation, external conflict index, Socioeconomic condition index, age dependency ratio and contributing family workers. Following node 40, we can see that the combination of a high level of GDP per capita, female wage, precipitation, socioeconomic condition with a low corruption index and age dependency ratio, allow getting a predicted value of the prevalence lower than 5%. Examples of countries in node 40 are Argentina, Brazil, Turkey and Mexico.

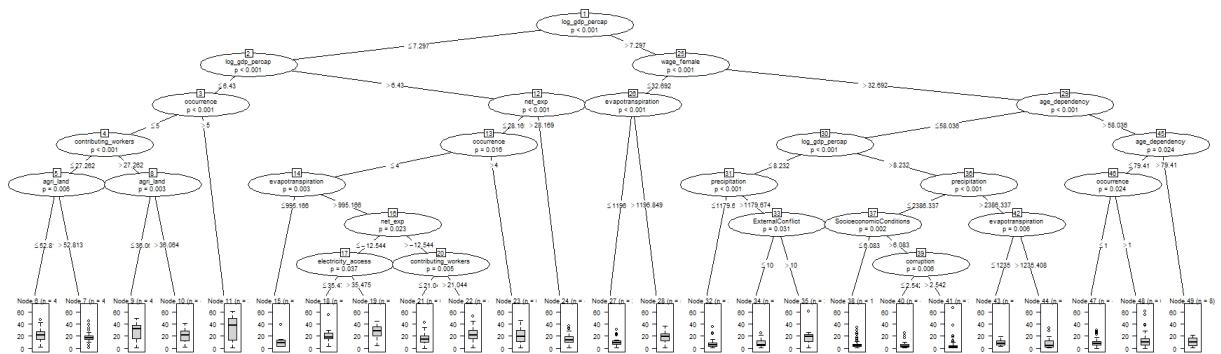


Figure 4.6: Conditional inference regression tree in the overall sample

- Global hunger index

There are many indicators to track progress on malnutrition. In order to capture and

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track progress with a single measure, the International Food Policy Research Institute (IFPRI) defined the Global Hunger Index (GHI). It is designed to comprehensively assess and track hunger at the global, regional and national levels (Von Grebmer et al., 2017). It attempts to assess the multidimensional nature of hunger, combining four key indicators of malnutrition: the proportion of undernourished people as a percentage of the population, the proportion of children under the age of five who suffer from wasting, the proportion of children under the age of five who suffer from stunting, and the mortality rate of children under the age of five. The index is based on a scale of 0 to 100 where 0 is the highest score. Although it provides good tracking of hunger by region, country and globally, it is less used in empirical analyzes due to the high rate of missing values.

Using this indicator as our dependent variable, the conditional inference regression tree results (see figure 4.7) indicate that a high level of GDP per capita is the most important determinant of food security. Furthermore, we also have other factors similar to the previous results such as age dependency ratio, female wage, the occurrence of extreme weather events, access to electricity, and employment in agriculture. Following node 7, we can see that a high level of age dependency ratio ($>80.9\%$) combined with a low level of GDP per capita (log value <5.8) leads to a high level of food insecurity as the predicted value of GHI is higher than 40. Countries in node 7 also include Ethiopia, Mozambique and Djibouti. Moreover, as was the case when considering the prevalence of underweight and depth of the food deficit, biofuels are not among the major determinants of food insecurity.

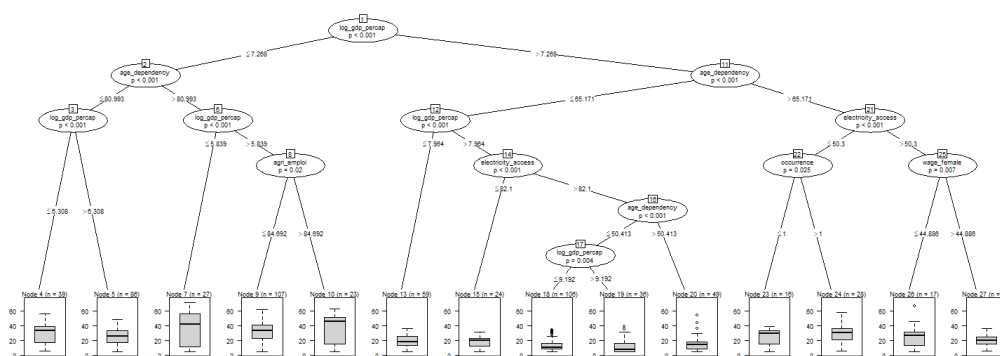


Figure 4.7: Conditional inference regression tree in the overall sample

4.5.3 Additional explanatory variables: real effective exchange rate, and net official development assistance and official aid received per capita

To test the robustness of our results we also include additional predictors such as the real effective exchange rate, and the net official development assistance and official aid received per capita.

According to the literature on the determinant of food security, the exchange rate can have a significant impact on food security, especially for vulnerable developing countries (Laroche-Dupraz et al., 2013). Specifically, Huchet-Bourdon et al. (2013) shows, in the short run, a depreciation of the national currency contributes to a deterioration of food security due to the increase in the food import bill and the decline in net export earnings; while an appreciation of national currency leads to improve food security, mainly in net importer countries. Hence, the real effective exchange rate was considered as a predictor related to the economic structure. Otherwise, following the literature on the rent of natural resources and the Dutch disease, the exchange rate makes it possible to capture the effect of the rent of natural resources. Indeed, the exploitation of resources favors the appreciation of the national currency (Comunale, 2017). Therefore, in this subsection, we run the

conditional inference regression tree analysis by adding the real exchange rate and removing the natural resource rent and extractive dependency index.

We also deemed the net official development assistance and official aid received per capita. Following the literature, aid has a positive impact on food security through an improvement in the level of food supply and access. [Clover \(2003\)](#); [Blizkovsky and Emelin \(2020\)](#) analysis show that the aid received leads to a significant increase in food production by means of the enhancement of agricultural performance and its contribution to the economy of developing countries. Some studies, though, point to the negative effect of foreign aid on institutions and economic growth, which they describe as the aid curse ([Djankov et al., 2008](#); [Lensink and Morrissey, 2000](#)). A large influx of aid does not necessarily increase well-being. High levels of aid can make it difficult to resolve the collective action problems inherent in reform efforts, creating moral hazard for recipients and donors alike. Therefore, when income does not depend on taxes collected from citizens and businesses, there are fewer incentives to responsibility. At the same time, corrupt government officials will try to perpetuate their rent-seeking activities involving low economic growth and food insecurity. [Wooster \(1997\)](#) explains that the civil war in Somalia was caused by the desire of different actors to control the large amount of food aid the country was receiving. We therefore assume the existence of a threshold above and below which the effect of the aid may vary.

Figure 4.8 provides the conditional inference regression tree results performed in the overall sample and including the real effective exchange rate and the official development assistance among the predictors. We can see that the main determinants of food security remains the GDP per capita and that biofuel production do not appear. Furthermore, official development assistance has an impact on food security, and it seems that the lower it is the better for food security. In fact, the low level of DFD is observed for country with a level of aid received per capita lower than or

equal to 5.82\$, such as Turkey, Argentina or Brazil.

The real effective exchange rate does not appear in the tree (figure 4.8), but the boosting model performed (see figure 4.15) allows us to conclude that even if its relative influence is low (1.51%), the exchange rate can be considered among the long-term determinants of food security. Furthermore, the relative influence of the aid received per inhabitant is also low, around 1.55%. As noted in previous sections, the most influential variable is again GDP per capita with the same level 30% and biofuels have the weakest influence (0.02%), which highlights the robustness of our results.

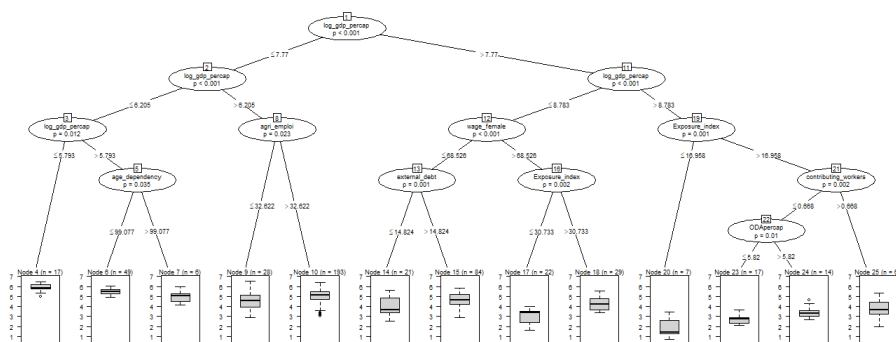


Figure 4.8: Conditional inference regression tree in the overall sample

4.5.4 Parametric method: panel data quantile regression

Since we used a non parametric method, the conditional inference regression tree, to test the existence of a conditional hunger trap by determining the key factors of food insecurity, in this subsection, we consider a parametric method, the quantile regression (Koenker and Hallock, 2001; Koenker, 2004) to check the accuracy of determinants of food insecurity identified. This method is less robust than the non parametric carried out above because it cannot take too many variables, however, it will allow us to test the effect of GDP per capita and biofuel production, and their significance on the level of the depth of the food deficit.

Quantile regressions are statistical tools whose purpose is to describe the impact

of independent variables on specific percentiles of a variable of interest. They allow a higher description than classical linear regressions, since they are interested in the entire conditional distribution of the variable of interest and not just the average of it. It is, therefore, a tool available to the econometrician to address the inherent limitations of the mean. Moreover, they can be more adapted for certain types of data including censored or truncated variables, presence of values extremes, non-linear models, etc. This method has two main advantages over least-squares regression. It can make no assumptions about the distribution of the target variable and tends to resist the influence of outliers. Many studies considered this method in their analysis. [Charnoz et al. \(2011\)](#) used it on french data to study the determinants of wage inequality and [Cornec \(2014\)](#) used it to forecast economic conditions.

Following [Machado and Silva \(2019\)](#), we apply a panel data quantile regression model. More precisely and as mentioned above, we are interested in estimating the conditional quantiles of the depth of the food deficit whose distribution is conditioned on a vector of covariates including GDP per capita and biofuel production, via the equation below:

$$DFD_{it} = \alpha_i + \beta X_{it} + (\phi_i + Zit\gamma)U_{it} \quad (4.8)$$

where DFD_{it} is our dependent variable, the depth of the food deficit; X_{it} is the k-vector of covariates; Z is a k-vector of known differentiable transformations of the components of X ; U_{it} is an unobserved random variable, independent and identically distributed across i and t , and independent of X_{it} ; α_i and ϕ_i two parameters capturing fixed effects; with $Pr\phi_i + Zit\gamma > 0 = 1$.

The results of quantile regression for our two variables of interest, GDP per capita and biofuel production, have been presented graphically (Figure 4.9) with the 95% confidence interval (shaded area) and in table 4.4. As described in the previous section, the level of GDP per capita has a relatively large and significant influence on food security. The coefficient corresponding to GDP per capita is always negative

(figure 4.9), which means that it shifts the overall distribution of the depth of the food deficit downwards and thus contributes to improving the level of food security. Its effect decreases sharply with the decile. Thus, the decrease in the first decile of the distribution of the conditional DFD following a 1% increase in GDP per capita is, once controlled by the other variables, 0.35% (significant at 10%), against 0.5% for the last decile. Therefore, this result highlights the importance of GDP per capita in reducing food insecurity, mainly for the country belonging to the last decile. These countries are considered highly food insecure because their level of food deficit depth is greater than 297 kilocalories per capita per day. Finally, as for the boosted results, figure 4.9 shows that the coefficient associated with the production of biofuels is not significant, which means that the relative influence of biofuels is small.

