The Impact of Renewable Energy Consumption on Food Prices: The Role of the Energy Policy Act of 2005

Bebonchu Atems* and Jehu Mette†

October 26, 2020

Abstract

The Energy Policy Act of 2005 increased the amount of biofuel that must be mixed with commercial gasoline sold in the US to 7.5 billion gallons by 2012. The Energy Independence and Security Act of 2007 further increased this requirement to 36 billion gallons by 2022. This increased production and consumption of biofuels, in particular, and renewable energy sources, in general, may compel farmers to divert significant quantities of cropland away from food and feed crops, which, in turn may lead to a rise in crop prices, feed prices, meat and poultry prices, and hence, overall food prices. Employing structural vector autoregression (SVAR) models and monthly U.S. data for the period 1974:01 to 2020:06, this paper examines, empirically, the impact of renewable energy consumption on food prices. We find, in general, that renewable energy shocks have no significant impact on food prices. For the period since the passage of the Energy Policy Act, however, a shock to biomass and wind energy consumption raises food prices significantly and persistently.

JEL Classification: E32, E50.

Keywords: Renewable energy production, Vector Autoregressions.

*David D. Reh School of Business; Clarkson University, Potsdam, NY. Email: batems@clarkson.edu

†Department of Economics, Kansas State University, Manhattan, KS. Email: mette@ksu.edu

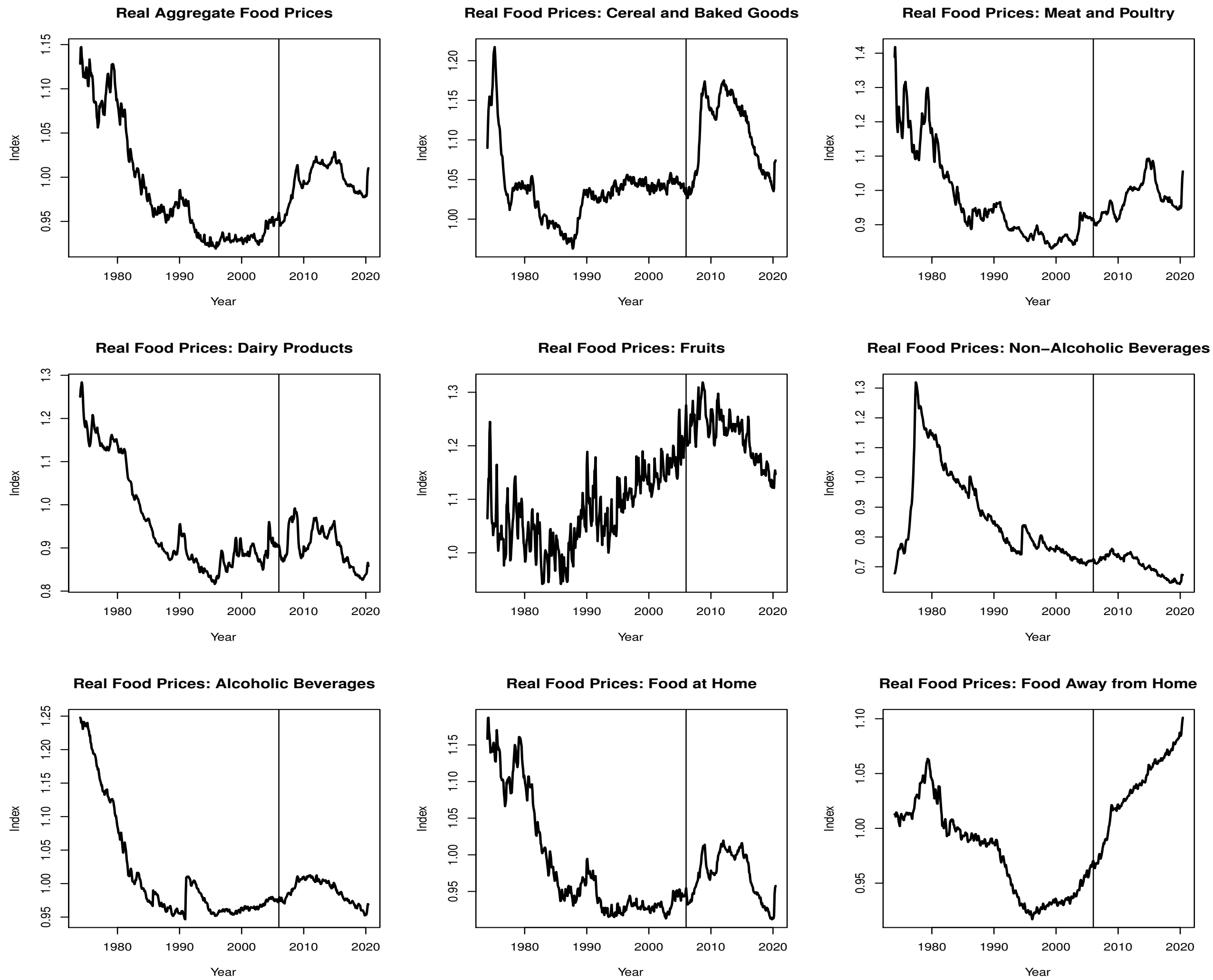
1 Introduction

Between 1974 and 2005, US real retail food prices experienced a persistent decline. In contrast, real retail food prices paid by American consumers have generally trended upward since 2006. Figure 1 plots these trends in US consumer prices from January 1974 to June 2020 for aggregate US food prices, as well as for the eight important components of food consumed by US households. The figure shows that overall food prices fell by more 16% between January 1974 and December 2005. Over the same period, the prices of meat and poultry, dairy products, alcoholic beverages, and overall food at home displayed even larger declines, decreasing by as much as 41%, 32%, 25%, and 20%, respectively. Consumer prices of the remaining food items fell at a slower pace, with fruits and vegetable prices falling by 12%, nonalcoholic beverages by 6%, cereals and baked goods by 5%, and overall food consumed away from home by 4%. Since 2006, however, US consumer prices have risen by over 5% in the aggregate, driven primarily by the increase in meat and poultry prices, prices of food consumed away from home, and cereals and baked goods, which respectively rose by 14%, 13%, and 4%. Other food prices have continued to trend downward since 2006, but at a much slower rate than during the 1974 to 2005 period. Overall, then, US real retail food prices have behaved quite differently before and after 2006.

This rise in US retail food prices to a multitude of factors, including the depreciation of the U.S. dollar in the late 2000s and early 2010s, trade policy, oil and other commodity price shocks, financial speculation, U.S. monetary policy. Abbott et al. (2011), for example, point out that a depreciating US dollar relative to the currencies of its trading partners increases imported food prices, making US retail food prices more expensive.[1] Giordani et al. (2016), Anderson and Martin (2011) and Bouet et al. (2012) argue that trade policy aimed at protecting the domestic market from, say, positive price shocks emanating from the global food market may have multiplier effects in that these actions may further disrupt

[1]For example, in January 2002, a Euro cost \$0.88. At its weakest point in April 2008, a Euro cost acquired about \$1.60. While the dollar has, in general, appreciated since its low in mid-2008, it still remains weak relative to the Euro, with one Euro costing \$1.12 at the time of this writing.

Figure 1: US Real Retail Food Prices: 1974:01-2020:06



Notes: Real food prices are the US consumer price index (CPI) for the respective food item, deflated by US core CPI. The vertical line identifies the January 2006.

international food markets. Foreign governments, in turn, may respond to these food market disruptions by implementing protective trade measures, which further escalates food prices. Using Structural VAR models, Anzuini et al. (2013), and Hammoudeh et al. (2015) provide evidence that a U.S. contractionary monetary policy shock leads to positive and persistent increases in food prices, but a fall in beverage prices. A causal link from oil prices to food prices is expected as higher oil prices may increase food production, processing, packaging, and distribution costs (Baumeister and Kilian, 2014).[2]

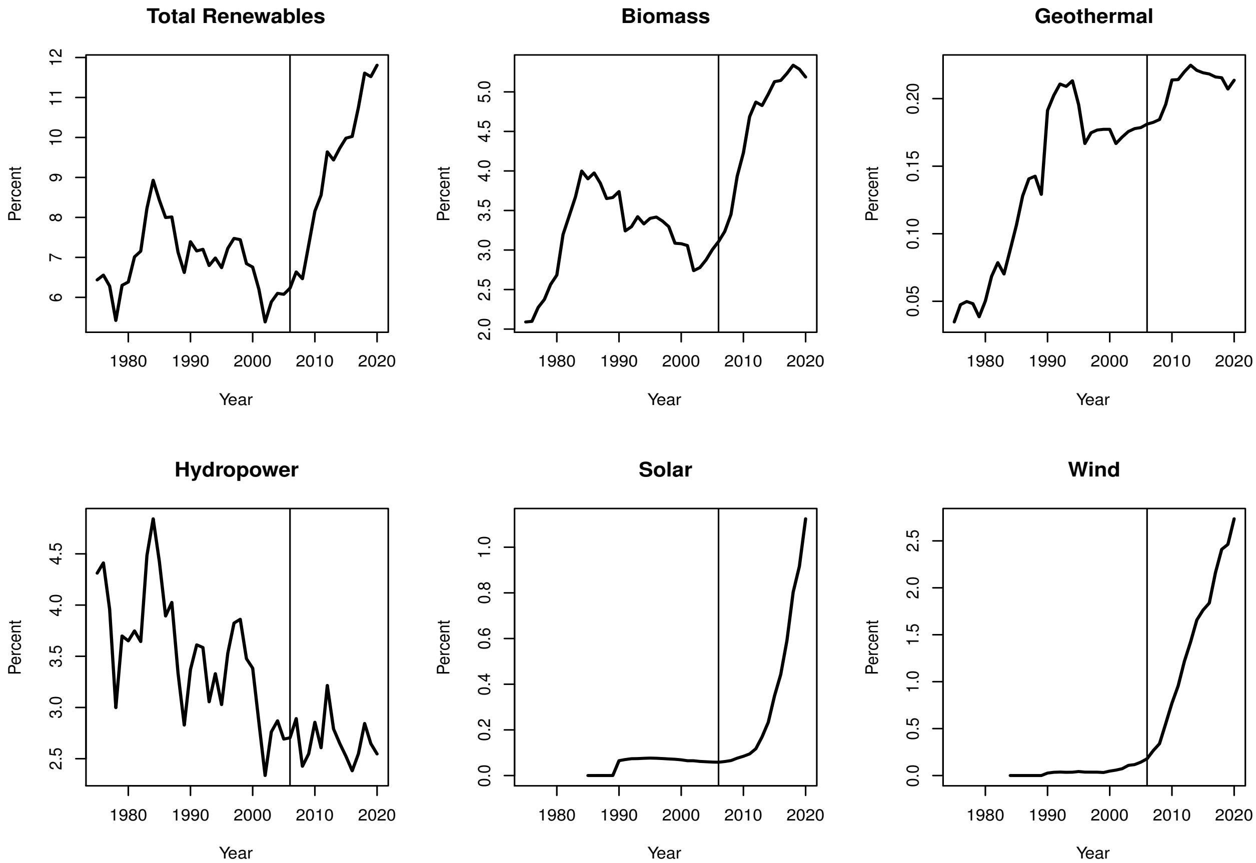
[2]Specifically, transportation costs, as well as costs associated with plastic and foam packaging can lead

While the factors discussed above may have contributed to the recent rise in food prices, many observers have also argued that the recent rise in biofuels production and consumption, in particular, and renewable energy sources, in general, may in part be responsible for escalating food prices. Figure 2 provides the rationale for this view. The percent of total renewable energy as a share of total US primary energy was smaller in 2006 than in 1974. Since 2006, however, total US renewable energy production and consumption has skyrocketed from about 6% of total primary energy to almost 12% in 2020. This rise has been primarily driven by the rise in the production and consumption of biomass, wind, and solar energy sources. Biomass rose from almost 3% in 2006 to about 6% in 2020, wind from 0.25% to about 3% over the same time period, while solar production and consumption rose twenty fold, from 0.06% to 1.4%. Equally importantly, Figures 1 and 2 illustrate that while there in no apparent link between food prices and renewable energy sources before 2006, a clear positive correlation is evident for the period from January 2006 to June 2020.