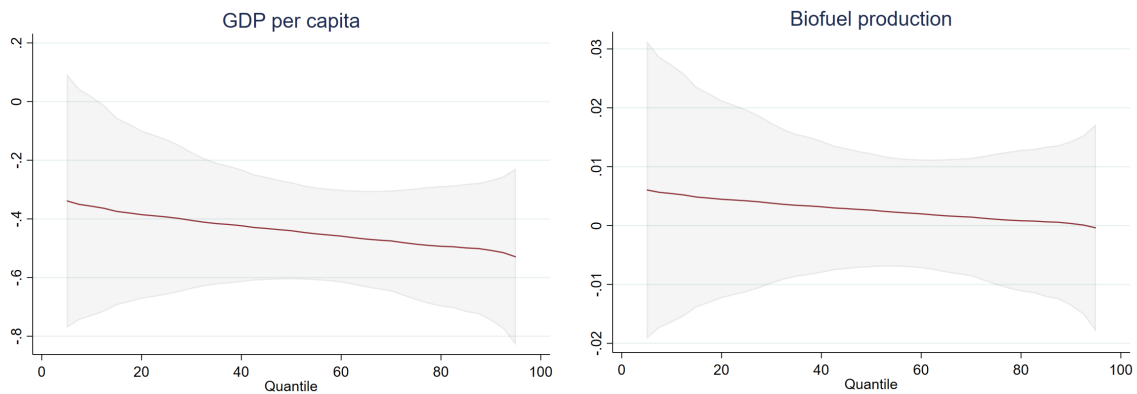


Figure 4.9: Quantile regression

4.6 Conclusion and Discussion

Given the increasing programs supporting food security, and the improvement of agricultural techniques and production, many people worldwide and mainly in developing countries face food insecurity. This raises some questions on the key drivers of food insecurity and the existence of an unconditional hunger trap. Therefore, in this paper, we considered the depth of the food deficit as our dependant

variable and performed several analyses to answer these questions.

The Markov transition matrix performed allowed us to test the unconditional hunger trap hypothesis. Findings gave us the probability to move from one state to another, and revealed through the ergodic distribution that all countries of our sample belonging to the severe, high, and moderate level of food insecurity will end up to the low level. Results also showed that it will take around 9 years to move from the severe level of food insecurity to the low one. Therefore, we can reject the hypothesis of an unconditional hunger trap. The only trap that could exist is the food security trap because, on average, a country is always expected to move to a low level of food insecurity. In addition, a country in a situation of severe, high or moderate level of food insecurity has more than 50% chance of having a negative growth rate of the depth of the food deficit that means an improvement of their level of food security. Thus, as we reject the hypothesis, it becomes necessary to identify the key drivers for each level of food insecurity.

The conditional inference regression inference tree provided the optimal decision tree for each level of food insecurity. Thus, it showed that critical factors of food insecurity are mainly related to the economic structure. Indeed, the most relevant variable is a low GDP per capita. However, for a country-period with a high level of food insecurity, the key determinants, in addition to GDP per capita, are the age dependency ratio, low precipitation, low socioeconomic conditions, and high corruption index. For a country with a low level of food insecurity, the key variables influencing their level include GDP per capita, precipitation, exposure sub-index, and conflict events. Food insecurity determinants seem closer to the capability approach developed by Sen than to the Malthusian approach.

Specifically, according to the results, low predicted values of the level of the food deficit appear for country-periods with a GDP per capita of more than US\$6,550 such as Turkey and Mexico. Then, country-periods with an exposure sub-index level

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less than or equal to 16.95 will have an average predicted value of the magnitude of the food deficit of about 4.48 kilocalories per capita per day. These results are in line with some authors showing that poverty, economic structure, trade openness, unemployment, and climate change are among the determinants of food insecurity. Hence, this analysis strengthens and contributes to the literature on food security determinants. Specifically, this paper allows us to conclude we need to combine policies and programs supporting food security with those contributing to improving poverty, economic growth, competitiveness and trade openness of countries, and climate change mitigation. In addition, policymakers could ensure that food security objectives are integrated into national poverty reduction strategies. The results also highlight the importance of armed conflict on food insecurity. In light of the resurgence of conflicts, particularly in Africa where populations are also the most food insecure, policymakers could reinforce the resilience of populations and measures to promote better access to food for displaced people.

To test the precision of our results, we performed the conditional inference regression tree using the global hunger index and the prevalence of underweight (percentage of children under 5) as dependent variables, and considering the additional predictors such as the real effective exchange rate and the net official development assistance and official aid received per capita, the boosted random forest, and the panel data quantile regression as robustness check. Findings have also led to the conclusion that GDP per capita is the key determinant of food security as its influence is higher than other drivers. Furthermore, boosting results also highlight the relative importance of women's wage. Hence, they should be specifically targeted in food security initiatives. Among others, this can be done by facilitating their access to public food procurement initiatives.

Contrary to some studies on the high negative effect of biofuel production on food security, the conditional inference regression tree results revealed that biofuels are

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not among the long-run key determinant of food insecurity. This finding was further enhanced with the panel data quantile regression because we did not find any significance of biofuels on food security. In addition, boosting model displayed that among the variables, biofuels have the lowest relative influence rate (0.01%) for the overall sample. As a result, to achieve the 13th objective of Sustainable Development Goals (Climate Action) without reducing food security, biofuel production can be a solution to save our planet by reducing dependency to fossil fuels.

As food security is multidimensional, these analyses can be extended by using other indicators as dependent variables or computing a synthetic index of food security with its indicators. A variable related to the covid-19 pandemic can also be included among the predictor variables. This study assesses the hunger trap and difference in terms of food insecurity between countries. Consequently, it could be performed at the micro level, focusing on analysing hunger trap and food insecurity determinants within a country.

4.7 Appendices of Chapter 4

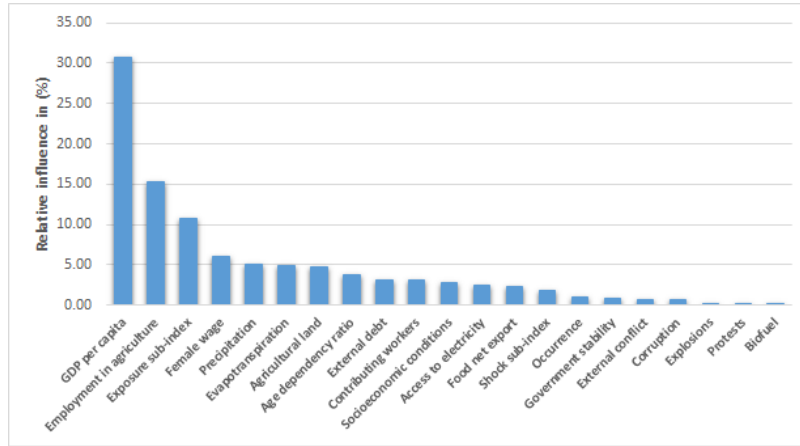


Figure 4.10: Boosting model in the overall sample: relative influence of each predictor variable

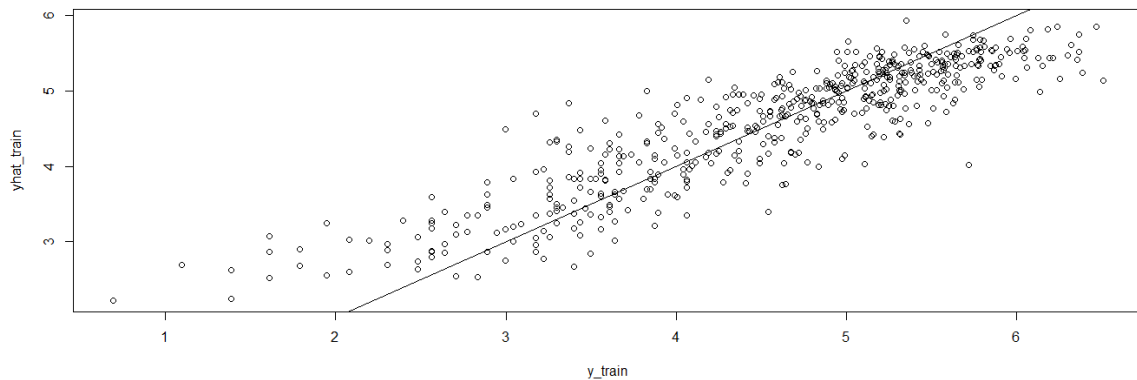


Figure 4.11: Boosting model in the overall sample: actual (y) vs prediction value (\hat{y}) of the outcome (depth of the food deficit) on the training dataset

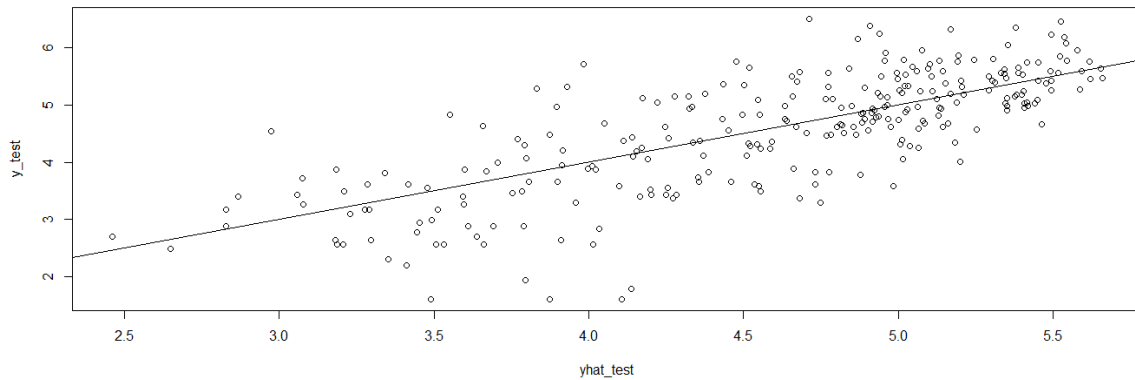


Figure 4.12: Boosting model in the overall sample: actual (y) vs prediction value (\hat{y}) of the outcome (depth of the food deficit) on the testing dataset

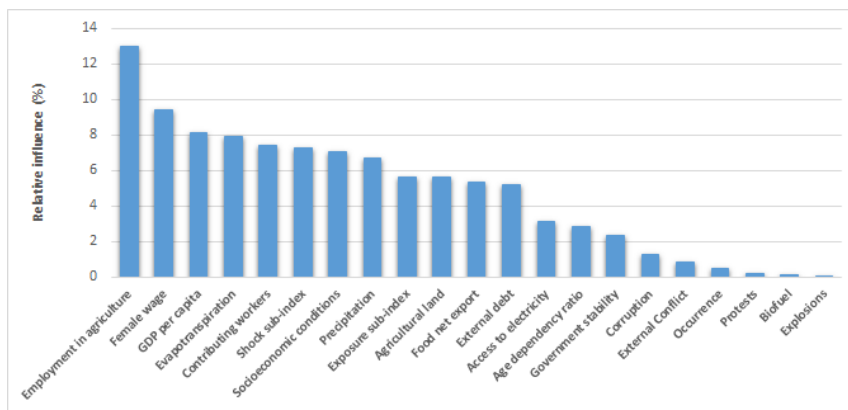


Figure 4.13: Boosting model in the sample of high food insecurity: relative influence of each predictor variable