This paper is motivated by the trends shown in Figures 1 and 2. We seek to investigate whether the correlation (or lack thereof, depending on the sample period under consideration) between renewable energy consumption and production, and food prices represents a causal link. There are compelling reasons to believe that changes production and consumption of some renewable energy sources may have causal impacts on food prices. Consider the case of biofuels. First, corn, sugar cane, soybeans, and other oilseeds are used both as food and as inputs to produce ethanol, biodiesel, or other biofuels. The diversion of food crops to biofuels leads to a clear "food-vs-fuel" trade-off (Gilbert, 2010), resulting in a leftward shift of the food supply curve, and raising food prices. Second, corn, soybeans, sorghum, oats, and barley are the primary ingredients used in commercially prepared feed. This shift from feed-related crops to biofuels raises the cost of producing meat, poultry, and dairy products, and consequently an increase in their prices. Third, competition between agricultural commodities and the raw materials used for biofuels (corn, soybean, and other

to substantial increases in food prices.

Figure 2: Percent of Total Primary Energy Production by Energy Sources: 1974:01-2020:06



Notes: Data collected from the Energy Information Administration (EIA). The vertical line identifies January 2006.

oilseeds) for land, water, fertilizers, and other scarce resources, puts further upward pressure on food prices. In addition, the extent to which diesel and other biofuels are used to power farm machinery and equipment will impact food prices.

Biofuels are but one example of a renewable energy source that may directly impact food prices. There are also reasons to believe that an expansion of other renewable energy sources may raise food prices. Like biofuels, competition between wind farms and agricultural land may lead to a diversion of land from the latter to the former. To the extent that this happens, food prices are expected to rise. Furthermore, while farmers do not operate windmills, they lease or sell the land required for their installation, receiving compensation that typically surpass prices agricultural land lease and sale prices (Myrna et al., 2019).

Given the considerable empirical evidence that land parcels and prices tend to be spatially correlated (Kostov, 2009, Wasson et al., 2013), the value of agricultural lands adjoining wind farms is expected to rise, leading to an increase in agricultural prices. A similar argument can be made with respect to geothermal, hydropower, and solar energy sources, although in these cases, the link to food prices is less clear, and ultimately an empirical question.

This paper is not the first to examine the link between renewable energy consumption and food prices. Serra and Zilberman (2013) summarizes the broader literature and key findings of the research of the impact on biofuels and food prices. Other papers that examine this research question applying time-series approaches, include Peidong et al. (2009), Zhang et al. (2010), Serra et al. (2011a, 2011b), Janda et al. (2011). One concern with these papers is that they rely on atheoretical time series models, making it difficult to attribute a causal interpretation to the (generally) positive correlations documented. These atheoretical models, for example, may not address potential simultaneity bias, since changes in the consumption of biofuels and other renewable energy sources may impact food prices, but changes in food prices are also expected to impact renewable energy consumption. There may be further endogeneity problems that arise from external factors that simultaneously determine movements in food prices and renewable energy consumption. For example, a global economic expansion is likely to lead to an increase both renewable energy consumption and food prices, making it misleading to invoke the ceteris paribus assumption when examining the "effect" of renewable energy consumption on food prices. Therefore, the increases in food prices cannot be attributed to increases in renewable energy consumption only. Put differently, food prices would have responded quite differently if, say, federal, state, and local government policies had been responsible an increase in renewable energy consumption of the same magnitude as the increase resulting from the economic expansion.

Cognizant of the above mentioned complications, this paper attempts to estimate the impact of shocks to U.S. renewable energy consumption on retail food prices paid by US consumers. Our econometric approach relies on structural vector autoregressions (SVAR), a methodology typically employed in modern empirical macroeconomics to estimate dynamic causal effects (see e.g. Cristiano et al., 1999, 2005; Kilian and Park, 2009; Atems et al., 2015). Applying this methodology to US monthly data for the period 1974:01 to 2020:12, we find no significant evidence to support the hypothesis that shocks to renewable energy consumption increase food prices. For the period since the passage of the Energy Policy Act, specifically, from 2006:01 to 2020:06, we find evidence that shocks to biomass and wind energy consumption lead to significant, and persistent increases aggregate food prices, as well as other important retail food prices. We find no evidence that shocks to geothermal, hydropower, and solar energy consumption impact food prices before, or since the passage of the Energy Policy Act. However, our results show that shocks to the various renewable energy sources considered explain a larger proportion of the fluctuations in food prices in the period since the Energy Policy Act than before.

This paper is related to the broader literature that employs structural dynamic econometric models to investigate the relationship between energy and food prices. Baumeister and Kilian (2014) apply an SVAR model to examine the impact of oil price shocks on food prices, concluding that "there is no evidence that oil price shocks have been associated with more than a negligible increase in US retail food prices in recent years" (page 691). Hausman et al. (2012) apply an SVAR model to analyze the response of US crop prices to shocks in acreage supply, reporting that a negative shock in own acreage leads raises soybean and corn prices. Other papers that apply SVAR models to the food-versus-fuel debate include among others, Carter et al. (2016), Qui et al. (2012), and Anzuini et al. (2013).

The rest of the paper proceeds as follows. Section 2 provides a brief review of the literature on the effect of biofuels in particular, and renewable energy in general, on food prices. Giving our findings that the effects of renewable energy shocks differ before and after 2006 - a period that coincides with the passage of the Energy Policy Act - Section 3 provides some background on the Energy Policy Act and how it possibly changed the relationship between renewable energy consumption and food prices. In Section 4, we present the data and discuss some stylized facts about renewable energy and food prices. In this section, we also conduct tests for and evidence (or lack thereof) of unit roots, cointegration, and structural breaks in the data. In Section 5, we discuss theoretical mechanisms through which changes in renewable energy consumption may impact food prices. The main results of the analysis are presented in Section 7. Section 8 presents concluding remarks.

2 Literature Review

The topic of renewable energy has gained growing attention both from the public and economic researchers in recent years. The concern for fossil fuels sustainability has lead many large economies to shift their energy policy toward more clean and renewable alternatives. Biofuels stand out both in their importance and future possibilities in this debate. The literature addressing the impact of renewables energies on food prices has produced several papers with mixed results.

Ajanovic (2011) focuses on biofuels production originating from first generation feedstock such as corn, wheat, and sugarcane asking the question of whether the then moderate increase in biofuels production had any significant effects on agricultural commodity prices. The study focused on biofuels production, land use, yields, feedstock as well as crude oil prices. Two main approaches are used thoughout. First, the basic relationship between quantities of crops output, costs of productions and expected market prices is used. Second, the review of the most relevant literature around the "food versus fuel" debate. The paper suggests that despite the modest but constant increase in bio-energy reliant fuels, feedstock production has increased as well and kept up. Altogether, the author concludes that biofuels and food commodities can cohabitate but emphasizes that a complete shift to biofuels would be impossible because of land limitations. Janda et al. (2012) contrasts this view by providing an overview of the motivating forces behind the increased use of biofuels and report that they are primarily policy driven and the first generation fuels not economically viable.

The study highlights the existence of heavy government subsidies enabling this orientation (with the exception of Brazil with its developed sugarcane based ethanol). The study further emphasizes that the environmental implication of these policies are for the most part ambiguous. They also undertake a review of the methods used in the literature. They report that more theory-based studies evaluating the impact of biofuels rely on partial equlibrium or computable general equilibrium models (CGE) with among others Rajagopal and Zlberman (2007) who provide a substantial overview of biofuels related models. Reduced form models linking prices in agricultural market and energy as does Serra and Zilberman (2012). Carter et al. (2017) estimate that corn prices were about 30% higher between 2014 to 2006 to the expected levels if the Energy Independence and Security Act of 2007 did not create a surge in demand. Their method involves a partially identified structural vector autoregressor model.

Mueller et al. (2008) also found that the increase in food prices and biofuels production could not be interpreted as causal. Then, the findings showed that the contribution of the biofuel production was at best modest but mostly non existent for food prices.

Tangermann (2008) makes the argument that based on competing land requierments for biofuels production and food commodities there was a serious risk to the global food supply based on this emerging trade off. Taking the example of India and China, the paper supports that speculators were not the culprit in the food prices surge observed, but that it was rather the biofuel production which was a significant element in the price increase. Likewise, Rathmann et al. (2010) provides further evidence that a competitiveness exist in land uses with regard to biofuel crops and traditional food commodities. The paper also report short run increases in food prices as a results of increased biofuel production. More recently, Mitchell (2010) is not only of the same view but goes as far as concluding that the most important factor in the observed increase emanated from the US and European Union policy shift in respect to biofuels. Berndes et al. (2003) in a review of 17 studies not only finds also mixed results but argues as well that the explanation lies in the uncertainty and diverging opinions in regard to land yields and energy crops production. Serra et al. (2013) provides another substantial survey of the biofuels and time series related literature with an exposition of the main methods used. There are theoretical modelling papers the like of Ciaian (2011) and Wright (2011) though they emphasize that these progress have not lead to a consensus for medelling food prices volatility.The study concludes that long run agricultural price levels is driven by energy prices and that instability in the latter is transferable to food markets. Serra et al. (2011) use a non-linear approach to address a similar question.With asmooth transition vector error correction model they investigate price relationship within the US ethanol industry. They study daily prices between mid 2005 and 2007. Their results suggest that ethanol, corn and oil prices have an equilibrium though only ethanol prices adjust in a non-linear way to long-run parity deviation. Furthermore, they find that ethanol prices respond to a shock to both oil and corn prices reaching a peak after 10 days which fades aproximately after a month . Other studies have found that to keep up with the world population growth and its demand in food supply, crop production must at least double by 2050. Yet, Ray and Mueller (2013) find that these expectations could not be met with the recorded yield levels worldwide. They further make the case that this difference between the reality and policymakers prognostic could make the trade off a major concern much earlier than 2050 when considering the increasing production of biofuels.

The biofuels production are not the only elements in this debate and the role of the other sources of renewable energy have also been extensively discussed in the literature. Zhang et al. (2010) presents an overview of the status of renewable energy development in China, and the targets for 2050. The country is arguably one of fastest growing economies of the past century but also the second largest emitter of carbon dioxide in the world according to the authors. Highlights of the paper include the China's Renewable Energy Law passed by congress in February 2005 with renewable energy covering already 23.4% of total installed power capacity. Qiu et al. (2012) deals with similar questions. Sayigh and Milborrow (2019) provides a thorough analysis of the cost of wind energy and its prevalence in recent years.The paper also reports that wind energy is also one of the cheapest in the renewable category. Lantz et al.(2016) shows that this alternative was not only cheaper, but supplied already up to 4.7% of the total United States electricity generation, a noteworthy growth considering that this number was essentially zero two decades earlier.

3 The Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007

Historically, U.S. food prices had been decreasing since the 70s but experienced a notable surge midway through the first decade of the millenium. A multitude of factors can explain this reversal, but many paper in the literature re-emphasize (see Carter et al.(2017), Janda et al. (2012)) that the shit in energy policy is a major factor. Two outstanding policy acts involing renewable energy comsumption and production happened around that time and in this section we will explore each in detail.

3.1 The Energy Policy Act of 2005

In response to an increase in volatility of oil prices, U.S. dependence on foreign energy, and the environmental consequences of carbon emissions and climate change, among other factors, the Energy Policy Act of 2005 was passed by the United States Congress in July 2005 and signed into law by President George W. Bush in August of the same year[3]. The purpose of the policy, therefore, was to enhance U.S. energy security, while ameliorating the environmental and sustainability concerns related to climate change. Most provisions of the bill were to be enacted between 2005 and 2009. Among these are provisions[4] pertaining to but not limited to:

[3]According to the Congressional Research Service, the 2005 Energy Act came during a period of all-time high of crude oil prices which hit $63 per barrel and gasoline reaching $2.4 per gallon. At the time the U.S. imported 58% of its oil. At the time the U.S. energy Information Administation predicted that imports grow to 68% of the domestic demand by 2025. https://www.everycrsreport.com/reports/RL33302.html

[4]congress.gov/bill/109th-congress/house-bill/6

1. Renewable Fuels Standard: That gasoline sold in the United States had to contain an increasing amount of renewables in 2006 the like of biodiesel or ethanol. Motor fuels must contain at least 4 billions gallons of the renewables in 2006 with a target of 7.5 billions by 2012 under a yearly increment of 700 millions gallons.

2. Domestic Energy : The act encourages production of energy on federal lands through reduced royalty and increased access for drilling activity and other energy projects.

3. Tax Reduction: A target of $ 14.5 billions decrease over 11 years to encourage domestic energy production.

4. Electricity: Several standing acts were repealed and the Federal Energy Regulatory Commission (FERC) was authorized to certify a national reliability organization (ERO) to enforce reliability standards.

The Enegy Act of 2005 was the first omnibus bill signed in the U.S. in more than a decade. Due to their size and the scope of non directly related topics they cover, these bills have faced criticism in the past (see Massicotte(2013)). Nevertheless, the act provided financial incentives for homeowners to make changes to their energy consumption. Another element was the tax credit offered to drivers of hybrid vehicles and the increased competition among car manufacturers for fuel efficient vehicles to meet the demand. In retrospective, these provisions reduced the reliance on fossil fuels both in the short and long run.