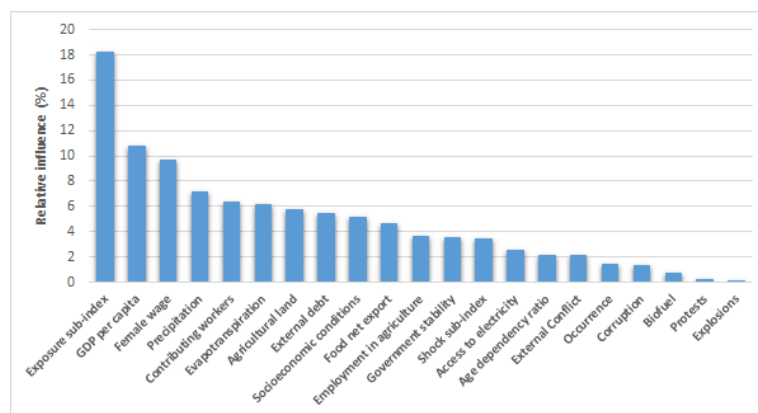


Figure 4.14: Boosting model in the sample of low food insecurity: relative influence of each predictor variable

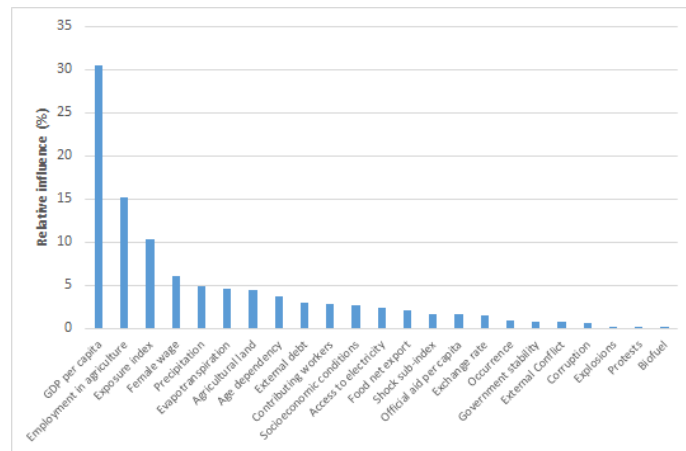


Figure 4.15: Boosting model in the overall sample and considering additional predictors

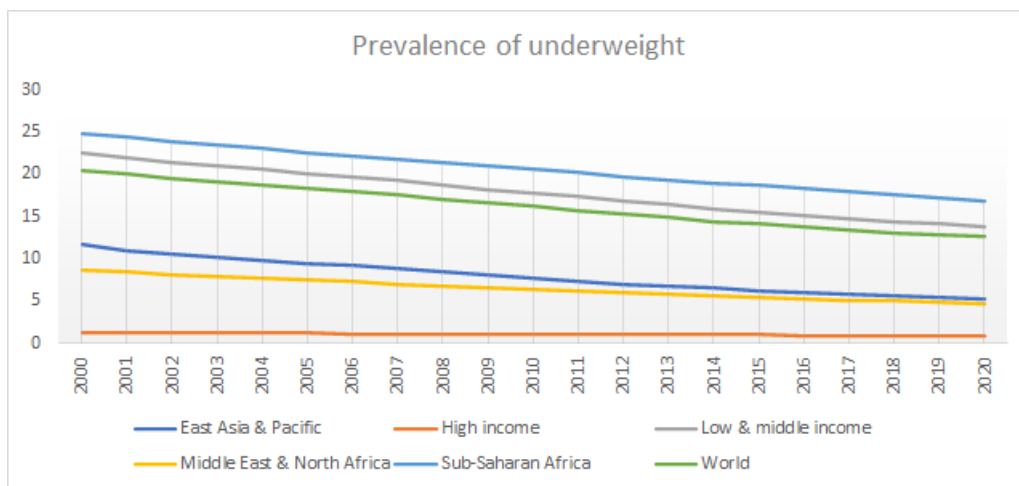


Figure 4.16: Evolution of the prevalence of underweight (% of children under 5)

Table 4.2: Example of observation per final node in the sample of high food insecurity

Node	Country	Year	DFD (real)	DFD (predict)	Error (abs value)
3	Myanmar	1992	6.24	6.10	0.14
3	Ethiopia	1997	6.36	6.10	0.26
3	Ethiopia	2002	6.05	6.10	0.05
3	Liberia	1997	5.74	6.10	0.36
3	Mozambique	1992	6.08	6.10	0.02
5	Bangladesh	1992	5.51	5.70	0.19
5	Cambodia	1997	5.34	5.70	0.36
5	Central African Rep	2002	5.77	5.70	0.07
5	Central African Rep	2007	5.72	5.70	0.02
5	Liberia	2002	5.68	5.70	0.02
6	Malawi	2002	5.21	5.25	0.04
6	Malawi	2007	5.19	5.25	0.06
6	Niger	1992	5.24	5.25	0.01
6	Uganda	1997	5.21	5.25	0.04
6	Burkina Faso	1992	5.18	5.25	0.07
8	Haiti	1992	6.25	6.05	0.20
8	Haiti	1997	6.35	6.05	0.30
8	Haiti	2002	6.30	6.05	0.25
8	Zimbabwe	2002	5.85	6.05	0.20
8	Zimbabwe	2007	5.77	6.05	0.28
11	Angola	2012	4.79	5.15	0.36
11	Armenia	2002	5.11	5.15	0.04
11	Bolivia	2012	5.10	5.15	0.05
11	Congo, Rep	2012	5.32	5.15	0.17
11	Guyana	1992	5.11	5.15	0.04
13	Angola	2002	5.87	5.50	0.37
13	Angola	2007	5.34	5.50	0.16
13	Botswana	1997	5.35	5.50	0.15
13	Cameroon	1997	5.58	5.50	0.08
13	Cameroon	2002	5.34	5.50	0.16
14	Afghanistan	1992	5.31	5.30	0.01
14	Afghanistan	1997	5.80	5.30	0.50
14	Afghanistan	2007	5.30	5.30	0.00
14	Armenia	1992	5.18	5.30	0.12
14	Bolivia	2002	5.40	5.30	0.10
15	Bangladesh	2002	4.93	4.90	0.03
15	Brazil	1997	4.62	4.90	0.28
15	Cambodia	2007	4.91	4.90	0.01
15	Cameroon	2007	4.92	4.90	0.02
15	Ecuador	1992	4.80	4.90	0.10

Table 4.3: Example of observation per final node in the sample of low food insecurity

Node	Country	Year	DFD (real)	DFD (predict)	Error (abs value)
4	Algeria	2012	3.43	3.50	0.07
4	Jordan	2002	3.64	3.50	0.14
4	Morocco	2007	3.66	3.50	0.16
4	South Africa	1992	3.40	3.50	0.10
4	Turkmenistan	2007	3.53	3.50	0.03
5	Armenia	2007	4.06	4.05	0.01
5	Belize	1992	4.06	4.05	0.01
5	Cuba	1992	3.66	4.05	0.39
5	Jamaica	2002	3.89	4.05	0.16
5	Peru	2012	4.26	4.05	0.21
8	Guinea	2007	5.05	4.15	0.90
8	Guinea	2012	4.83	4.15	0.68
8	Cote d'Ivoire	1997	4.29	4.15	0.14
8	Cote d'Ivoire	2007	4.58	4.15	0.43
8	Cote d'Ivoire	2012	4.62	4.15	0.47
9	Cote d'Ivoire	1992	4.19	4.10	0.09
9	Cote d'Ivoire	2002	4.73	4.10	0.63
9	Afghanistan	2012	5.00	4.10	0.90
9	Cabo Verde	1997	4.69	4.10	0.59
9	Nigeria	1997	4.32	4.10	0.22
10	Fiji	1992	3.74	3.80	0.06
10	Fiji	1997	3.56	3.80	0.24
10	Kiribati	1992	3.83	3.80	0.03
10	Kiribati	1997	3.61	3.80	0.19
10	Kyrgyzstan	2012	3.91	3.80	0.11
12	Turkey	1992	1.10	1.50	0.40
12	Turkey	1997	1.39	1.50	0.11
12	Turkey	2002	1.79	1.50	0.29
12	Turkey	2007	1.39	1.50	0.11
12	Mexico	2002	3.43	1.50	1.93
13	Barbados	1997	3.33	3.30	0.03
13	Brazil	2007	3.30	3.30	0.00
13	Chile	2007	3.30	3.30	0.00
13	Costa Rica	2012	3.61	3.30	0.31
13	Uruguay	2002	3.26	3.30	0.04

Table 4.4: Panel data quantile regression

	Quantile (0.25)	Quantile (0.5)	Quantile (0.75)
	DFD(log)	DFD(log)	DFD(log)
Biofuel	0.004 (0.008)	0.003 (0.005)	0.001 (0.006)
GDP per capita (log)	-0.393*** (0.135)	-0.440*** (0.085)	-0.486*** (0.097)
Exposure index	0.039*** (0.015)	0.031*** (0.009)	0.023** (0.011)
Evapotranspiration	0.001* (0.001)	0.001*** (0.0004)	0.001** (0.0005)
Female wage	-0.004 (0.008)	-0.007 (0.005)	-0.010* (0.006)
Agricultural land	-0.006 (0.008)	-0.009* (0.005)	-0.012** (0.006)
External debt	-0.0003 (0.0004)	-0.0001 (0.0002)	0.0001 (0.0003)
Corruption	-0.009 (0.035)	-0.011 (0.022)	-0.0124 (0.026)
Precipitation	0.0001 (0.0001)	0.001 (0.0001)	0.0001 (0.0001)
Shock index	-0.003 (0.003)	-0.002 (0.002)	-0.001 (0.002)
Age dependency	-0.013* (0.008)	-0.008 (0.005)	-0.003 (0.005)
Access to electricity	-0.020*** (0.004)	-0.017*** (0.003)	-0.014*** (0.003)
Government stability	0.047*** (0.015)	0.043*** (0.010)	0.039*** (0.011)
Protests	-0.00003 (0.00007)	-0.00001 (0.00005)	0.00001 (0.00006)
Explosions	0.0001 (0.0004)	0.0000 (0.0003)	-0.00004 (0.0003)
Employment in agriculture	-0.013*** (0.004)	-0.014*** (0.003)	-0.015*** (0.003)
<i>N</i>	454	454	454

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4.5: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Depth of the food deficit	549	4.55	1.05	0.69	6.51
Agricultural land	529	41.31	21.05	0.45	85.39
Employment in agriculture	534	41.39	24.69	0.40	90.83
Contributing workers	534	14.28	13.20	0.01	52.57
Population growth	533	2.03	1.36	-5.09	14.24
Unemployment	534	8.38	6.15	0.16	39.30
Female wage	534	43.77	28.80	0.86	99.59
Male wage	534	47.70	22.86	6.43	97.99
Corruption	408	2.36	0.90	0.00	5.00
External debt	460	58.20	58.46	0.00	517.85
Biofuel production	319	4.29	34.93	0.00	423.74
Temperature	534	22.30	5.91	-0.69	29.11
Precipitation	534	1191.53	862.53	23.24	4601.26
Evapotranspiration	534	1418.30	337.58	769.86	2478.56
Government Stability	408	7.95	1.92	1.83	11.50
Shock sub-index	509	33.90	16.61	3.40	89.39
Exposure sub-index	535	35.78	12.71	4.09	86.08
GDP per capita	538	7.62	1.20	5.09	11.07
Socioeconomic conditions	408	4.88	2.08	0.00	11.00
Investment profile	408	7.18	2.06	0.00	11.50
Internal conflict	408	8.33	2.15	0.00	12.00
External conflict	408	9.78	1.70	2.00	12.00
Military in politics	408	3.11	1.65	0.00	6.00
Battles	170	74.63	229.81	0.00	1902.00
Explosions	170	27.95	224.89	0.00	2853.00
Protest	170	131.90	1082.25	0.00	14022.00
Riots	170	38.11	177.63	0.00	1642.00
Strategic development	170	36.82	315.72	0.00	4098.00
Civil violence	170	80.76	234.56	0.00	2229.00
Age dependency ratio	548	65.61	20.57	15.86	111.25
Trade openness	488	75.36	38.99	0.22	311.35
Natural shock index	513	42.16	17.06	2.25	91.03
Religious tensions	408	4.27	1.39	0.00	6.00
Manufacturing value added	360	579.78	937.11	7.56	10039.09
Natural resources rent	428	10.85	13.06	0.00	74.13
Food net exporter	549	0.74	0.44	0.00	1.00
Occurrence	363	3.42	3.87	1.00	29.00
Extractives dependence index	99	40.63	26.26	4.05	93.26
Access to electricity	302	63.41	33.37	0.01	100
Real effective exchange rate	198	104.39	26.25	41.07	236.02
Net official development assistance	537	62.63	83.16	-27.94	641.06

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Table 4.6: Evolution of the Depth of the food deficit per country from 1992 to 2016

Country	1992	2016	(%)	Country	1992	2016	(%)
Afghanistan	202	173	-14%	Lebanon	13	29	123%
Algeria	48	20	-58%	Lesotho	99	76	-23%
Angola	499	90	-82%	Liberia	211	256	21%
Argentina	15	2	-87%	Madagascar	180	229	27%
Armenia	177	41	-77%	Malawi	332	139	-58%
Azerbaijan	163	12	-93%	Malaysia	31	14	-55%
Bangladesh	247	116	-53%	Maldives	69	34	-51%
Barbados	16	21	31%	Mali	107	23	-79%
Belize	58	40	-31%	Mauritania	95	36	-62%
Benin	190	48	-75%	Mauritius	57	35	-39%
Bolivia	261	104	-60%	Mexico	46	29	-37%
Botswana	168	177	5%	Mongolia	210	156	-26%
Brazil	110	10	-91%	Morocco	39	31	-21%
Brunei Darussalam	21	12	-43%	Mozambique	437	181	-59%
Burkina Faso	177	167	-6%	Myanmar	511	103	-80%
Cambodia	205	97	-53%	Namibia	252	325	29%
Cameroon	260	63	-76%	Nepal	149	51	-66%
Cape Verde	100	68	-32%	Nicaragua	420	122	-71%
Central African Republic	356	380	7%	Niger	188	56	-70%
Chad	470	261	-44%	Nigeria	140	42	-70%
Chile	60	20	-67%	Oman	118	33	-72%
China	188	74	-61%	Pakistan	179	172	-4%
Colombia	101	62	-39%	Panama	188	66	-65%
Congo, Rep.	322	206	-36%	Paraguay	133	71	-47%
Costa Rica	33	35	6%	Peru	222	50	-77%
Cote d'Ivoire	66	93	41%	Philippines	184	93	-49%
Cuba	39	7	-82%	Rwanda	426	232	-46%
Djibouti	669	118	-82%	Sao Tome and Principe	146	40	-73%
Dominican Republic	247	86	-65%	Saudi Arabia	18	9	-50%
Ecuador	122	70	-43%	Senegal	163	63	-61%
Egypt, Arab Rep.	26	12	-54%	Sierra Leone	333	160	-52%
Ethiopia	644	236	-63%	South Africa	30	13	-57%
Fiji	42	30	-29%	Sri Lanka	228	192	-16%
Gabon	70	18	-74%	Sudan	283		-100%
Gambia, The	86	32	-63%	Suriname	107	56	-48%
Georgia	463	55	-88%	Swaziland	97	192	98%
Ghana	352	19	-95%	Tajikistan	187	250	34%

Table 4.7: Evolution of the Depth of the food deficit per country from 1992 to 2016 (continued)

Country	1992	2016	(%)	Country	1992	2016	(%)
Guatemala	89	101	13%	Tanzania	157	238	52%
Guinea	165	115	-30%	Thailand	280	53	-81%
Guinea-Bissau	156	143	-8%	Timor-Leste	323	184	-43%
Guyana	166	74	-55%	Togo	268	75	-72%
Haiti	519	546	5%	Trinidad and Tobago	88	55	-38%
Honduras	154	85	-45%	Tunisia	5	3	-40%
India	165	109	-34%	Turkey	3	1	-67%
Indonesia	136	51	-63%	Turkmenistan	57	22	-61%
Iran, Islamic Rep.	31	31	0%	Uganda	150	172	15%
Iraq	46	185	302%	United Arab Emirates	14	18	29%
Jamaica	70	58	-17%	Uruguay	58	24	-59%
Jordan	33	13	-61%	Uzbekistan	20	29	45%
Kazakhstan	18	18	0%	Vanuatu	69	41	-41%
Kenya	209	135	-35%	Venezuela, RB	91	9	-90%
Kiribati	46	22	-52%	Vietnam	368	83	-77%
Kuwait	305	21	-93%	Yemen, Rep.	179	182	2%
Kyrgyzstan	105	40	-62%	Zambia	235	405	72%
Lao PDR	325	128	-61%	Zimbabwe	327	259	-21%

Table 4.8: Source of variables

Variables	Source
Dependent variable	
Depth of the food Deficit	World Development Indicators
Global hunger index	International food policy research institute
Prevalence of children underweight	Food and Agriculture Organization
Economic structure	
GDP per capita	World Development Indicators
External debt	International Monetary fund
Contributing family workers	World Development Indicators
Trade openness	World Development Indicators
Socioeconomic conditions	International Country Risk Guide
Investment profile	International Country Risk Guide
Government stability	International Country Risk Guide
Female wage	World Development Indicators
Male wage	World Development Indicators
Access to electricity	World Development Indicators
Natural resources rent	World Development Indicators
Food net export	World Development Indicators
Unemployment	World Development Indicators
Corruption	International Country Risk Guide
Real Effective Exchange Rate	World Development Indicators
Official Development Assistance	World Development Indicators
Renewable energy	
Biofuels	Energy Information Administration
Weather conditions and events	
Temperature	Center for Studies and Research on International Development
Precipitation	Center for Studies and Research on International Development
Evapotranspiration	Center for Studies and Research on International Development
Occurrence of extreme weather events	Emergency events database
Natural shock index,	World Development Indicators
Agricultural sector	
Agricultural land	World Development Indicators
Employment in agriculture	World Development Indicators
Armed conflicts	
Internal conflict	International Country Risk Guide
External conflict	International Country Risk Guide
Military in politics	International Country Risk Guide
Battles	Armed Conflict Location and Event Data project
Explosions	Armed Conflict Location and Event Data project
Riots	Armed Conflict Location and Event Data project
Violence against civils	Armed Conflict Location and Event Data project
Religious tensions	International Country Risk Guide
Other indexes	
Shock sub-index	Foundation for studies and Research on International Development
Exposure sub-index	Foundation for studies and Research on International Development

CHAPTER 5

Conclusion

Dans un contexte marqué par le changement climatique et la dépendance aux énergies fossiles, il est important de trouver des sources d'énergie alternatives. Les biocarburants, qui sont produits dans de nombreux pays à partir de matières organiques, principalement des cultures agricoles, sont considérés comme une solution à la crise énergétique. Ce type de production contribue à la croissance économique des pays en développement et réduit les émissions de gaz à effet de serre. Cependant, les biocarburants sont produits à partir de cultures agricoles. Selon certaines études, leur production pourrait favoriser une hausse des prix des denrées alimentaires et l'insécurité alimentaire. L'objectif de la thèse est d'apporter un nouvel éclairage sur le possible lien entre la production de biocarburants et la sécurité alimentaire, afin de déduire des recommandations en termes de politiques économiques. Trois études originales en économie appliquée ont été réalisées dans la thèse, qui nous ont permis d'obtenir un certain nombre de résultats.

5.1 Résultats

Le chapitre 2 a analysé l'effet des biocarburants sur la sécurité alimentaire en retenant deux pays en développement, l'Indonésie et le Mexique. Ces deux pays produisent différents biocarburants : l'Indonésie est l'un des leaders dans la production de biodiesel et le Mexique est spécialisé dans le bioéthanol. L'objectif de cette étude

était d'identifier si l'effet de l'adoption des biocarburants sur la sécurité alimentaire dépendait du type de biocarburants produits. Utilisant la méthode du contrôle synthétique, nous avons montré que les résultats diffèrent selon le pays retenu. En effet, la production de biocarburants a un effet positif sur la sécurité alimentaire en Indonésie, contrairement au Mexique. Ces résultats contrastés peuvent s'expliquer par le fait que les biodiesels indonésiens sont principalement produits à partir d'huile de palme et de jatropha. Ce dernier n'étant pas directement utilisé dans la consommation humaine. De plus, l'Indonésie étant le premier exportateur d'huile de palme et de biodiesel, les recettes peuvent ensuite être affectées aux importations alimentaires. L'effet négatif observé au Mexique pourrait être dû au fait qu'il utilise principalement du maïs, un des aliments de base de nombreux mexicains, pour produire du bioéthanol. Par conséquent, les politiques publiques en faveur des biocarburants doivent être attentives au mode de production du biocarburant, afin de rendre complémentaire la production de biocarburant et la sécurité alimentaire.

Dans le chapitre 3, nous avons étudié si les chocs de prix des denrées alimentaires pouvaient provenir des chocs de prix des biocarburants. Plus précisément, cette étude a évalué les réponses dynamiques des prix alimentaires - principalement du maïs - aux chocs des prix mondiaux du bioéthanol en utilisant la méthode de projection locale. Les résultats obtenus montrent qu'en général, une augmentation du prix mondial du bioéthanol conduit également à une hausse du prix au producteur du maïs. Cependant, cet impact disparaît trois ans après le choc. Son intensité varie selon le niveau de revenu, l'ouverture commerciale, le niveau de production du maïs, les groupes de pays, le régime de change, le commerce net de maïs ou les politiques publiques. L'impact est plus important dans les pays à haut revenu ou ayant un haut niveau d'ouverture commerciale par rapport aux pays ayant un faible revenu ou un faible niveau d'ouverture commerciale. L'analyse de l'asymétrie en ce qui concerne la direction et l'ampleur des chocs indique une compensation entre les effets positifs

et négatifs des chocs, suggérant qu'il n'y a pas d'effet net négatif sur la sécurité alimentaire, plus précisément sur l'accès à la nourriture. Les résultats de cette étude nous ont donc permis d'évaluer les facteurs qui conduisent à la transmission des chocs de prix des biocarburants sur les prix des denrées alimentaires et soulignent que ces effets ne sont significatifs qu'à court terme. Ces résultats pourront ainsi aider les pouvoirs publics à mieux cibler les politiques de régulation des prix alimentaires en cas de chocs des prix des biocarburants.