3.2 The Energy Independence and Security Act of 2007 (EISA)

This following act was signed on December 19, 2007 by President Bush to further address the goals of the 2005 act. Among others, it was aiming to give the U.S. a greater energy independence and security, enhance the production of clean energy resources and protect consumers[5].

[5] https://www.epa.gov/laws-regulations/summary-energy-independence-and-security-act

The EISA was to solidify the original target and bring more aggressive requirments through three main provisions here summarised[6]:

1. Corporate Average Fuel Economy (CAFE): The setting of 35 miles per gallon as target for the combined fleet of cars and light trucks by model year 2020.

2. Renewable Fuels Standard (RFS). There is a modified standard (compared to the 2005 Act) starting instead at 9.0 billion gallons in 2008 and rising to 36 billion gallons by 2022.

3. Energy Efficiency Equipment Standards: The law includes various new standards for lighting and for residential and commercial appliance equipment. The equipment includes residential refrigerators, freezers, refrigerator-freezers, metal halide lamps, and commercial walk-in coolers and freezers.

A notable decision was also the repealing of two tax subsidies in order to offset the estimated cost to implement the CAFE provision.

4 Data and Stylized Facts

4.1 Data on Renewable Energy Consumption

The data on renewable energy production and consumption come from the US Department of Energy's Energy Information Administration (EIA). The agency provides a number of measures of energy production and consumption at different frequencies and geographic level. For our purposes, we utilized the data on total renewable energy and various disaggregate measures, namely biomass, wind power, geothermal, hydroelectric power, and solar. All data are available in British Thermal Unit (BTU) for comparability across sources. The data are monthly, and cover the period, January 1974 to June 2020, except for wind and solar, start in January 1983 and January 1984, respectively. All the measures of renewable energy are

[6] https://www.everycrsreport.com/reports/RL34294.html

expressed as a share of total primary energy, and further expressed in per capita terms by dividing by monthly US population, collected from the Federal Reserve Economic Data (FRED). Expressing the data in this format is common in the literature (see e.g. Sadorsky, 2009; Mishra et al., 2009; Kumar, 2020; Liu et al., 2020).

Figure 2 displays the trends US renewable energy consumption as a percent of total primary energy consumption from January 1974 to June 2020. Except for hydropower, which displays a downward trend, consumption of most renewable energy sources in the US has risen since 1974, but this rise is most apparent after 2005. In the figure, we include a vertical line in January 2006 to make this difference in the consumption of various renewable energy sources even clearer. In fact, since January 2006, total US renewable energy consumption as a share of total US primary energy consumption doubled from about 6% to 12%. This doubling in total renewable energy consumption has been fueled by the consumption of biomass, which includes biodiesels, biogas, wood, wood waste, ethanol, municipal solid waste and landfill gas. While the consumption of geothermal energy has more than quadrupled since 1974, it still comprises a negligible proportion of total primary energy consumption. On the other hand, consumption of solar and wind energy, which each stood almost 0% in 2006, now stands at approximately 1.2% and 3% of primary energy consumption, respectively.

The literature has suggested a number of reasons for this expansion of renewable energy consumption. Rentschler (2013) suggests that the increased volatility and prices of oil and other nonrenewable energy sources has played a significant role. Bowden and Payne (2010) attribute it to the US dependence on non-renewable energy sources finding a bidirectional Granger-causality between commercial and residential non-renewable energy consumption and real GDP. Zweibel et al. (2008) argue that the environmental consequences of carbon emissions and climate change have, in part, been responsible for the shift away from fossil fuels to alternative energy sources. These factors have led to US government policies and programs that provide incentives in the form of subsidies, tax credits, and rebates for choosing to produce renewable energy contributing to the pattern. Chief among these policies have been the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007.

4.2 Data on Food Prices

The data on food prices are also monthly, from January 1974 to June 2020 . We use the consumer price index of the food item as the measure of food prices for that item. All the food prices are collected from FRED, and are expressed in real terms by deflating by the US CPI excluding both food and energy (core CPI). To measure aggregate food prices, we use the US city average food and beverages CPI for all urban consumers. In addition to aggregate food prices, we consider eight important food prices, namely cereals and bakery products; meats, poultry, fish, and eggs (meat and poultry, henceforth); dairy and related products; fruits and vegetables (fruits, henceforth), alcoholic beverages; non-alcoholic beverages; food at home; and food away from home. These food prices have been considered by Baumeister and Kilian (2014) in their study of the impact of oil shocks on food prices.

As shown in Figure1, aggregate US retail food prices displayed a downward trend until the mid 2000s, after which they started rising, peaking in January 2015. While real food prices in the aggregate began to fall in 2015, they still exceed their January 2006 levels. Prices of cereals and baked products, meat and poultry, and food away from home generally mimic aggregate food prices. However, not all food prices have trended in a similar manner. Prices of fruits and vegetables have declined persistently since 2009, while prices of dairy products, alcoholic beverages, and non-alcoholic beverages are below their 2006 levels.

4.3 Time-Series Properties

In this section, we examine the time series properties of our data by conducting a series of tests for unit root, cointegration, and structural breaks.

4.3.1 Unit Root and Stationarity Testing

Many tests for unit roots and/or stationarity exists but for this analysis we will only use the Augmented Dickey Fuller test and the Phillips-Perron Test. The first takes the general form:

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \delta_1 \Delta y_{t-1} + ... + \delta_{p-1} \Delta y_{t-p+1} + \epsilon_t \tag{1}$$

The null hypothesis of this test is that a unit root exist in the time series. The alternative is different depending on the version of the ADF, that is whether we consider a constant, a linear trend, or both. We usually decide between stationarity and trend stationarity. The ADF statistic is a negative number and the more negative it is the stronger the null can be rejected. When both α and β in Equation (1) are zero, we are running an ADF without a drift nor trend. When β alone is zero in Equation (1), we are running an ADF with drift but not linear trend. The idea is that is the series actually has a unit root then the lagged y_{t-1} will provide no relevant information to predict the change in y_t beyond the one coming from Δy_{t-m}. So essentially, the test checks whether γ is statistically different from zero:

$$DF = \frac{\gamma}{SE(\gamma)}$$

where DF is the Dickey-Fuller test statistics and SE denotes the standard error. The value of the test statistic is then compared to the critical values from the Dickey Fuller t-distribution.

On the other hand, the Phillips-Perron (PP) test (Phillips and Perron (1988)) differs from the ADF test mainly on how it deals with serial correlation and heteroskedasticity in the errors. The PP test proceeds by estimating the model:

$$\Delta y_t = \beta' D_t + \Pi y t - 1 + \epsilon_t \tag{2}$$

The test statistic can be tought of as an autocorrelation-robust Dickey-Fuller statistic.

Davidson and Mackinnon (2004) report that the ADF test preforms better than the PP test in finite samples.

As emphasized by Bierens (2001), regressions estimated with data that contain unit roots are likely to be spurious. Secondly, there may exists linear combinations of two or more nonstationary series which are stationary, meaning that these linear combinations may be interpreted as long-run relationships. For these reasons, We conduct both tests discussed above on all series and report the results in Table 1.

Our tests for stationarity1 show that all energy measures are stationary in the three versions of the ADF test as well as the Phillips-Perron test. The aggregate and disaggregated measures of food prices are shown to be non stationnary in levels. To avoid the sort of spurious regressions problems documented by Granger and Newbold (1974) when using a mixture of I(0) and I(1) variables, we follow Atems et al. (2015) and first log difference our food prices measures. We proceed with a first log difference of both categories and obtain stationary series2.

4.3.2 Testing for Structural Break

Looking at Figures 1 and 2 it is apparent that renewable energy production and food prices behaved very differently before and after the mid 2000s. In particular, US retail food prices decreased persistently until the mid 2000s, after which they experience a significant rise. Similarly, US consumption of renewable energy was generally low before the mid 2000s, but have more than doubled since then. This raises the question of whether there has been a structural break in these series, and whether this potential break may impact the relationship between renewable energy consumption and food prices. Baumeister and Kilian (2014) emphasize that there is no consenscus as to a clear date when the relationship between energy and food prices may have changed. The Energy Policy Act was signed into Law by President Bush in August 2005, making that date a candidate date. Using the Narayan and Popp (2010) test, Mishra and Smyth (2014) estimate a structural break in US natural gas

Table 1: Unit Root Tests for Variables in Levels

	Augmented Dickey-Fuller			Phillips - Perron Test	
Variable	None	Drift	Drift and Trend	z-alpha	z-tau
Renewable Energy Sources					
Total Renewable Energy	-0.57	-4.46	-5.03	0.23(0.93)	-2.86(-3.765)
Biomass	-0.51	-3.70	-4.51	-19.17(3.07)	-3.52(-2.86)
Geothermal	-0.78	-5.96	-6.32	-87.5(6.83)	-3.52(-2.86)
Wind power	-0.55	-1.36	-4.28	0.77(0.96)	-3.52(-2.86)
Hydropower	-1.71	-6.35	-10.04	-28.16(3.54)	-3.52(-2.86)
Solar power	-2.90	-3.90	-5.45	0.23(0.93)	-3.52(-2.86)
Food Prices					
Food Price Index	-0.058	-1.98	-2.72	-5.51(1.64)	-3.52(-2.86)
Cereals & baked goods	0.34	-1.14	0.20	-4.47(1.63)	-3.52(-2.86)
Meat and poultry	0.03	-1.06	-1.65	-4.21(1.44)	-3.52(-2.86)
Dairy products	-0.38	-2.56	-2.51	-12.18(2.34)	-3.52(-2.86)
Fruits	0.08	-2.48	-2.83	-6.65(2.1)	-3.52(-2.86)
Non-alcoholic beverages	-1.84	-1.73	-3.05	-3.92(1.46)	-3.52(2.86)
Alcoholic beverages	-0.05	-1.98	-1.66	-7.31(1.91)	-3.52(-2.86)
Food at home	-0.55	-1.06	-0.82	-5.00(1.45)	-3.53(-2.86)
Food away from home	2.77	2.39	-3.54	1.30(-1.16)	-3.52(-2.86)

***Notes*: The lag length optimization uses the Akaike Information Criteria (AIC). The 5% critical value for the test with drift and trend=-2.87; trend=-3.42; and none=-1.95.**

consumption in December 2005, and attribute this break to the Energy Policy Act of 2005. Carter et al. (2013) states that informed market participants would have known by late 2006 of a coming surge in ethanol production, suggesting a structural break in late 2006. Avalos tests for, and finds a structural break in US food prices in May 2006. What is evident from this discussion is that many papers agree that the underlying structure of US renewable energy and food prices changed some time between August 2005 and 2006, but there is no consensus as to the exact date.

In this paper, we select January 2006 as a candidate break data, and use the Chow test to confirm this date. Figure 3 presents the results of the Chow test. For five of the six renewable energy consumption measures considered, the test rejects the null hypothesis of no structural break and confirming the conjecture of a break in January 2006. Similarly, at the 5% level, the test supports our conjecture of a break in January 2006 for aggregate food

Table 2: Augmented Dickey-Fuller(ADF) unit root test: Level and log first differences

	ADF(Levels)			ADF(Log first differences)		
Variable	None	With Drift	Drift and Trend	None	With Drift	Drift and Trend
Renewable Energy Sources						
Total Renewable Energy	-0.57	-4.46	-5.03	-10.335	-10.330	-10.304
Biomass	-0.51	-3.70	-4.51	-9.733	-9.759	-9.799
Geothermal	-0.78	-5.96	-6.32	-9.771	-9.737	-9.712
Wind power	-0.55	-1.36	-4.28	-8.641	-8.746	-8.803
Hydropower	-1.71	-6.35	-10.04	-8.542	-8.520	-8.491
Solar power	-2.90	-3.90	-5.45	-7.753	-7.786	-7.760
Food Prices						
Food Price Index	-0.058	-1.98	-2.72	-10.277	-10.287	-10.733
Cereals & baked goods	0.34	-1.14	0.20	-9.305	-9.274	-9.506
Meat and poultry	0.03	-1.06	-1.65	-7.139	-7.144	-7.551
Dairy products	-0.38	-2.56	-2.51	-9.474	-9.447	-9.628
Fruits	0.08	-2.48	-2.83	-10.764	-10.738	-10.809
Non-alcoholic beverages	-1.84	-1.73	-3.05	-9.089	-9.202	-9.286
Alcoholic beverages	-0.05	-1.98	-1.66	-9.695	-9.670	-10.235
Food at home	-0.55	-1.06	-0.82	-10.105	-10.074	-10.614
Food away from home	2.77	2.39	-3.54	-10.105	-10.074	-10.614

***Notes*: The lag length optimization uses the Akaike Information Criteria (AIC). The 5% critical value for the test with drift and trend=-2.87; trend=-3.42; and none=-1.95.**

prices, fruits and vegetables, nNon-alcoholic beverages, alcoholic beverages, and food away from home. The test also rejects the null hypothesis of no structural break in 2006 for meat and poulty prices at the 10% level. However, for cereal and baked goods, dairy products, and food at home, the hypothesis of a break in January 2006 is rejected.