Les résultats obtenus au chapitre 3 invitent naturellement à mener une analyse de long terme. Par ailleurs, malgré la multiplication des programmes de soutien à la sécurité alimentaire, de nombreuses personnes dans le monde sont confrontées à l'insécurité alimentaire, et ce principalement dans les pays en développement. Ces deux points ont soulevé des questions sur les principaux déterminants de long terme de l'insécurité alimentaire et sur la probable existence d'un piège inconditionnel de la faim, ce que nous avons étudié dans le chapitre 4. Pour ce faire, nous avons utilisé la matrice de transition de Markov et la distribution ergodique afin de tester l'hypothèse de l'existence d'une trappe de la faim inconditionnelle. La matrice de transition réalisée nous a donné la probabilité de passer d'un état d'insécurité alimentaire à un autre et a révélé, par la distribution ergodique, que tous les pays de notre échantillon appartenant aux niveaux d'insécurité alimentaire sévère, élevé et modéré convergeront vers le niveau faible. Selon nos résultats, il faudrait environ 9 ans à un pays en situation d'insécurité alimentaire sévère pour passer au niveau inférieur. Ainsi, nos résultats rejettent l'hypothèse d'un piège de la faim inconditionnelle. De plus, un pays en situation d'insécurité alimentaire sévère, élevée ou modérée a plus de 50% de chance d'avoir un taux de croissance négatif de la profondeur du déficit alimentaire, ce qui signifie une amélioration de son niveau de sécurité alimentaire. Nous avons ensuite identifié les déterminants critiques pour chaque niveau d'insécurité alimentaire à travers l'arbre de régression à inférence

conditionnelle, afin de vérifier si les biocarburants en font partie. Cette méthode non-paramétrique a montré que la variable la plus pertinente est le faible niveau de produit intérieur brut par habitant. Les autres déterminants dépendent du niveau d'insécurité alimentaire. Dans les pays présentant un niveau d'insécurité alimentaire élevé, nous retrouvons le taux de dépendance de l'âge des jeunes (% de la population en âge de travailler), les faibles précipitations, les faibles conditions socio-économiques et un niveau de corruption élevé. Pour un pays présentant un faible niveau d'insécurité alimentaire, ce sont les précipitations, le sous-indice d'exposition et les conflits armés qui importent.

Contrairement à certaines études qui concluent à un effet négatif de la production de biocarburants sur la sécurité alimentaire, les résultats de l'arbre de régression à inférence conditionnelle révèlent que les biocarburants ne font pas partie des déterminants clés de long terme de l'insécurité alimentaire. En outre, le modèle de boosting a montré que parmi les variables retenues, les biocarburants ont le taux d'influence relatif le plus faible (0,01%) pour l'échantillon global. Les résultats de ce chapitre permettent, encore une fois, d'apporter un éclairage nouveau sur le lien biocarburant et sécurité alimentaire.

5.2 Principaux enseignements

Globalement, les résultats obtenus dans la thèse montrent que, dans certaines conditions, les biocarburants ne constituent pas un frein à l'atteinte du deuxième Objectif de Développement Durable à court terme et ont une influence relativement faible à long terme. Ils peuvent donc être un moyen de lutte contre le changement climatique sans pénaliser la sécurité alimentaire. Ces conditions incluent le type de matières premières agricoles utilisées pour la production de biocarburants, la compétitivité du pays sur le marché international et les politiques commerciales. Ainsi, une réglementation stricte sur l'utilisation des biocarburants, ainsi que des

politiques et des plans renforcés visant à promouvoir leur compétitivité sur le marché international pourraient être bénéfiques à la fois pour la production de biocarburants et la sécurité alimentaire dans les pays en développement.

Comme elles interagissent mutuellement, les politiques de sécurité alimentaire et les politiques en matière de biocarburants ne peuvent être dissociées. Par conséquent, la sécurité alimentaire et le droit à l'alimentation doivent être des préoccupations prioritaires dans la conception de toute politique en matière de biocarburants. Pour cette raison, les gouvernements ou les décideurs publics doivent adopter une stratégie coordonnée entre la sécurité alimentaire et la sécurité énergétique. Ils peuvent concevoir des mécanismes pour empêcher que la demande de biocarburants (déterminée par le marché) puisse contribuer à altérer le niveau de sécurité alimentaire par le biais de l'augmentation des prix et de la diminution de l'accès à la terre et aux ressources pour l'alimentation. L'élaboration de méthodes et de lignes directrices pour des politiques alimentaires, de biocarburants et bioénergétiques coordonnées aux niveaux national et international permettra d'évaluer le potentiel national des biocarburants et de fournir une orientation préliminaire sur l'intégration des politiques des biocarburants dans un plan national de sécurité alimentaire.

Un autre canal qui permettrait à la fois de réduire la dépendance aux énergies fossiles et d'assurer la sécurité alimentaire serait l'intégration commerciale. En effet, en présence d'un marché stable, elle joue un rôle très important dans l'atteinte de la sécurité alimentaire en ce sens qu'elle favoriserait le commerce des biocarburants mais également des denrées alimentaires et permettrait d'assurer un équilibre entre les régions ayant un déficit et ceux présentant un surplus alimentaire.

Par ailleurs, nos résultats indiquent que pour favoriser la sécurité alimentaire, il serait important d'orienter les politiques et les programmes de soutien à la sécurité alimentaire vers la réduction de la pauvreté, la croissance économique, la compétitivité du pays, l'ouverture commerciale et l'atténuation du changement

climatique. Plus spécifiquement, les décideurs politiques pourraient veiller à ce que les objectifs de sécurité alimentaire soient intégrés dans les stratégies nationales de réduction de la pauvreté.

Les résultats soulignent également l'importance relative des femmes et des conflits armés sur la sécurité alimentaire. Les femmes devraient être spécifiquement ciblées dans les initiatives de sécurité alimentaire car elles y contribuent de manière significative et positive. Cela peut se faire en facilitant leur accès aux initiatives publiques d'approvisionnement alimentaire, aux terres et aux ressources financières pour mener à bien leurs activités. Les conflits, quant à eux, ont un effet négatif. De ce fait, au vu de la recrudescence des conflits, principalement en Afrique où les populations sont aussi les plus confrontées à l'insécurité alimentaire, les décideurs politiques pourraient renforcer la résilience des populations et les mesures visant à favoriser un meilleur accès aux denrées alimentaires des personnes déplacées.

Enfin, on ne peut parler de sécurité alimentaire sans évoquer le développement du secteur agricole en lui-même. Ainsi, en accord avec les résultats de nos analyses, il faudrait promouvoir un développement agricole durable. Cela passe principalement par la mise en place et le renforcement de systèmes alimentaires résilients principalement dans les pays en développement.

5.3 Pistes de recherche futures

Notre analyse de l'impact des biocarburants sur la sécurité alimentaire fait face, comme toute étude, à certaines limites. Tout d'abord, ces travaux de recherche pourraient être étendus en évaluant les effets directs de la production de biocarburants sur la sécurité alimentaire à travers les prix alimentaires à la consommation lorsque ces données deviendront davantage disponibles. Par exemple, le chapitre 3 utilise les données les plus accessibles concernant les prix alimentaires qui sont les prix à la

production ou l'indice des prix à la consommation. Il serait intéressant d'utiliser les prix à la consommation pour l'huile de palme ou le maïs en dollar ou toute autre monnaie locale. Ces données sont, à l'heure actuelle, très peu disponibles.

La sécurité alimentaire étant un concept multidimensionnel, nos analyses pourraient être approfondies en utilisant d'autres indicateurs que ceux que nous avons utilisés comme variables dépendantes. Par exemple, un indice synthétique de sécurité alimentaire qui tiendrait compte de toutes les dimensions pourrait être construit.

La pandémie de la covid-19 a eu des répercussions négatives sur la sécurité alimentaire, principalement dans les pays en développement. Afin d'étudier plus précisément cet impact, des travaux futurs devraient inclure cette pandémie parmi les variables de contrôle lorsque les données seront plus accessibles. De même, la fragilité des chaînes d'approvisionnement des denrées alimentaires ayant un impact négatif sur la sécurité alimentaire, une variable captant cet aspect devrait être considérée dans les variables de contrôle.

Dans les chapitres 3 et 4, nous avons mené des études considérant des échantillons de pays. Il serait peut-être intéressant de conduire des analyses par pays, afin d'obtenir des recommandations de politiques publiques plus ciblées.

Un autre aspect, non étudié dans la thèse, concerne l'effet de la production des biocarburants sur la déforestation et la dégradation des sols. Des travaux futurs pourraient examiner si les biocarburants de première et de deuxième génération contribuent, au lieu de déforester, à restaurer des terres dégradées. Par exemple, le jatropha est connu pour ses propriétés en termes de restauration des sols. De ce point de vue, la production de biocarburants à base de jatropha pourrait contribuer à une meilleure gestion des bassins versants et donc à la sécurité alimentaire. Ces recherches doivent permettre de tirer des conclusions en termes de recommandations de politiques publiques, afin que la production de biocarburants ne pénalise ni la

sécurité alimentaire ni la déforestation.

CHAPTER 6

RÉSUMÉ EXTENSIF EN FRANÇAIS

Ces dernières décennies ont été marquées par des événements météorologiques extrêmes. Partout dans le monde, l'occurrence des inondations a augmenté de manière significative au cours des trente dernières années, tout comme les températures extrêmes depuis le début des années 2000. Les sécheresses et les incendies de forêt ont suivi une évolution en dents de scie, tandis que les tempêtes et les glissements de terrain sont restés constants à l'échelle mondiale sur cette période.

Les différents rapports et études indiquent que ces événements météorologiques extrêmes sont des manifestations du changement climatique. Ce dernier émane de l'augmentation des émissions de gaz à effet de serre (GES) provenant des activités humaines, plus précisément des combustibles fossiles (IPCC, 2007; Bernstein et al., 2008; Dodman, 2009; O'Neill et al., 2001).

Selon le dernier rapport du *Working Group II* publié par le groupe d'experts intergouvernemental sur l'évolution du climat (GIEC), si la tendance des émissions se maintient, le réchauffement induit pourrait dépasser les 2°C en 2050 ; et toute hausse supplémentaire, même de dixièmes de degré, augmentera l'intensité et la fréquence des événements extrêmes identifiés (IPCC, 2022). Un réchauffement mondial de 1,5°C entrainera des pics de températures 4,1 fois plus fréquents ; tandis qu'à 2°C, ils le seront 5,6 fois plus (Chow et al., 2022).

Ainsi depuis plusieurs décennies, les conférences annuelles sur le changement clima-

tique cherchent à réduire les émissions de GES et la dépendance aux énergies fossiles. Lors de la dernière conférence à Glasgow - la COP26 - les pays ont réaffirmé l'objectif de l'Accord de Paris, qui consiste à maintenir la température mondiale à un niveau inférieur à 2°C par rapport au niveau préindustriel et à continuer les efforts visant à la limiter à 1,5°C (Falkner, 2016). Partant du constat que les émissions mondiales de GES proviennent principalement des combustibles fossiles, une des solutions proposées afin de limiter ces émissions et la dépendance aux énergies fossiles a été la promotion des énergies renouvelables incluant les biocarburants.