5 Mechanisms Through Which Renewables Affect Food Prices

An overwhelming proportion of the findings and opinions in the literature point to a growing competition for land use allocation between biofuels and traditional crops used for food. Rathmann, Szklo, Schaeffer (2010) analyze the literature and found evidences that the emer-

Table 3: Results of the Chow Structural Break Test

Variable	Test statistic	p-value
Renewable Energy Sources		
Total Renewable Energy	7.219	0.020
Biomass	6.872	0.032
Geothermal	18.026	0.000
Wind power	13.702	0.001
Hydropower	15.058	0.001
Solar power	2.458	0.117
Food Prices		
Food Price Index	7.296	0.026
Cereals & baked goods	2.425	0.297
Meat and poultry	5.612	0.061
Dairy products	0.014	0.993
Fruits	6.802	0.033
Non-alcoholic beverages	65.008	0.000
Alcoholic beverages	10.991	0.000
Food at home	0.954	0.621
Food away from home	12.404	0.002

gence of biofuels had altered the dynamics of land use but only in the short run. More recently, Muscat et al. (2020) review 75 studies dealing with the question of competition. The review suggest that the allocative dilemma is supported by evidences and requires a holistic analysis. Rather than a Hecksher-Ohlinian decision at trading geographical units, it appears that it is individual farmers regardless of their crops or regional specialization who have progressively moved towards the production of renewable energy type sources.The involvement in this energy harvest has greatly varied among farmers plausibly for two reasons. First, renewable energy harvesting has a high upfront opportunity cost.Taking the example of solar energy, there is a very large requirement of land for relatively small energy output. It takes 3500 acres of land to produces about 392 megawatts. In perspective, if the US were to rely on solar energy alone, it would require an area of 22,000 acres or the size of the Mojave desert[7]. Secondly, besides the case of biomass (generated from a particular strand

[7]The National Renewable Energy Laboratory state that 3.4 acres of panels are needed to produce one gigawatt hour over a year. The estimate need for the U.S. is about 4 pettawatts of electrity for a year. https://www.cia.gov/library/publications/the-world-factbook/rankorder/2233rank.html

of corn), getting started in the renewable energy field could mean abandoning traditional crops for which farmers already have both physical and human capital .Once the Energy Policy Act of 2005 was introduced, the ethanol composition of commercial gas became a monitored requirement and the demand for suitable biofuels increased.This sudden increase in the demand for such crops most likely caused a short run surge in the biofuel market price with its then inelastic supply. Over time, in reaction to these prices, the producers of these biofuel crops have had an opportunity to expand their operations and new comers to enter this now lucrative market. We believe that these dynamics have strongly affected the supply of food crops and in terms the food items they are the inputs of.

Taking the case of wind then, the idea of farms growing crops and also benefiting from sporadic installation of wind mills is not very accurate. In practice, the installation of a windmill operation requires the establishment of multiple GPS trackers and the creation of new roads to properly install the machines. In other words, the loss in land is not simply the towers seen from afar. "Farmers with wind generators may lose the option of aerial application of farm protection products, seed, fertilizers, etc. on their farm ground. ... The fact is, it is dangerous to fly within the confines of a wind generator farm." an information available on the Illinois Agricultural Aviation Association (IAAA) website[8]. The reliability of wind turbines has been making improvement in recent years but they still constitute a danger for farmers who potentially work around it on a daily basis. This hazard makes this trade off between crops production and wind energy the more pressing as more and more rural localities have their revenue funded by wind electricity production.An extreme example is Sheldon, NY which fully eliminated local taxes because revenue from wind energy sufficed for the local budget. This double edged reliance could lead the farmers to shift toward full time wind production and decrease or abandon altogether food inputs production as a source of income.

[8]https://agaviation.com/wind-farms/

6 Empirical Methodology

This section provides details of the econometric methodology used in this paper. Specifically, we present a VAR model to evaluate the impact of renewable energy shocks on food prices. We incorporate the various measures of renewable energy and food prices into the VAR model one at a time, since it is not feasible to include all of them in one model.

For each measure of renewable energy consumption and food prices, we estimate the bivariate reduced-form VAR model:

$$\begin{bmatrix} R_t \\ F_t \end{bmatrix} = \begin{bmatrix} A_{11}(L) & A_{12}(L) \\ A_{21}(L) & A_{22}(L) \end{bmatrix} \begin{bmatrix} R_t \\ F_t \end{bmatrix} + \begin{bmatrix} \varepsilon_{R,t} \\ \varepsilon_{F,t} \end{bmatrix} \tag{3}$$

where R_t is a measure of renewable energy consumption, F_t represents the measure of food prices, L is the lag operator, and $A(\cdot)$ is a polynomial in L. In equation (3), $\varepsilon_{R,t}$ and $\varepsilon_{F,t}$ are the reduced form residuals for each equation. The lag order, L, is chosen by minimizing the Akaike Information Criteria (AIC).

Let $u_{R,t}$ and $u_{F,t}$ respectively denote the structural shocks to renewable energy consumption and food prices. We assume that the reduced-form residuals and the structural shocks have the following relationship:

$$\begin{bmatrix} \varepsilon_{R,t} \\ \varepsilon_{F,t} \end{bmatrix} = B_0^{-1} \begin{bmatrix} u_{R,t} \\ u_{F,t} \end{bmatrix} \tag{4}$$

where B_0 is a non-singular matrix that describes the contemporaneous relationship between the two variables:

$$B_0 = \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix} \tag{5}$$

Further restrictions must be imposed on B_0 in order to identify the structural shocks

$u_{R,t}$ and $u_{F,t}$. In this paper, we impose the assumption that shocks to renewable energy consumption impact food prices contemporaneously, whereas it takes at least a month for shocks to food prices to affect renewable energy consumption. This assumption implies that $B_{12} = 0$ in Equation (5), yielding:

$$B_0 = \begin{bmatrix} B_{11} & 0 \\ B_{21} & B_{22} \end{bmatrix} \tag{6}$$

Premultiplying Equation (3) by B_0 in Equation (6) results in the SVAR model:

$$\begin{bmatrix} B_{11} & 0 \\ B_{21} & B_{22} \end{bmatrix} \begin{bmatrix} R_t \\ F_t \end{bmatrix} = \begin{bmatrix} B_{11} & 0 \\ B_{21} & B_{22} \end{bmatrix} \begin{bmatrix} A_{11}(L) & A_{12}(L) \\ A_{21}(L) & A_{22}(L) \end{bmatrix} \begin{bmatrix} R_t \\ F_t \end{bmatrix} + \begin{bmatrix} u_{R,t} \\ u_{F,t} \end{bmatrix} \tag{7}$$

We use this identified VAR model to construct impulse response functions and perform forecast error variance decomposition analyses.

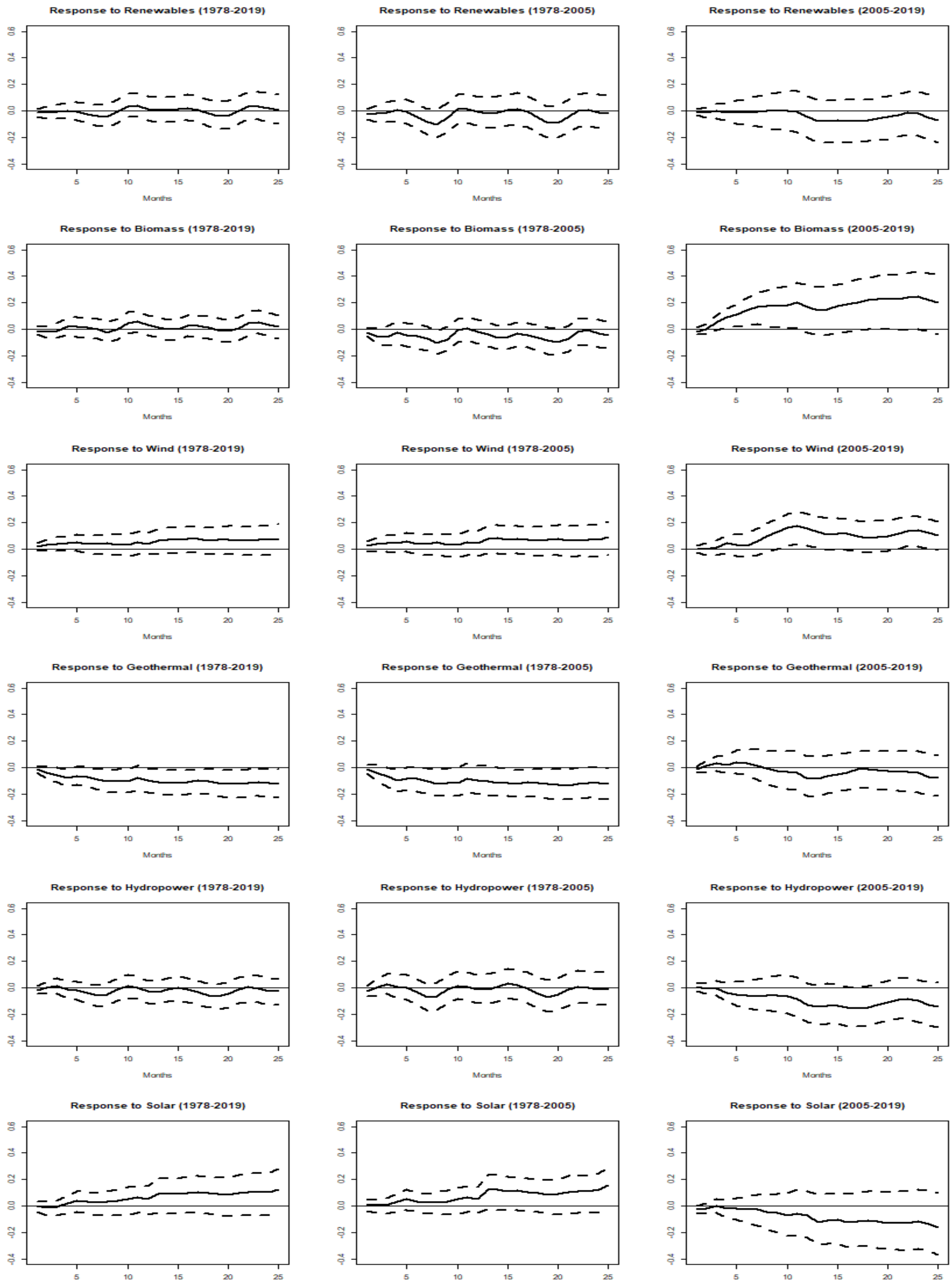
7 Empirical Results

In this section, we present the responses of aggregate and disaggregate measures of food prices to a 1% shock in energy consumption. Energy consumption is either the total renewable consumption or the disaggregate measures, namely biomass, geothermal, hydropower, solar, and wind. We report these responses for the entire sample period (1974:1-2020:06), as well as two subsample periods, namely 1974:1-2005:12, and 2006:1-2020:06. The latter period is intended to capture the effects, if any, that shocks to renewable energy consumption have on food prices, following the energy policy shift in 2005. The solid lines in the impulse response functions represent the cumulative impulse response estimates, with the dotted line depicting the 90% confidence bands obtained through a wild bootstrap procedure (Goncalves and Kilian, 2004) with 1000 repetitions. We also report forecast error variance decompositions to assess the quantitative importance of the various renewable energy shocks for movements in food prices over the three sample periods.

7.1 Impulse responses and variance decomposition for aggregate food prices

The response of aggregate food prices to a shock in each of the various renewable energy consumption measures is shown in Figure 3. The first row shows the response to total renewable energy consumption for the entire sample and the two subsamples. It is apparent that the response of aggregate food prices is not significantly different from zero for any of the three periods. Total renewable energy consumption, however, contains measures of solar, wind, hydropower, and geothermal consumption. It is not exactly clear how and/or why some of these sources may impact food prices. Consequently, there is need to disaggregate total renewable energy consumption into its various components and examine which of these components, if any, impacts food prices.

Figure 3: Impact of Renewables on Aggregate Food Prices



The second row of Figure 3 displays the responses of aggregate food prices to a shock to biomass consumption. The effect of the biomass shock differs depending on the sample period under consideration. For the entire sample period - January 1974 to June 2020 - a shock to biomass consumption has no statistically significant impact on food prices. The second and third graphs of that row, however, show that this finding is primarily driven by the impact of biomass consumption for the January 1974 to December 2005 period. After 2005, however, an increase in biomass consumption is followed by a rise in aggregate food prices for the first 24 months. This increase is significantly different from zero between months 3 to 10 and around month 20. The highest aggregate food price response occurs after eight months with a cumulative impact of approximately 0.2% suggesting that a 1% transitory shock to biomass energy consumption leads to a cumulative aggregate food price increase of about 0.2% after eight months. This result is consistent with recent findings linking biofuels and food prices, including Mitchell (2018), Chen and Önal (2016), and Hochman et al. (2014). This finding that an increase in biomass consumption increases food prices is not surprising because producers, in order to increase supply to meet the increase in demand for biomass, must divert large quantities of cropland away from food and feed crops to biomass production. This diversion, all else equal, decreases the supply of food crops and animal feed, leading to a rise in crop prices, feed prices, and hence, meat prices.

In the third row of Figure 3, we consider the impact of wind on aggregate food prices. For the first the January 1974 to June 2020 and January 1974 to December 2005 periods, a shock to wind energy consumption has no impact on food prices. In the later sample period, however, a shock of 1% to wind energy consumption raises aggregate food prices by as much as 0.21% after eleven months, and 0.18% after twenty two months. That a shock to wind energy consumption raises food prices over the 2006 to 2020 sample period is consistent with the findings of, among others, Myrna et al. (2019), who, using data for Germany from 2007 to 2016, report a higher cumulative capacity of wind turbines in communities leads to higher farmland transaction prices, with farmland prices per hectare rising 0.4% following a doubling of the average cumulative capacity of wind turbines per community. In addition, they find that farmlands that are directly affected by a wind turbine experience stronger price increases. These increases in farmland prices raise food prices, as they raise the cost of production for farmers.

The last three rows of Figure 3 show responses of aggregate food prices to a shock to geothermal, hydropower, and wind energy consumption, respectively. A 1% shock to geothermal consumption lowers food prices significantly in the entire sample and the early subsample, whereas the impact in the later sample is not essentially zero. Looking at the responses to hydropower and wind, at no instant do food prices display a response that is statistically different from zero.

Table 4 shows the percent of the forecast error variance of aggregate food prices explained by the various renewable energy sources based on the SVAR model described in Section 6. The forecast error variance decompositions quantify the average importance of the various renewable sources for fluctuations in aggregate food prices. Panels A and B of the Figure show that shocks to the various renewable energy sources have very small explanatory power for fluctuations in aggregate food prices. Renewable energy shocks typically explain less than 3% of both the short run and long run variance of food prices, except for biomass consumption, which explains 5.3% and 7.1% of the long run variability of food prices in the 1974:01-2020:06 and 1974:01-2005:12 periods, respectively. The decomposition of variance analysis for the later sample period shown in panel C reveals that the explanatory power of renewable energy consumption for unpredictable movements in food prices has increased considerably, with shocks to biomass, wind, hydropower, and geothermal energy consumption respectively explaining roughly 7.8%, 8.4%, 10.8%, and 12.4% of the overall variability of food prices over the January 2006 to June 2020 period.

Based on the results discussed so far, the rest of the analysis will focus in the food price responses to shocks to biomass and wind energy for the period January 2006 to June 2020. Results for the other renewable energy sources and different subsamples generally

Table 4: Percent contribution of shocks to Renewable Energy Consumption to the Variability of Aggregate Food Prices

Horizon	Total Renewables	Biomass	Wind	Hydropower	Geothermal	Solar
A: 1974-2020						
1	0.000	0.000	0.000	0.000	0.000	0.000
5	0.614	2.697	0.167	0.269	0.696	0.196
10	1.099	3.603	0.967	1.012	0.923	1.410
15	1.033	3.674	1.303	1.611	1.861	2.445
20	1.523	4.675	1.471	1.970	2.195	2.618
25	1.582	4.831	1.854	2.558	2.481	3.213
30	1.709	5.265	1.954	2.544	2.629	3.234
35	1.950	5.307	2.112	2.983	2.634	3.334
B: 1974-2005						
1	0.000	0.000	0.000	0.000	0.000	0.000
5	1.204	3.836	0.223	0.000	0.679	0.306
10	2.006	5.345	1.111	0.505	0.951	1.484
15	2.185	5.393	1.414	1.363	1.953	2.868
20	2.927	6.532	1.597	2.462	2.344	3.068
25	3.075	6.695	1.890	2.916	2.594	3.510
30	3.237	7.095	2.011	3.733	2.735	3.698
35	3.563	7.130	2.096	3.718	2.746	3.785
C : 2005-2020						
1	0.000	0.000	0.000	0.000	0.000	0.000
5	1.223	1.430	4.339	1.759	2.208	3.181
10	2.989	3.664	7.010	5.773	5.639	4.621
15	2.657	5.036	7.42	6.448	7.546	5.533
20	3.591	6.447	7.942	8.138	9.461	5.514
25	3.655	6.681	8.106	9.158	10.119	5.452
30	4.0191	7.198	8.015	9.886	11.044	5.685
35	4.313	7..765	8.406	10.775	12.359	5.913

Notes: Forecast error variance decompositions based on structural VAR model.

mimic the corresponding responses to a total renewable energy shock. That is, impulse response functions are generally statistically indistinguishable from zero, while decomposition of variance analyses suggests that the shocks explain very small proportions of the variance of various food prices considered. These results have been appended in Appendix A.

7.2 Impulse Response Functions for Disaggregate Food Prices

To understand the finding above that a shock to biomass and wind energy increase food prices for the period since January 2005, this section examines the responses of disaggregate food prices indexes to the two shocks for the same time period. We focus on eight food products whose prices are likely to be impacted by shocks to biomass and wind energy consumption, namely cereals and baked goods, meat and poultry, dairy, fruits, alcoholic and non-alcoholic beverages, food at home and food away from home.These food prices As with the aggregate food price measure, all disaggregate food prices are deflated by the core CPI to express them in real terms. Recall that the analysis here focuses on the period 2006:01-2020:06.

For each disaggregate food price index and each renewable energy source (biomass and wind), we estimate a series of bivariate VAR models containing the renewable energy source and the food price measure of interest. We maintain the assumption that a shock to biomass and wind energy consumption impacts food prices contemporaneously, whereas the food prices impact biomass and wind energy consumption with a lag of at least a month. As before, the solid lines depict the cumulative impulse response estimates, while the dashed lines are the 90% confidence bands obtained via the wild bootstrap with 1000 repetitions.

Figure 4 presents the impulse responses of each of the eight disaggregate food price measures to a shock of 1% to biomass consumption. The figure shows that a biomass shock raises food prices, with the increase being statistically different from zero for meat and poultry, fruits, alcoholic and non-alcoholic beverages, food at home, and food away from home. This rise in food prices following a biomass shock over the January 2006 to June 2020 period is exactly what one would expect. To face growing domestic demand for biofuels, US biomass production has increased tremendously in recent years. A large share of the biomass is converted to ethanol and biodiesel for transportation purposes. In 2001, the US produced only 3 billion bushels of soybean with only a small proportion going to biodiesel production. By 2018, the production had risen to 4.5 billion bushels, with over a quarter used for biofuels according to the United Soybean Board.[9] Between 2010 and 2018, the share of total soybean oil consumed as biodiesel doubled from 15% to 30%.[10] A 2019 Energy Information Administration (EIA) report, in fact, revealed that soybean oil now comprises the largest share of U.S. biodiesel production.[11] Similarly, the U.S. Department of Agriculture's National Agriculture Statistics Services reported in its annual crop production summary of 2019 that corn production rose from 9.5 to 14.42 billions bushels between 2001 and 2018 (a 52% increase), while the share going to biofuels production increased from 7% to almost 40%.[12] These developments in biomass production are crucial especially when considering that corn and soybean also represent the largest cost share of animal feed. This unprecedented increase in the demand for biofuels has decreased the portion of land dedicated to growing food and feed-related crops, thereby raising crop, animal and poultry feed, meat, and poultry prices, and hence, overall all food prices. This finding is also consistent with recent findings linking biofuels and food prices, including Mitchell (2018), Chen and Önal (2016), and Hochman et al. (2014).

In Table 5, we present the contribution of the shock to biomass consumption to the variability in the various food price indexes. The table shows that for the January 2006 to June 2020 period, the explanatory power of the biomass shock generally rises as the forecast horizon increases. One month after the shock, a biomass explains only ??% of the variability of meat and poultry prices. The explanatory power of the shock rises to as much as 7% after three years. A similar pattern is apparent for the other food price measures.

Figure 4 displays the impact of a shock to wind energy consumption on disaggregate food prices. The results are generally consistent with the responses to total renewable energy shown in Figure 4. That is, the shock raises food prices. However, only the responses of cereals and baked goods, alcoholic and non-alcoholic beverages, and food away from home

---

[9] https://www.nass.usda.gov/Newsroom/archive/2019/02-08-2019.php#:~:text=Soybean%20production%20for%202018%

[10] **Source:** The Energy Information Administration reported in May 2019 that the share of soybean oil in biodiesel went from 15% to 30%. that https://www.eia.gov/todayinenergy/detail.php?id=39372.

[11] https://www.eia.gov/todayinenergy/detail.php?id=39372

[12] **Source:** Atems et al. got from the USDA. https://www.nass.usda.gov/Publications/Todays_Reports/reports/cropan20.p

Table 5: Percent contribution of shocks to Biomass Consumption to the Variability of Disaggregate Food Prices

Horizon	Cereals & Baked Goods	Meat & Poultry	Dairy	Fruits	Nonalcoholic Beverages	Alcoholic Beverages	Food at Home	Food Away from Home
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	9.776	1.031	1.115	1.554	1.433	4.615	3.285	2.019
10	12.04	6.618	5.700	3.094	4.783	8.009	6.177	3.657
15	10.54	5.733	7.162	2.977	8.137	8.797	8.488	4.885
20	11.29	6.805	8.215	2.983	8.892	9.695	8.397	6.282
25	11.58	6.336	8.500	2.993	10.234	9.398	9.191	6.453
30	11.62	6.734	9.013	2.995	10.191	9.341	9.640	6.985
35	12.16	7.024	9.276	3.205	10.425	9.903	10.251	7.381

Notes: Forecast error variance decompositions based on structural VAR model.

are statistically different from zero. To quantify the average importance of the wind energy shock for movements in food prices, Table 5 shows the forecast error variance decompositions. It is immediately apparent that for all the food prices considered, there is an increase in the explanatory power of wind prices overtime, but this increase varies considerable between the various food price measures. For example, wind energy explains less than 4% of the variability of meat and poultry prices at any forecast horizon, but explains as much as 11%, 14%, and 20% of fluctuations in the prices of cereals and baked goods, food at home, and nonalcoholic beverages, respectively.

Table 6: Percent contribution of shocks to Wind Consumption to the Variability of Disaggregate Food Prices

Horizon	Cereals & Baked Gds	Meat & Poultry	Dairy	Fruits	Nonalcoholic Beverages	Alcoholic Beverages	Food at Home	Food Away from Home
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	3.333	2.583	1.115	1.997	8.623	3.904	5.418	4.165
10	10.79	3.571	5.700	5.823	14.389	6.579	8.617	6.184
15	10.24	3.438	7.162	6.799	15.131	6.226	10.601	6.229
20	10.94	3.419	8.215	6.885	17.377	7.018	11.742	6.492
25	10.95	3.393	8.500	6.690	18.399	7.250	12.694	6.346
30	10.81	3.289	9.013	6.534	18.919	7.262	13.543	6.177
35	11.41	3.329	9.276	6.570	20.001	7.955	14.019	6.318

Notes: Forecast error variance decompositions based on structural VAR model.

8 Conclusion

Since the passage of the Energy Policy Act of 2005, there has been a substantial increase in total U.S. renewable energy production and consumption, particularly biomass, solar, and wind. this period has also coincided with significant increases in food prices paid by U.S. consumers. This positive correlation has raised the question of the increase in US renewable energy production and consumption has causal impacts on food prices. There are a number of theoretical reasons to believe that an increase in the production and consumption certain renewable energy sources may increase food prices. Consider the case of biofuels. Corn, sugar cane, soybeans, and other oilseeds are used both as food and as inputs to produce ethanol, biodiesel, or other biofuels. From a supply point of view, therefore, a diversion of food crops to biofuels results in a leftward shift of the food supply curve, leading to a rise in food prices. Second, corn, soybeans, sorghum, oats, and barley are the primary ingredients used in commercially prepared feed. This shift from feed-related crops to biofuels raises the cost of producing meat, poultry, and dairy products, ultimately leading to an increase in their prices. Third, competition between agricultural commodities and the raw materials used for biofuels for land, water, fertilizers, and other scarce resources puts further upward pressure on food prices. In addition, the extent to which diesel and other biofuels are used to power farm machinery and equipment will impact food prices.