En effet, selon Demirbas (2009), les biocarburants sont une source d'énergie renouvelable. Ils contribuent à la réduction des émissions de GES par rapport aux carburants d'origine fossile (Righelato and Spracklen, 2007; Janda et al., 2012). Les biocarburants, principalement le biodiesel de jatropha, le diesel de lignocellulose et l'éthanol issu de la canne à sucre permettent de réduire les GES. Par conséquent, ils pourraient répondre à plusieurs questions cruciales telles que la sécurité énergétique et la réduction des émissions de GES, en particulier dans les pays en développement (Rajagopal et al., 2007). De plus, selon le rapport McKinsey (2009), les biocarburants principalement de première génération comptent parmi les solutions les plus profitables car ils sont coût-efficaces. La production de biocarburants assurerait la sécurité des économies en réduisant la dépendance aux combustibles fossiles et en créant des emplois dans une industrie des biocarburants en pleine croissance.

Depuis le début des années 2000, nous assistons à une croissance de la production des énergies renouvelables. Selon les données de l'Administration américaine des Informations sur l'Énergie (AIE), la part de la production mondiale des énergies renouvelables dans l'énergie totale est passée de 8,5% en 2000 à environ 11% en 2019. Parmi ces énergies renouvelables, la part de biocarburants a également augmenté entre 2000 et 2019, passant d'environ 3,8% à 21%.

Cependant, en dépit des avantages des biocarburants dans la lutte contre le change-

ment climatique grâce à leur potentiel de réduction des émissions de GES, de nombreux auteurs mettent en avant leurs inconvénients. En effet, la production des biocarburants pourrait avoir des effets négatifs sur la sécurité alimentaire car elle entraînerait une baisse de l'offre et de l'accessibilité alimentaire, ce qui est bien connu dans la littérature économique sous le vocable « nourriture contre biocarburants ». L'objectif de la thèse est de contribuer à ce débat.

Ce résumé extensif de notre thèse sera structuré comme suit. La section 6.1 définira les notions de biocarburants et de sécurité alimentaire. La section 6.2 présentera les déterminants de la sécurité alimentaire et la section 6.3 les effets des biocarburants sur la sécurité alimentaire. Nous présenterons les résultats obtenus dans la thèse dans la section 6.4. Enfin, nous fournirons les principaux enseignements et les pistes de recherche futures dans les sections 6.5 et 6.6.

6.1 Biocarburants et Sécurité alimentaire : définitions

Le sujet de cette thèse est d'analyser le lien entre les biocarburants et la sécurité alimentaire. Cette section s'attardera sur la définition des biocarburants et de la sécurité alimentaire.

6.1.1 Biocarburants

Les biocarburants sont des agrocarburants produits directement ou indirectement à partir de la biomasse des matières organiques, notamment les matières végétales et les déchets animaux (Demirbas, 2008; Pathak et al., 2013). Ils peuvent se présenter sous trois principales formes : solide (le bois de chauffage, le charbon de bois, etc.), gazeuse (le biogaz), et liquide (le bioéthanol, le biodiesel, l'huile de pyrolyse, etc.).

En fonction du type de traitement des matières premières, une distinction fonda-

mentale peut être faite entre les biocarburants primaires et secondaires (Nigam and Singh, 2011). Les biocarburants primaires sont le bois de chauffage, les copeaux de bois et les granulés. Ces combustibles sont brûlés directement, généralement pour répondre aux besoins de cuisson, de chauffage ou d'énergie dans des applications industrielles à petite ou grande échelle. Les biocarburants secondaires, quant à eux, se présentent sous la forme de solides, de liquides ou de gaz et peuvent être utilisés dans un plus large éventail d'applications, notamment les transports et les processus industriels à haute température (Nijs, 2014).

Les biocarburants sont classés en deux catégories : les biocarburants conventionnels ou de première génération (les plus utilisés) et les biocarburants avancés qui regroupent les deuxième, troisième et quatrième générations (Janda et al., 2012). Ceux de première génération sont essentiellement produits grâce aux cultures traditionnellement utilisées pour l'alimentation. Les types les plus courants sont le biodiesel et le bioéthanol. Le biodiesel est généralement produit à partir d'huile de ricin, de palme, de soja, de tournesol, de colza ou de jatropha, tandis que le bioéthanol est obtenu à partir de la canne à sucre, du manioc, du blé, du maïs, des pommes de terre ou du sorgho. L'enjeu des biocarburants de deuxième génération est d'utiliser les parties non alimentaires des cultures telles que le bois, la paille, les tiges, les feuilles, les déchets végétaux, ainsi que d'autres cultures qui n'ont pas de destination alimentaire comme le jatropha ou le miscanthus. Les biocarburants de troisième génération, quant à eux, sont obtenus à partir d'algues. Ceux de quatrième génération sont très expérimentaux et n'ont pas encore été clairement définis. Toutefois, certaines technologies de quatrième génération regroupent la décomposition des biocarburants à haute température, les réactions de photosynthèse artificielle et la modification génétique d'organismes pour qu'ils sécrètent des hydrocarbures.

Selon les données de l'AIE des États-Unis, entre 2000 et 2019 la production de biocarburants de première génération a augmenté, passant d'environ 315.000 barils

par jour en 2000 à une production estimée à 2.690.000 barils par jour en 2019 avec un taux de croissance annuel moyen de 12,4%.

Cette croissance est principalement due à la production des États-Unis, considérés comme le principal producteur de biocarburants au monde avec une production moyenne estimée à 690.000 barils/jour entre 2000 et 2019. En 2019, sa production de bioéthanol s'élevait à 1.029.000 barils/jour de bioéthanol et 112.000 bbl/jour de biodiésel. Après les États-Unis, le deuxième plus grand producteur de biocarburants au monde est le Brésil. Ses productions de bioéthanol et de biodiesel étaient respectivement de 540.000 barils/jour et 99.000 barils/jour en 2019. Certains pays comme l'Allemagne, la France, le Canada, l'Indonésie sont également classés parmi les principaux producteurs de biocarburants. Les plus gros producteurs sont donc les pays développés ou en développement, comme le Brésil et l'Indonésie. Les pays d'Afrique ont une production relativement faible.

6.1.2 Sécurité alimentaire

Lors de la Conférence mondiale de l'alimentation de 1974, la sécurité alimentaire était largement considérée comme un problème de production alimentaire insuffisante et instable ([Lang and Barling, 2012](#); [Weiss and Jordan, 1976](#)). En effet, dans les années 1970, le débat sur la sécurité alimentaire portait principalement sur la capacité collective des nations du monde à produire suffisamment d'aliments pour nourrir une population en expansion ([Stringer and Anderson, 2000](#)).

En 1996, le Sommet Mondial de l'alimentation propose la définition suivante de la sécurité alimentaire "la sécurité alimentaire existe lorsque toutes les personnes, à tout moment, ont un accès physique et économique à une nourriture suffisante, sûre et nutritive qui répond à leurs besoins et à leurs préférences alimentaires pour mener une vie active et saine".

La sécurité alimentaire est un concept large, comprenant quatre dimensions qui

sont l'accès, la disponibilité, la stabilité et l'utilisation (Barrett, 2002). Selon Roy et al. (2006), l'accès à la nourriture peut être décrit comme la capacité ou le droit d'un individu à accéder à des ressources adéquates, pour acquérir des aliments appropriés. Les droits sont identifiés comme l'ensemble de toutes les commodités sur lesquelles une personne peut établir un choix étant donné les dispositions légales, politiques, économiques et sociales de la communauté dans laquelle elle vit. La disponibilité alimentaire prend en compte la quantité et la qualité appropriées de nourriture fournie par la production nationale ou les importations, y compris l'aide alimentaire. Pangaribowo et al. (2013) définissent cette dimension comme la quantité de nourriture qui est et sera physiquement disponible pour une population pendant une certaine période ce qui est très probablement liée à la production et à la disponibilité du marché. L'utilisation fait référence à l'aspect sanitaire et fait ressortir l'importance des intrants non alimentaires dans la sécurité alimentaire. Cette dimension se rapporte donc à un régime alimentaire adéquat, une eau propre, de l'assainissement et des soins de santé pour atteindre un état de bien-être nutritionnel où tous les besoins physiologiques sont satisfaits. La stabilité alimentaire renvoie à la capacité d'obtenir de la nourriture au fil du temps, quels que soient les chocs soudains ou évènement cycliques. Elle considère ainsi les dimensions de disponibilité et d'accessibilité précédemment définies.

Alors que la sécurité alimentaire fait référence à un accès adéquat à une quantité suffisante de nourriture à tout moment, l'insécurité alimentaire mesure principalement la faim. Par conséquent, la faim peut être liée à l'une ou à toutes les dimensions de la sécurité alimentaire. Selon Sen (1981), nous pouvons distinguer l'insécurité alimentaire chronique et l'insécurité alimentaire transitoire. L'insécurité alimentaire chronique est associée à des problèmes de pauvreté continue ou structurelle et à de faibles revenus. L'insécurité alimentaire transitoire, quant à elle, implique des périodes d'intensification de la pression sur les denrées alimentaires causée par des

catastrophes naturelles, un effondrement économique ou un conflit. Pour [Barrett \(2002\)](#), l'insécurité alimentaire transitoire se subdivise en trois catégories : l'insécurité alimentaire périodique, régulière et conjoncturelle. Un exemple d'insécurité alimentaire périodique est le cycle saisonnier typique de l'agriculture à faible revenu. L'insécurité alimentaire régulière est causée par des événements répétitifs et/ou quasi-périodiques. Enfin, l'insécurité alimentaire conjoncturelle est due à la conjonction d'une insécurité alimentaire périodique ou régulière avec des catastrophes irrégulières telles que les troubles civils et les guerres.

L'insécurité alimentaire se mesure en général en fonction de la disponibilité et de la consommation apparente des aliments de base ou de l'apport énergétique lorsque nous voulons établir un lien entre la faim et la sous-nutrition ([Clay, 2002](#)). Cette mesure correspond aux anciennes définitions plus étroites de l'insécurité alimentaire ([Jarosz, 2011](#)). Des études ([Wiesmann, 2004](#)) font référence à l'indice de la faim dans le monde comme mesure de l'insécurité alimentaire. Bien que les données soient peu disponibles, cet indice semble être l'un des meilleurs indicateurs de mesure de l'insécurité alimentaire car il permet de surveiller la faim dans le monde par pays et par région. Par ailleurs, d'autres indicateurs permettent également d'évaluer le niveau d'insécurité alimentaire à travers une estimation du nombre de personnes affectées. Il s'agit, entre autres, du nombre de personnes sous-alimentées et de la prévalence de la sous-alimentation. Cette dernière indique le pourcentage de personnes sous-alimentées dans la population totale.

Selon les données de la FAO, la prévalence de la sous-alimentation a connu une baisse entre 2000 et 2019 suivie d'une hausse entre 2019 et 2020. Cette hausse peut être attribuée à la pandémie de la covid-19 qui a eu des effets négatifs sur la sécurité alimentaire dans le monde. Il s'avère que la sous-alimentation reste l'un des problèmes majeurs principalement en Afrique subsaharienne. Ces niveaux de sécurité alimentaire peuvent être imputés à de nombreux facteurs que nous examinons dans

la section suivante.

6.2 Les déterminants de la sécurité alimentaire

La sécurité alimentaire est considérée comme l'un des enjeux majeurs du monde actuel. Elle est indispensable pour que tous les individus puissent être en santé et développer leur plein potentiel. Plusieurs études ont été réalisées afin d'identifier les déterminants de la sécurité alimentaire ([Barrett, 2002, 2010](#); [Pinstrup-Andersen, 2009](#)). Ces facteurs incluent entre autres les caractéristiques socio-économiques, l'environnement naturel, la qualité des institutions et les conflits ainsi que les politiques sectorielles.

6.2.1 Les caractéristiques socio-économiques

Selon [Timmer \(2004\)](#), la faim est liée à la pauvreté car les personnes vivant dans l'indigence sont souvent confrontées à l'insécurité alimentaire. Par conséquent, à l'échelle macroéconomique, plus il y a de croissance économique et une bonne redistribution des richesses, moins il y a d'insécurité alimentaire. En effet, parmi les approches pour assurer la sécurité alimentaire, la première est le taux et la répartition de la croissance économique, également appelée croissance pro-pauvre. Cela peut favoriser la création d'emplois et l'augmentation des revenus de la population. Ainsi, une croissance économique durable peut contribuer à faire reculer la famine et la sous-alimentation, principalement dans les pays en développement ([Manap and Ismail, 2019](#)).

En plus de la croissance économique, la structure démographique fait également partie des déterminants de la sécurité alimentaire ([Bremner, 2012](#)). En effet, la plupart des pays qui comptent le plus grand nombre de personnes sous-alimentées ont également des taux de fécondité et une croissance démographique élevés. La

croissance démographique implique une augmentation considérable de la quantité d'aliments nécessaires pour nourrir convenablement la population. Par conséquent, la pression démographique peut compromettre à la fois la disponibilité et l'accès à la nourriture (Jenkins and Scanlan, 2001; Tilman et al., 2001; Senauer and Sur, 2001). Cependant, plus la population est jeune, plus elle peut avoir un effet bénéfique sur la sécurité alimentaire car un capital humain important peut contribuer aux activités productives, notamment du secteur agricole.

6.2.2 L'environnement naturel

Le changement climatique représente une menace importante pour la sécurité alimentaire. Selon Molotoks et al. (2021), il est l'une des principales causes de l'augmentation de la faim dans le monde et des graves crises alimentaires. Le réchauffement de la planète contribue à augmenter la fréquence des événements extrêmes, mais aussi à diminuer la qualité des terres et la disponibilité des ressources en eau dans certaines régions (Harvey, 2011). Les événements extrêmes tels que la sécheresse ou les inondations ont un impact négatif sur les quatre dimensions de la sécurité alimentaire (FAO et al., 2018), et notamment sur la disponibilité et l'accessibilité alimentaire en raison de la diminution du rendement des cultures (Wheeler and Von Braun, 2013). Par ailleurs, les régions ne sont pas exposées de la même façon. Par exemple, Barrios et al. (2008) montrent que les changements climatiques survenus depuis les années 1960 peuvent expliquer une part importante de l'écart de production agricole entre l'Afrique Sub-saharienne et le reste du monde en développement.

6.2.3 Qualité institutionnelle et conflits

Les conflits et événements armés contribuent à accroître l'insécurité alimentaire en raison de la baisse de la production et de l'offre alimentaire. Les conflits sont

également un facteur clé des crises alimentaires graves, comme la famine (Bode, 2018; Martin-Shields and Stojetz, 2019). En effet, sur les 144 millions d'enfants souffrant d'un retard de croissance, 85% vivent dans des pays touchés par des conflits. La faim et la malnutrition sont bien pires lorsque les conflits se prolongent et que les institutions sont faibles.

En effet, en plus des troubles civils, la qualité institutionnelle des pays peut affecter la sécurité alimentaire. La corruption, l'instabilité gouvernementale et les tensions religieuses pourraient éroder la sécurité alimentaire en réduisant, entre autres, la production et l'accès alimentaire (Barrett, 2013; Önder, 2021).

6.2.4 Les politiques sectorielles

Les politiques agricoles peuvent avoir un impact direct sur la disponibilité alimentaire intérieure par leur effet sur la production alimentaire. Elles agissent également par le biais des marchés des facteurs, des intrants et des produits, qui déterminent les niveaux, la répartition géographique et temporelle de la production, du stockage et de la transformation (Magrini et al., 2017).

En plus des politiques agricoles, le commerce international affecte également la sécurité alimentaire, mais son effet global n'est pas clair. En effet, l'intégration des marchés a un impact positif sur la sécurité alimentaire car elle contribuerait à assurer un équilibre entre les pays déficitaires et ceux excédentaires en denrées alimentaires (World Bank, 2020). De même, l'ouverture commerciale réduit la variabilité de l'offre d'aliments de base en aidant à compenser les chocs négatifs comme des sécheresses sur l'offre domestique. Toutefois, il faut noter que la libéralisation des échanges pourrait exacerber cette variabilité des quantités en présence d'un marché mondial moins stable. En effet, la volatilité des prix alimentaires qui en résulte peut négativement affecter la disponibilité alimentaire (Asche et al., 2015; Kang, 2015).

Outre les déterminants cités ci-dessus, la sécurité alimentaire peut aussi être affectée

par l'adoption et la production des énergies renouvelables tels les biocarburants. En effet, nombreuses sont les études analysant les effets positifs et négatifs des biocarburants sur la sécurité alimentaire.

6.3 Impacts des biocarburants sur la sécurité alimentaire

La demande de biocarburants de première génération augmente en raison de nombreux facteurs tels que les besoins énergétiques croissants liés à l'augmentation de la population, l'augmentation du prix du pétrole, la recherche de sources d'énergie décarbonées et renouvelables, et le désir d'augmenter les revenus agricoles dans les pays développés (Aiff et al., 2013). Cependant, la production de biocarburants peut avoir divers impacts sur la sécurité alimentaire (Gasparatos et al., 2015). Les effets peuvent provenir directement de la production ou indirectement des politiques de soutien aux biocarburants.

6.3.1 Effets liés à la production des biocarburants

L'un des effets négatifs de la production des biocarburants sur la sécurité alimentaire résulte de l'utilisation de certaines denrées alimentaires comme matières premières. En effet, l'utilisation des denrées tels le maïs, la canne à sucre ou l'huile de palme peut contribuer à une diminution de leur disponibilité pour la consommation humaine. Dans la mesure où la baisse de la consommation de ces denrées affectera principalement des personnes pauvres et vulnérables, la production des biocarburants augmentera la faim et la malnutrition. Cette situation pourrait également favoriser l'accroissement des prix.

Rajagopal et al. (2007) et Zilberman et al. (2013b) montrent que l'introduction des biocarburants a été responsable d'un quart de l'inflation des prix alimentaires dans

le monde en 2007 et 2008. Se focalisant sur la production de bioéthanol à partir de la canne à sucre, il apparaît que de 1983 à 2013, plus la part de canne à sucre associée à la production d'éthanol était importante, plus le prix du sucre augmentait. La sécurité alimentaire peut donc être mise en péril principalement dans les pays en développement importateurs nets de denrées alimentaires ([Chauvin et al., 2012](#)).

Dans la plupart de ces pays en développement, le taux de pauvreté est très élevé. Étant donné que les pauvres consacrent environ deux tiers de leurs revenus à l'alimentation, une variation à la hausse des prix des aliments impliquerait une variation de leur revenu réel et donc de l'accessibilité à ces aliments. Dans de nombreux pays d'Amérique latine, les hausses de prix de 2007-2008 ont entraîné des réductions significatives de l'apport calorique, tant au niveau national qu'au niveau des ménages, principalement pour les enfants de moins de deux ans des ménages pauvres ([Robles et al., 2010](#)). En outre, le sens de l'évolution du revenu réel dépend de la position commerciale du ménage. D'une part, les vendeurs nets de denrées alimentaires bénéficieraient des hausses de prix, tandis que les acheteurs nets verraient leur revenu réel diminuer à court terme. D'autre part, des prix alimentaires bas peuvent négativement affecter les vendeurs ou les producteurs de denrées alimentaires. C'est l'essence même du dilemme des prix alimentaires ([Timmer et al., 1983](#)).

Par ailleurs, certaines études montrent que la production de biocarburants induit un changement direct ou indirect de l'utilisation des terres. Les terres supplémentaires nécessaires à la production de biocarburants s'étendent vers les zones forestières entraînant une déforestation ([de Carvalho et al., 2015](#); [Choumert et al., 2017](#)).

Cependant, selon [Ewing and Msangi \(2009\)](#), il existe des possibilités pour que la production de biocarburants crée des emplois et augmente localement l'offre d'énergie, fournisse des avantages aux personnes vulnérables tout en améliorant la sécurité alimentaire. En effet, la chaîne de production du bioéthanol est plus intensive en

main-d'œuvre que la chaîne de production du pétrole, ce qui peut favoriser l'emploi et l'amélioration des revenus dans les zones rurales. Ceci est cohérent avec l'idée que l'expansion des biocarburants peut générer des revenus supplémentaires dans le secteur agricole. En Ethiopie, la production de ricin pour les biocarburants a permis aux agriculteurs d'améliorer leur sécurité alimentaire. En effet, la vente des graines de ricin a contribué à générer des revenus aux agriculteurs leur permettant par la suite d'acheter et de stocker des denrées alimentaires (Negash and Swinnen, 2013).

De même, les programmes de production des biocarburants favoriseraient également les sources d'énergie alternatives pour les usages domestiques et contribueraient à améliorer la productivité et les revenus des femmes. Un exemple de l'impact des biocarburants sur les revenus des femmes a été observé en Inde. À l'initiative de l'Institut international de recherche sur les cultures des zones tropicales semi-arides (ICRISAT) en 2007, un projet d'huile de pongamia mené par des femmes a été mis en œuvre pour faire fonctionner de petits générateurs produisant de l'électricité. Ce projet a également permis aux femmes d'être plus indépendantes financièrement.

Ainsi, le développement responsable et durable des biocarburants peut contribuer à améliorer le développement rural, à réduire la pauvreté dans de nombreux pays en développement tout en améliorant la sécurité alimentaire (Arndt et al., 2012).

6.3.2 Effets liés aux politiques de soutien aux biocarburants

Les politiques de soutien aux biocarburants visent à promouvoir l'utilisation de carburants issus de la biomasse et d'autres carburants renouvelables dans les transports. Les crédits d'impôts, exonérations fiscales, mandats de mélange ou d'utilisation et les restrictions commerciales sont considérés comme les mécanismes les plus courants expliquant l'expansion des biocarburants (Blanco Fonseca et al., 2010; Sorda et al., 2010). Ces politiques tendent à stabiliser les prix des biocarburants car elles induisent un certain niveau de consommation et de production (Beckman et al., 2015).

Selon [Durham et al. \(2012\)](#), ces politiques visant à promouvoir la production de biocarburants ont pour effet d'augmenter le prix de certains produits agricoles de base. La conséquence est une réduction de la consommation et du bien-être nutritionnel des consommateurs ([Afiff et al., 2013](#)). Toutefois, [Choumert et al. \(2018\)](#) à travers une méta-analyse de la littérature sur les modèles d'équilibre général calculable, ont constaté que les politiques de soutien aux biocarburants génèrent des impacts significatifs sur le produit intérieur brut (PIB) et les revenus des ménages.