There are also reasons to believe that an expansion of other renewable energy sources may raise food prices. Like biofuels, competition between wind farms and agricultural land may divert land from the latter to the former. To the extent that this happens, food prices are expected to rise. Furthermore, while farmers do not operate windmills, they lease and sell the land required for their installation, receiving compensation that typically surpass agricultural land lease and sale prices. If land parcels and prices are spatially correlated, the value of agricultural lands adjoining wind farms is expected to rise, leading to an increase in agricultural prices. A similar argument can be made with respect to geothermal, hydropower, and solar energy sources, although in these cases, the link to food prices is less clear.

Using an SVAR model and monthly US data for the period 1974:01-2020:06, this paper examines the impact of shocks to renewable energy consumption on food prices. The identification of structural shocks relies on the assumption that shocks to renewable energy consumption impact food prices contemporaneously, whereas it takes at least a month for shocks to food prices to affect renewable energy consumption. Our results provide no significant evidence to support the hypothesis that shocks to renewable energy consumption increase food prices for the entire sample period. However, for the period since the passage of the Energy Policy Act, specifically, from 2006:01 to 2020:06, we find evidence that shocks to biomass and wind energy consumption lead to significant and persistent increases food prices in the aggregate, as well as other important retail food prices. Geothermal, hydropower, and solar energy consumption have no impact on food prices before, or since the passage of the Energy Policy Act. We do, nevertheless, find that shocks to the various renewable energy sources considered explain a larger proportion of the fluctuations in food prices in the period since the Energy Policy Act than before.

The results of this paper raise important policy questions. In response to the increased volatility of oil and other nonrenewable energy prices, the U.S. dependence on foreign energy, the environmental consequences of carbon emissions and climate change, US federal, state, and local government officials have enacted policies that provide subsidies, rebates, and tax credits for renewable energy production, the installation of renewable energy systems, renewable energy portfolio standards, and the creject the reation of markets for renewable certificates. That a rise in biomass and wind energy production and consumption increases food prices raises concerns about poverty, hunger, and food security, which must be taken into consideration when promoting biofuel, wind, and other renewable energy programs.

References

[1] Abbott, Philip, Christopher Hurt, Wallace Tyner (2011). What's driving food prices in 2011? *Farm Foundation*, Issue Report.

[2] Ajanovic, Amela (2011). "Biofuels versus food production: Does biofuels production increase food prices?" *Energy* 36, no. 4: 2070-2076.

[3] Anderson, Kym, John Cockburn, and Will Martin (2011). Would freeing up world trade reduce poverty and inequality? The vexed role of agricultural distortions. *The World Bank*.

[4] Anzuini, Alessio, Patrizio Pagano, and Massimiliano Pisani (2015). "Macroeconomic effects of precautionary demand for oil." *Journal of Applied Econometrics* 30, no. 6: 968-986.

[5] Atems, Bebonchu, Devin Kapper, and Eddery Lam (2015). "Do exchange rates respond asymmetrically to shocks in the crude oil market?." Energy Economics 49: 227-238.

[6] Baumeister, Christiane, and Lutz Kilian (2014). "Do oil price increases cause higher food prices?." *Economic Policy* 29, no. 80: 691-747.

[7] Berndes, Göran, Monique Hoogwijk, and Richard Van den Broek (2003). "The contribution of biomass in the future global energy supply: a review of 17 studies." *Biomass and bioenergy* 25, no. 1: 1-28.

[8] Bierens: Diagnostic testing. In: Baltagi B.H. (ed.): A Companion to Theoretical Econometrics. Blackwell Publishing Ltd.

[9] Bouët, Antoine, David Laborde-Debucquet, Elisa Dienesch, and Kimberly Elliott (2012). "The costs and benefits of duty-free, quota-free market access for poor countries: Who and what matters." Journal of Globalization and Development 3, no. 1.

[10] Bowden, Nicholas, and James E. Payne (2010). "Sectoral analysis of the causal relationship between renewable and non-renewable energy consumption and real output in the US." *Energy Sources, Part B: Economics, Planning, and Policy* 5, no. 4: 400-408.

[11] Carter, Colin A., Gordon C. Rausser, and Aaron Smith (2017). "Commodity storage and the market effects of biofuel policies." *American Journal of Agricultural Economics* 99, no. 4: 1027-1055.

[12] Carter, Colin, Gordon Rausser, and Aaron Smith (2012). "The effect of the US ethanol mandate on corn prices." Unpublished manuscript 9, no. 12 : 49-55.

[13] Chen, Xiaoguang, and Hayri Önal (2016). "Renewable energy policies and competition for biomass: Implications for land use, food prices, and processing industry." *Energy Policy* 92 : 270-278.

[14] Ciaian, Pavel. "Food, energy and environment: Is bioenergy the missing link?" (2011). *Food Policy* 36, no. 5 : 571-580.

[15] Davidson, Russell, and James G. MacKinnon (2004). Econometric theory and methods. Vol. 5. New York: Oxford University Press.

[16] Gilbert, Christopher L. (2010) "How to understand high food prices." *Journal of agricultural economics* 61, no. 2: 398-425.

[17] Giordani, Paolo, Nadia Rocha, Michele Ruta (2016). Food prices and the multiplier effect of trade policy. *Journal of International Economics*, 101: 102-122.

[18] Gonçalves, Sılvia, and Lutz Kilian (2004). "Bootstrapping autoregressions with conditional heteroskedasticity of unknown form." *Journal of econometrics* 123, no. 1: 89-120.

[19] Granger, Clive WJ, Paul Newbold, and J. Econom (1974). "Spurious regressions in econometrics." Baltagi, Badi H. *A Companion of Theoretical Econometrics*: 557-61.

[20] Hammoudeh, Shawkat, Duc Khuong Nguyen, and Ricardo M. Sousa (2015). "US monetary policy and sectoral commodity prices." *Journal of International Money and Finance* 57: 61-85.

[21] Hausman, Catherine, Maximilian Auffhammer, and Peter Berck (2012). "Farm acreage shocks and crop prices: an SVAR approach to understanding the impacts of biofuels." *Environmental and Resource Economics* 53, no. 1: 117-136.

[22] Hochman, Gal, Deepak Rajagopal, Govinda Timilsina, and David Zilberman (2014). "Quantifying the causes of the global food commodity price crisis." *Biomass and Bioenergy* 68: 106-114.

[23] Hochman, Gal. "Biofuels at a Crossroads." *Choices* 29, no. 1 (2014): 1-5.

[24] Janda, Karel, Ladislav Kristoufek, and David Zilberman (2012). "Biofuels: policies and impacts." *Agricultural Economics* 58, no. 8: 372-386.

[25] Kilian, Lutz, and Cheolbeom Park (2009). "The impact of oil price shocks on the US stock market." *International Economic Review* 50, no. 4 : 1267-1287.

[26] Kostov, Philip (2009). "A spatial quantile regression hedonic model of agricultural land prices." *Spatial Economic Analysis* 4, no. 1 (2009): 53-72.

[27] Lantz, Eric, Benjamin Sigrin, Michael Gleason, Robert Preus, and Ian Baring-Gould (2016). Assessing the Future of Distributed Wind: Opportunities for behind-the-meter Projects. No. NREL/TP-6A20-67337. National Renewable Energy Lab.(NREL), Golden, CO (United States).

[28] Massicotte, Louis (2013). "Omnibus bills in theory and practice." *Canadian parliamentary review* 36, no. 1: 13-17.

[29] Mishra, Vinod, and Russell Smyth (2014). "Is monthly US natural gas consumption stationary? New evidence from a GARCH unit root test with structural breaks." *Energy Policy* 69: 258-262.

[30] Mishra, Vinod, Susan Sharma, and Russell Smyth (2009). "Are fluctuations in energy consumption per capita transitory? Evidence from a panel of Pacific Island countries." *Energy Policy* 37, no. 6: 2318-2326.

[31] Mitchell, Donald (2010). Biofuels in Africa: opportunities, prospects, and challenges. The World Bank.

[32] Mitchell, Donald (2008). A note on rising food prices (Policy Research Working Paper #4682, Development Prospects Group). Washington, DC: World Bank.

[33] Mueller, Sherry A., James E. Anderson, and Timothy J. Wallington (2011). "Impact of biofuel production and other supply and demand factors on food price increases in 2008." *Biomass and bioenergy* 35, no. 5: 1623-1632.

[34] Muscat, A., E. M. de Olde, H. H. E. van Zanten, R. Ripoll Bosch, and I. J. M. de Boer (2020). "Principles for the use of biomass in a circular economy." In WIAS Annual Conference 2020: Frontiers in Animal Sciences, pp. 34-34. WIAS.

[35] Myrna, Olena, Martin Odening, and Matthias Ritter (2019). "The influence of wind energy and biogas on farmland prices." *Land* 8, no. 1: 19.

[36] Narayan, Paresh Kumar, and Stephan Popp (2010). "A new unit root test with two structural breaks in level and slope at unknown time." *Journal of Applied Statistics* 37, no. 9: 1425-1438.

[37] Peidong, Zhang, Yang Yanli, Zheng Yonghong, Wang Lisheng, and Li Xinrong (2009). "Opportunities and challenges for renewable energy policy in China." *Renewable and Sustainable Energy Reviews* 13, no. 2: 439-449.

[38] Phillips, Peter CB, and Pierre Perron (1988). "Testing for a unit root in time series regression." *Biometrika* 75, no. 2: 335-346.

[39] Qiu, H., Sun, L., Huang, J. & Rozelle, S. 2012.Liquid biofuels in China: current status, government policies, and future opportunities and challenges. *Renewable and Sustainable Energy Reviews* 16(5): 3095–3104.

[40] Rajagopal, Deepak, and David Zilberman (2007). *Review of environmental, economic and policy aspects of biofuels*. The World Bank.

[41] Rathmann, Régis, Alexandre Szklo, and Roberto Schaeffer (2010). "Land use competition for production of food and liquid biofuels: An analysis of the arguments in the current debate." *Renewable Energy* 35, no. 1: 14-22.

[42] Ray, Deepak K., Nathaniel D. Mueller, Paul C. West, and Jonathan A. Foley (2013). "Yield trends are insufficient to double global crop production by 2050." *PloS one* 8, no. 6: e66428.

[43] Rentschler, Jun E. Oil price volatility, economic growth and the hedging role of renewable energy (2013). *The World Bank.*

[44] Sadorsky, Perry (2009). "Renewable energy consumption and income in emerging economies." *Energy policy* 37, no. 10 : 4021-4028.

[45] Sayigh, Ali, and David Milborrow (eds 2019). The Age of Wind Energy: Progress and Future Directions from a Global Perspective. Springer Nature.

[46] Serra, Teresa, David Zilberman, and José Gil (2011). "Price volatility in ethanol markets." *European review of agricultural economics* 38, no. 2 : 259-280.

[47] Serra, Teresa, David Zilberman, Jose M. Gil, and Barry K. Goodwin (2011). "Nonlinearities in the US corn-ethanol-oil-gasoline price system." *Agricultural Economics* 42, no. 1: 35-45.

[48] Serra, Teresa, and David Zilberman (2013). "Biofuel-related price transmission literature: A review." *Energy Economics* 37: 141-151.

[49] Tangermann, Stefan (2008). What 's causing global food price inflation? Vox, https://voxeu.org/article/food-price-inflation-biofuels-speculators-or-emerging-market-demand

[50] Wasson, James R., Donald M. McLeod, Christopher T. Bastian, and Benjamin S. Rashford (2013). "The effects of environmental amenities on agricultural land values." *Land Economics* 89, no. 3: 466-478.

[51] Wright, Brian D. "The economics of grain price volatility." (2011). *Applied Economic Perspectives and Policy* 33, no. 1: 32-58.

[52] Zhang, Xiliang, Wang Ruoshui, Huo Molin, and Eric Martinot (2010). "A study of the role played by renewable energies in China's sustainable energy supply." *Energy* 35, no. 11: 4392-4399.

[53] Zweibel, Ken, James Mason, and Vasilis Fthenakis (2008). "A solar grand plan." *Scientific American* 298, no. 1: 64-73.

Appendix

Table 7: Contribution of Biomass and Wind to Variability of Dairy Products Prices

	Biomass			Wind		
Horizon(Months)	1974-2020	1974-2006	2006-2020	1974-2020	1974-2006	2006-2020
1	0.000	0.000	0.000	0.000	0.000	0.000
5	0.709	1.179	1.115	0.000	0.076	4.359
10	1.476	2.549	5.700	0.005	0.076	4.285
15	1.744	2.570	7.162	0.005	0.076	4.023
20	2.078	3.012	8.215	0.005	0.076	3.865
25	2.125	3.028	8.500	0.005	0.076	3.786
30	2.225	3.182	9.013	0.005	0.076	3.687
35	2.262	3.188	9.276	0.005	0.076	3.680

Table 8: Contribution of Biomass and Wind to Variability of Cereals and Baked Goods Prices

	Biomass			Wind		
Horizon(Months)	1974-2020	1974-2006	2006-2020	1974-2020	1974-2006	2006-2020
1	0.000	0.000	0.000	0.000	0.000	0.000
5	2.071	3.754	9.776	1.412	3.653	3.333
10	2.727	4.232	12.04	3.348	5.694	10.79
15	2.844	4.454	10.54	3.835	6.225	10.24
20	3.668	5.251	11.29	4.441	6.747	10.94
25	3.802	5.416	11.58	4.654	7.060	10.95
30	4.209	5.816	11.62	4.786	7.163	10.81
35	4.265	5.841	12.16	4.932	7.323	11.41

Table 9: Contribution of Biomass and Wind to Variability of Alcoholic Beverage Prices

	Biomass			Wind		
Horizon(Months)	1974-2020	1974-2006	2006-2020	1974-2020	1974-2006	2006-2020
1	0.000	0.000	0.000	0.000	0.000	0.000
5	3.760	4.094	4.615	0.049	0.052	3.904
10	4.540	4.871	8.009	0.050	0.052	6.579
15	4.280	4.794	8.797	0.503	0.052	6.226
20	5.401	5.769	9.695	0.503	0.052	7.018
25	5.372	5.779	9.398	0.503	0.052	7.250
30	5.847	6.189	9.341	0.503	0.052	7.262
35	5.822	6.185	9.903	0.503	0.052	7.955

Table 10: Contribution of Biomass and Wind to Variability of Non-Alcoholic Beverage Prices

	Biomass			Wind		
Horizon	1974-2020	1974-2006	2006-2020	1974-2020	1974-2006	2006-2020
1	0.000	0.000	0.000	0.000	0.000	0.000
5	1.717	2.195	1.433	1.051	1.085	8.623
10	4.083	5.106	4.783	5.608	6.743	14.389
15	4.070	5.416	8.137	6.417	7.829	15.131
20	4.393	5.815	8.892	7.334	8.371	17.377
25	4.947	6.360	10.234	7.639	8.518	18.399
30	5.085	6.476	10.191	7.675	8.548	18.919
35	5.303	6.654	10.425	7.767	8.560	20.001

Figure 4: Impact of a Shock to Biomass Consumption on Disaggregate Food Prices

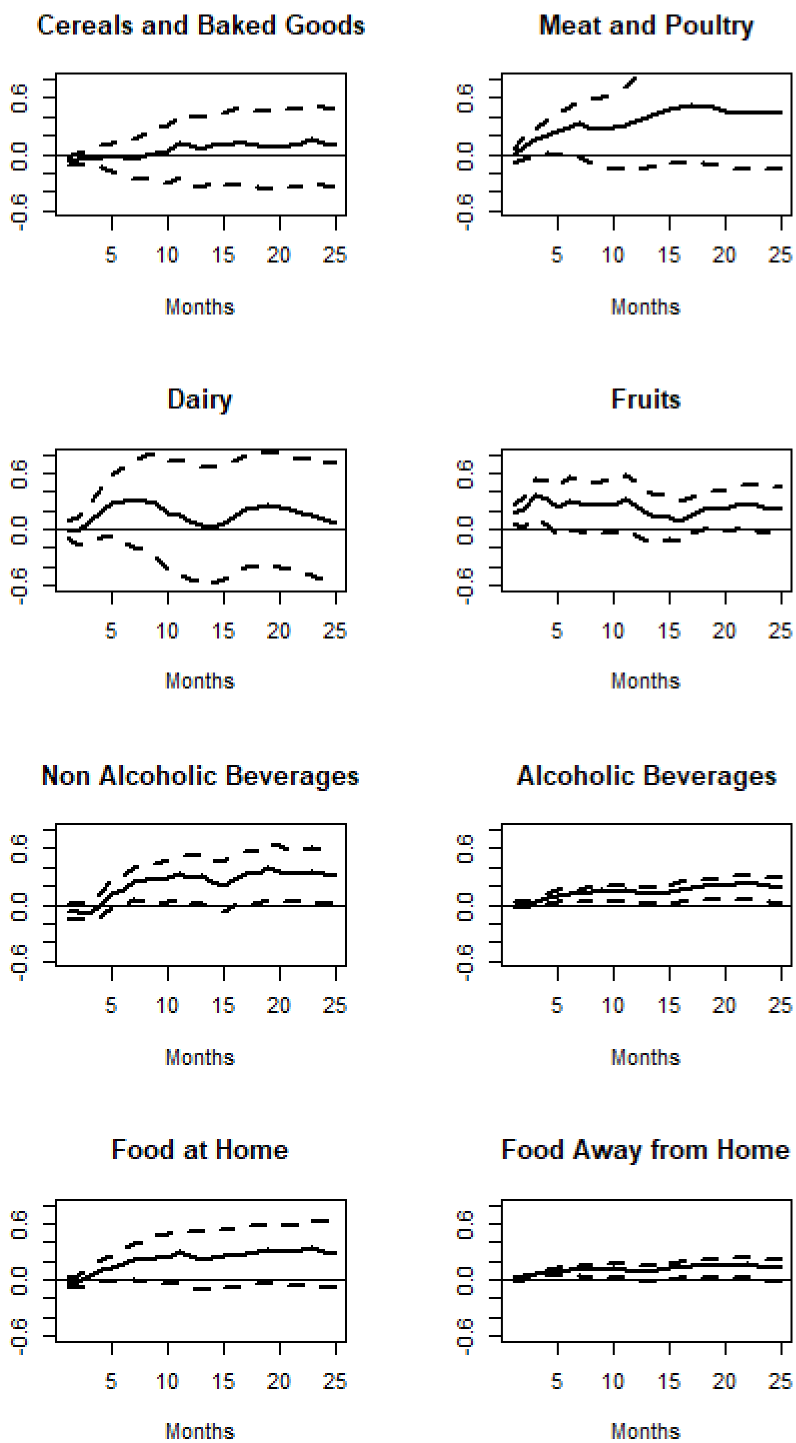


Figure 5: Impact of a Shock to Wind Energy Consumption on Disaggregated Food Prices

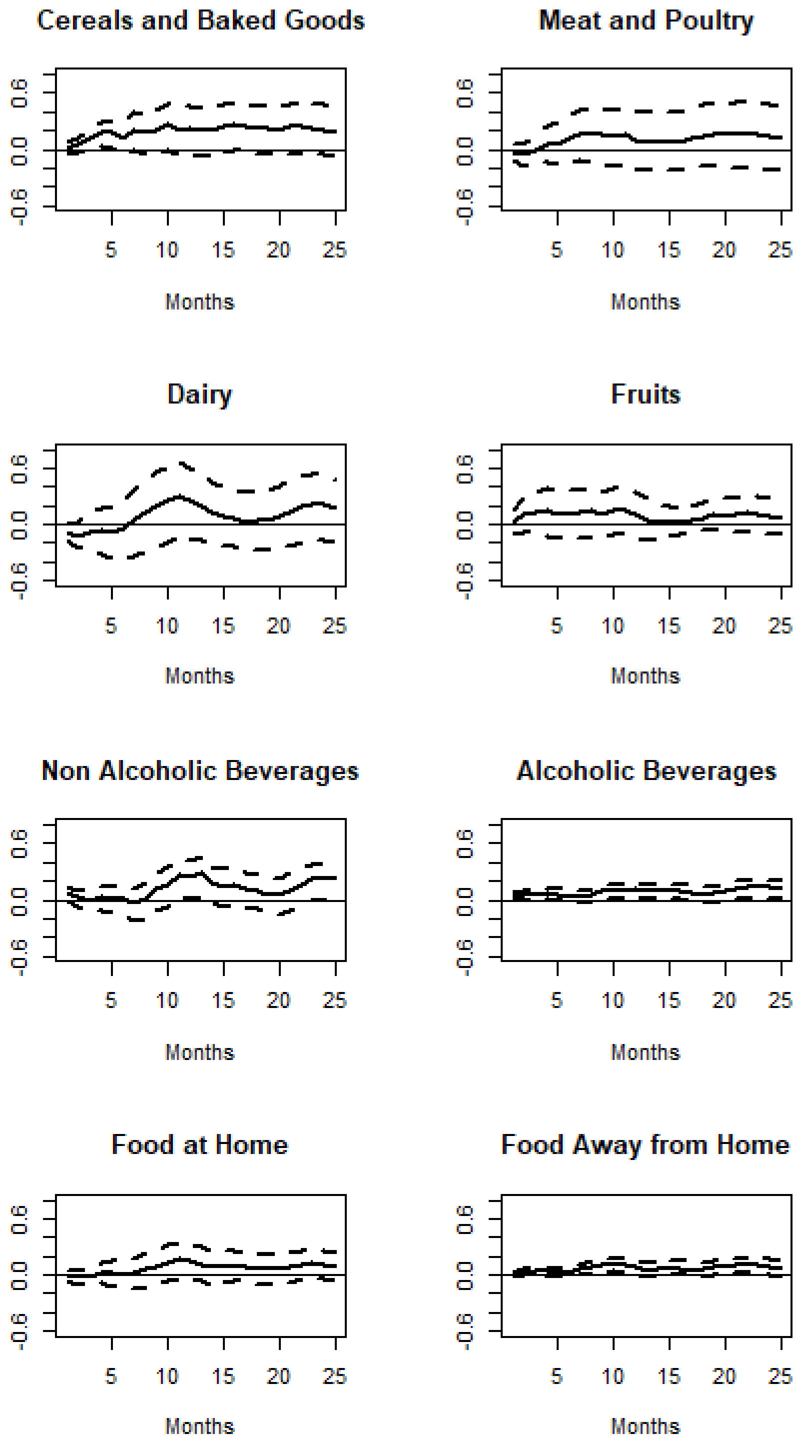


Table 11: Contribution of Biomass and Wind to Variability of Meat and Poultry Prices

	Biomass			Wind		
Horizon(Months)	1974-2020	1974-2006	2006-2020	1974-2020	1974-2006	2006-2020
1	0.000	0.000	0.000	0.000	0.000	0.000
5	0.467	1.093	1.031	0.535	1.218	2.583
10	1.169	1.949	6.618	0.543	1.259	3.571
15	1.207	2.069	5.733	0.543	1.259	3.438
20	1.347	2.240	6.805	0.543	1.259	3.419
25	1.551	2.509	6.336	0.543	1.259	3.393
30	1.612	2.582	6.734	0.543	1.259	3.289
35	1.731	2.698	7.024	0.543	1.259	3.329

Table 12: Contribution of Biomass and Wind to Variability of Fruits Prices

	Biomass			Wind		
Horizon(Months)	1974-2020	1974-2006	2006-2020	1974-2020	1974-2006	2006-2020
1	0.000	0.000	0.000	0.000	0.000	0.000
5	1.022	1.484	1.554	0.509	0.594	1.997
10	2.224	2.907	3.094	0.942	0.654	5.823
15	3.352	4.461	2.977	0.977	0.661	6.799
20	3.335	4.468	2.983	0.979	0.661	6.885
25	3.192	4.330	2.993	0.979	0.661	6.690
30	3.155	4.292	2.995	0.979	0.661	6.534
35	3.129	4.264	3.205	0.979	0.661	6.570

Table 13: Contribution of Biomass and Wind to Variability of Prices

	Biomass			Wind		
Horizon(Months)	1974-2020	1974-2006	2006-2020	1974-2020	1974-2006	2006-2020
1	0.000	0.000	0.000	0.000	0.000	0.000
5	2.696	4.089	2.019	0.223	0.317	4.165
10	3.821	5.752	3.657	1.115	1.279	6.184
15	3.823	5.680	4.885	1.452	1.599	6.229
20	4.733	6.668	6.282	1.649	1.892	6.492
25	4.870	6.799	6.453	1.937	2.104	6.346
30	5.237	7.121	6.985	2.023	2.213	6.177
35	5.275	7.155	7.381	2.108	2.263	6.318