[Enciso et al. \(2016\)](#) notent que la suppression des politiques de soutien aux biocarburants aurait un effet significatif sur la variabilité des prix des biocarburants, mais seulement un impact marginal sur la variabilité des prix des produits agricoles de base. Sans politique en matière de biocarburants, la demande mondiale de biocarburants diminuerait de 25% pour le bioéthanol et de 32% pour le biodiesel. Toutefois, les prix ne diminueraient que modérément pour les produits de base du bioéthanol, comme le blé et les céréales secondaires, tandis que les prix des produits de base du biodiesel, notamment des huiles végétales, seraient plus affectés.

Par conséquent, la baisse des prix et la diminution de l'utilisation des cultures à des fins de production de biocarburants pourraient se traduire par une alimentation plus abordable pour la population et par un renforcement de la sécurité alimentaire. Cependant, l'abolition des politiques en matière de biocarburants ne conduirait pas nécessairement à une augmentation de la sécurité alimentaire mondiale. En effet, les cultures pourraient être réaffectées à des utilisations concurrentes telles que l'alimentation animale ou des usages industriels.

6.4 Contribution de la thèse

Cette thèse contribue à la littérature sur le dilemme "nourriture contre carburant" en étudiant l'impact de la production des biocarburants sur la sécurité alimentaire.

Elle concentre son analyse sur les effets attendus à court et long terme, et propose des solutions qui permettraient de favoriser à la fois la production des biocarburants et la sécurité alimentaire. Elle se focalise sur les impacts des biocarburants sur la disponibilité alimentaire, les prix des denrées alimentaires, le déficit alimentaire, et vérifie si la production des biocarburants fait partie des principaux déterminants de long terme de l'insécurité alimentaire.

Plus spécifiquement, le chapitre 2 considère les effets de la production de biocarburants sur la sécurité alimentaire. L'analyse porte sur l'Indonésie et le Mexique et utilise la méthode de contrôle synthétique. L'Indonésie est l'un des grands producteurs mondiaux de biodiesel, tandis que le Mexique est spécialisé dans le maïs et l'éthanol. Les résultats montrent que la production de biodiesel affecte positivement la sécurité alimentaire grâce à une augmentation de la consommation énergétique quotidienne par habitant et de la production alimentaire. Toutefois, l'effet inverse est obtenu pour le bioéthanol. Ces résultats peuvent s'expliquer de la façon suivante. La production de biodiesel en Indonésie utilise des matières premières qui n'entrent pas dans la consommation humaine comme le jatropha. Par ailleurs, les exportations de biodiesel génèrent des revenus qui peuvent être alloués aux importations alimentaires. Au Mexique, la production de bioéthanol réduit la sécurité alimentaire parce qu'elle repose sur l'utilisation de maïs, aliment de base de nombreux Mexicains. En outre, les exportations mexicaines d'éthanol rivalisent avec celles des États-Unis. Par conséquent, l'analyse du lien entre sécurité alimentaire et biocarburants diffère selon les modalités de production de ces derniers.

Le chapitre 3 considère la question importante du possible lien entre la production de biocarburants et l'augmentation des prix des denrées alimentaires. Plus précisément, il analyse la transmission dynamique des chocs des prix mondiaux du bioéthanol aux prix alimentaires, en particulier les prix du maïs. La méthode des projections locales permet d'estimer les réponses dynamiques à chaque période prise en considération.

Les résultats montrent qu'il y a une réponse positive des prix du maïs aux chocs de prix du bioéthanol qui s'estompent en moyenne au bout de trois ans. Par ailleurs, en moyenne, l'asymétrie par rapport à la direction des chocs révèle un effet net nul, suggérant que la production du bioéthanol n'affecte pas la sécurité alimentaire. Cependant, une analyse désagrégée de l'intensité des impacts révèle une hétérogénéité importante.

En dépit des nombreux programmes visant à éradiquer la faim dans le monde, des millions de personnes font encore face à l'insécurité alimentaire. Le chapitre 4 vise à tester l'existence d'une trappe inconditionnelle de la faim et à déterminer si la production de biocarburants fait partie des déterminants de long terme de l'insécurité alimentaire. Le calcul des probabilités de passage d'un état d'insécurité alimentaire à l'aide de la matrice de transition de Markov et la distribution ergodique servent à tester l'hypothèse d'une trappe inconditionnelle de la faim. Ensuite, l'estimation d'un arbre de régression d'inférence conditionnelle permet d'identifier les principaux moteurs de l'insécurité alimentaire. Les résultats indiquent que les pays en développement ne sont pas pris dans une trappe inconditionnelle de la faim. Le résultat de la matrice de transition montre que tous les pays ayant des niveaux élevés d'insécurité alimentaire ont une probabilité non nulle de passer à un niveau faible dans un temps limité. De plus, compte tenu des caractéristiques des pays, les résultats de l'arbre de régression d'inférence conditionnelle montrent que la variable la plus importante est le PIB par habitant et que la production de biocarburants ne fait pas partie des déterminants de long terme de l'insécurité alimentaire. Nos résultats suggèrent que la production de biocarburants peut être un moyen de lutte contre le changement climatique sans pénaliser la sécurité alimentaire.

6.5 Principaux enseignements

Globalement, les résultats obtenus dans la thèse montrent que, dans certaines conditions, les biocarburants ne constituent pas un frein à l'atteinte du deuxième Objectif de Développement Durable à court terme et ont une influence relativement faible à long terme. Ils peuvent donc être un moyen de lutte contre le changement climatique sans pénaliser la sécurité alimentaire. Ces conditions incluent le type de matières premières agricoles utilisées pour la production de biocarburants, la compétitivité du pays sur le marché international et les politiques commerciales. Ainsi, une réglementation stricte sur l'utilisation des biocarburants, ainsi que des politiques et des plans renforcés visant à promouvoir leur compétitivité sur le marché international pourraient être bénéfiques à la fois pour la production de biocarburants et la sécurité alimentaire dans les pays en développement.

Comme elles interagissent mutuellement, les politiques de sécurité alimentaire et les politiques en matière de biocarburants ne peuvent être dissociées. Par conséquent, la sécurité alimentaire et le droit à l'alimentation doivent être des préoccupations prioritaires dans la conception de toute politique en matière de biocarburants. Pour cette raison, les gouvernements ou les décideurs publics doivent adopter une stratégie coordonnée entre la sécurité alimentaire et la sécurité énergétique. Ils peuvent concevoir des mécanismes pour empêcher que la demande de biocarburants (déterminée par le marché) puisse contribuer à altérer le niveau de sécurité alimentaire par le biais de l'augmentation des prix et de la diminution de l'accès à la terre et aux ressources pour l'alimentation. L'élaboration de méthodes et de lignes directrices pour des politiques alimentaires, de biocarburants et bioénergétiques coordonnées aux niveaux national et international permettra d'évaluer le potentiel national des biocarburants et de fournir une orientation préliminaire sur l'intégration des politiques des biocarburants dans un plan national de sécurité alimentaire.

Un autre canal qui permettrait à la fois de réduire la dépendance aux énergies fossiles

et d'assurer la sécurité alimentaire serait l'intégration commerciale. En effet, en présence d'un marché stable, elle joue un rôle très important dans l'atteinte de la sécurité alimentaire en ce sens qu'elle favoriserait le commerce des biocarburants mais également des denrées alimentaires et permettrait d'assurer un équilibre entre les régions ayant un déficit et ceux présentant un surplus alimentaire.

Par ailleurs, nos résultats indiquent que pour favoriser la sécurité alimentaire, il serait important d'orienter les politiques et les programmes de soutien à la sécurité alimentaire vers la réduction de la pauvreté, la croissance économique, la compétitivité du pays, l'ouverture commerciale et l'atténuation du changement climatique. Plus spécifiquement, les décideurs politiques pourraient veiller à ce que les objectifs de sécurité alimentaire soient intégrés dans les stratégies nationales de réduction de la pauvreté.

Les résultats soulignent également l'importance relative des femmes et des conflits armés sur la sécurité alimentaire. Les femmes devraient être spécifiquement ciblées dans les initiatives de sécurité alimentaire car elles y contribuent de manière significative et positive. Cela peut se faire en facilitant leur accès aux initiatives publiques d'approvisionnement alimentaire, aux terres et aux ressources financières pour mener à bien leurs activités. Les conflits, quant à eux, ont un effet négatif. De ce fait, au vu de la recrudescence des conflits, principalement en Afrique où les populations sont aussi les plus confrontées à l'insécurité alimentaire, les décideurs politiques pourraient renforcer la résilience des populations et les mesures visant à favoriser un meilleur accès aux denrées alimentaires des personnes déplacées.

Enfin, on ne peut parler de sécurité alimentaire sans évoquer le développement du secteur agricole en lui-même. Ainsi, en accord avec les résultats de nos analyses, il faudrait promouvoir un développement agricole durable. Cela passe principalement par la mise en place et le renforcement de systèmes alimentaires résilients principalement dans les pays en développement.

6.6 Pistes de recherche futures

Notre analyse de l'impact des biocarburants sur la sécurité alimentaire fait face, comme toute étude, à certaines limites. Tout d'abord, ces travaux de recherche pourraient être étendus en évaluant les effets directs de la production de biocarburants sur la sécurité alimentaire à travers les prix alimentaires à la consommation lorsque ces données deviendront davantage disponibles. Par exemple, le chapitre 3 utilise les données les plus accessibles concernant les prix alimentaires qui sont les prix à la production ou l'indice des prix à la consommation. Il serait intéressant d'utiliser les prix à la consommation pour l'huile de palme ou le maïs en dollar ou toute autre monnaie locale. Ces données sont, à l'heure actuelle, très peu disponibles.

La sécurité alimentaire étant un concept multidimensionnel, nos analyses pourraient être approfondies en utilisant d'autres indicateurs que ceux que nous avons utilisés comme variables dépendantes. Par exemple, un indice synthétique de sécurité alimentaire qui tiendrait compte de toutes les dimensions pourrait être construit.

La pandémie de la covid-19 a eu des répercussions négatives sur la sécurité alimentaire, principalement dans les pays en développement. Afin d'étudier plus précisément cet impact, des travaux futurs devraient inclure cette pandémie parmi les variables de contrôle lorsque les données seront plus accessibles. De même, la fragilité des chaînes d'approvisionnement des denrées alimentaires ayant un impact négatif sur la sécurité alimentaire, une variable captant cet aspect devrait être considérée dans les variables de contrôle.

Dans les chapitres 3 et 4, nous avons mené des études considérant des échantillons de pays. Il serait peut-être intéressant de conduire des analyses par pays, afin d'obtenir des recommandations de politiques publiques plus ciblées.

Un autre aspect, non étudié dans la thèse, concerne l'effet de la production des biocarburants sur la déforestation et la dégradation des sols. Des travaux futurs

pourraient examiner si les biocarburants de première et de deuxième génération contribuent, au lieu de déforester, à restaurer des terres dégradées. Par exemple, le jatropha est connu pour ses propriétés en termes de restauration des sols. De ce point de vue, la production de biocarburants à base de jatropha pourrait contribuer à une meilleure gestion des bassins versants et donc à la sécurité alimentaire. Ces recherches doivent permettre de tirer des conclusions en termes de recommandations de politiques publiques, afin que la production de biocarburants ne pénalise ni la sécurité alimentaire ni la déforestation.

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