Table 14: Contribution of Biomass and Wind to Variability of Prices

	Biomass			Wind		
Horizon(Months)	1974-2020	1974-2006	2006-2020	1974-2020	1974-2006	2006-2020
1	0.000	0.000	0.000	0.000	0.000	0.000
5	0.538	0.968	3.285	1.796	2.138	5.418
10	1.085	1.503	6.177	2.068	2.702	8.617
15	1.223	1.709	8.488	3.282	4.190	10.601
20	2.072	2.780	8.397	3.468	4.483	11.742
25	2.213	2.922	9.191	4.230	5.319	12.694
30	2.633	3.402	9.640	4.391	5.504	13.543
35	2.857	3.541	10.251	4.724	5.840	14.019

Figure 6: Impact of Renewable Energy Consumption of Food Prices 1974 to 2006

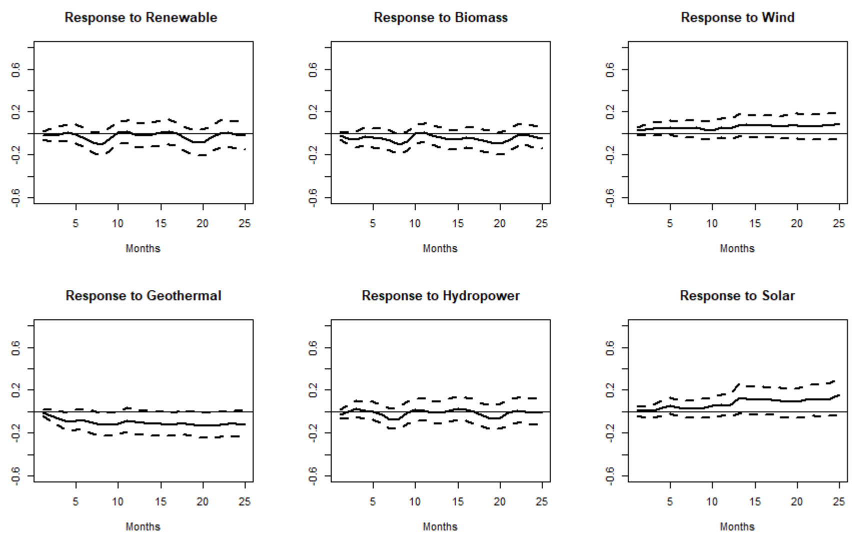


Figure 7: Impact of Renewable Energy Consumption of Food Prices 1974 to 2020

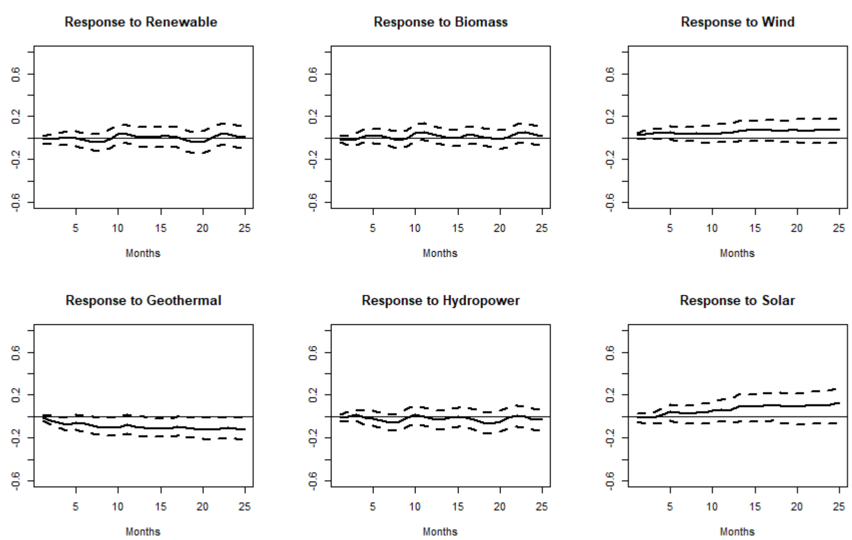


Figure 8: Impact of Biomass Consumption on Disaggregated Food Prices 1974 to 2006

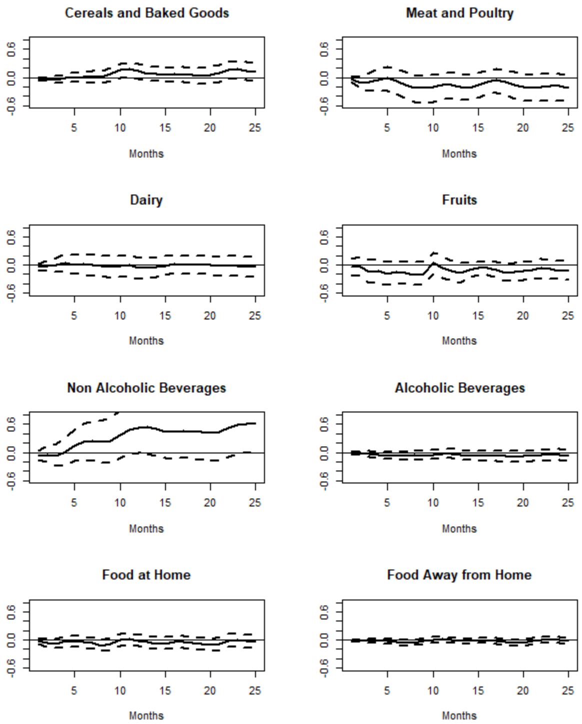


Figure 9: Impact of Biomass Consumption on Disaggregated Food Prices 1974 to 2020

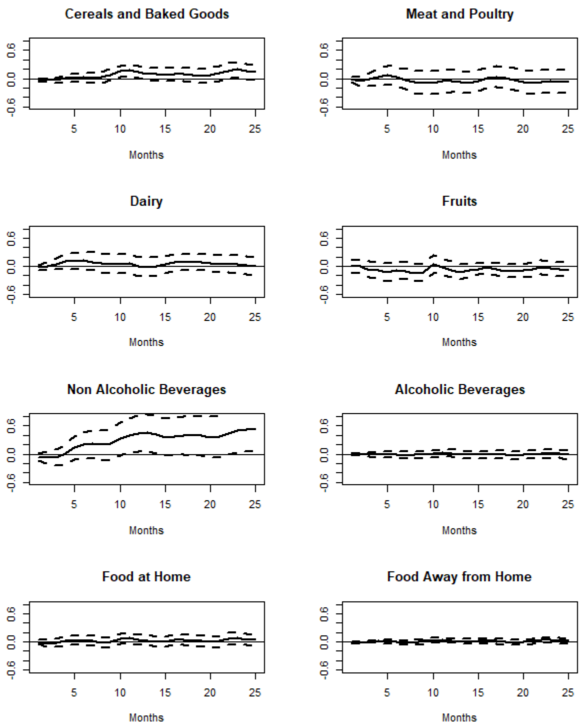


Figure 10: Impact of Wind Energy Consumption on Disaggregated Food Prices 1974 to 2005

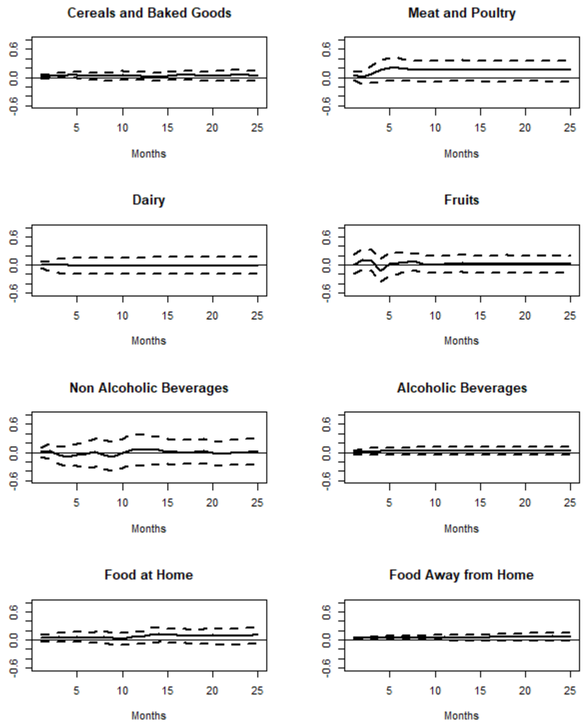


Figure 11: Impact of Wind Energy Consumption on Disaggregated Food Prices 1974 to 2020

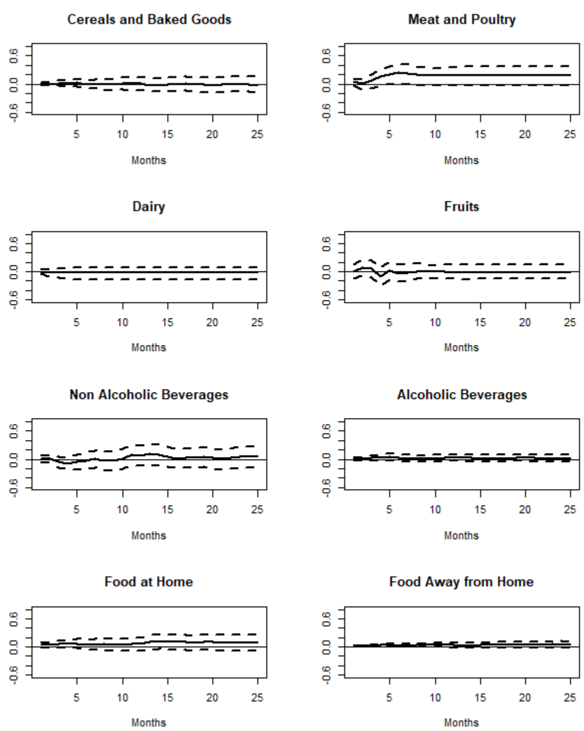


Figure 12: Impact of Geothermal Energy Consumption on Disaggregated Food Prices 2006 to 2020

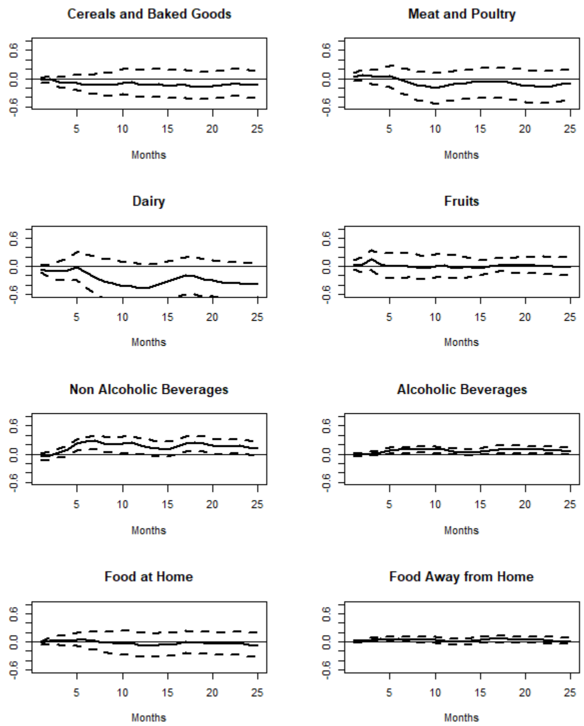


Figure 13: Impact of Hydropower Consumption on Disaggregated Food Prices 2006 to 2020

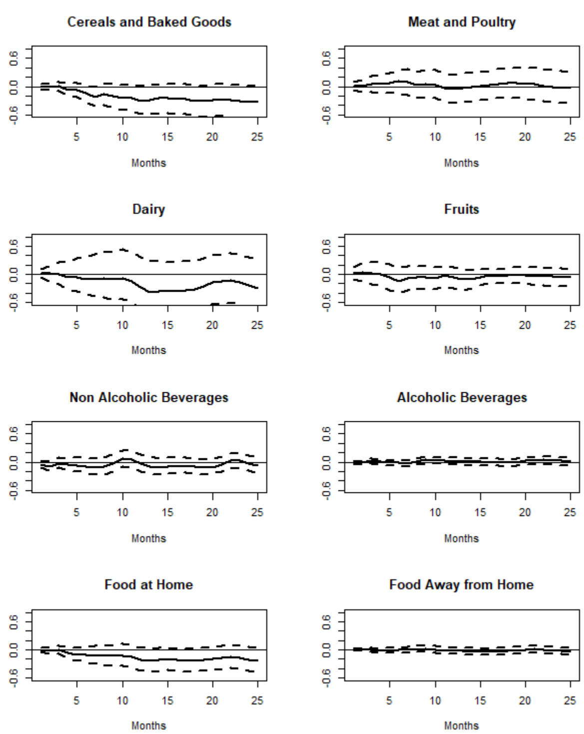


Figure 14: Impact of Solar Power Consumption on Disaggregated Food Prices 2006 to 2020