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IES Working Paper 30/2023

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Bibliographic information:
Janda K., Sila J., Zilberman D. (2023): " Fueling Financial Stability: The Financial Impact of U.S. Renewable Fuel Standard " IES Working Papers 30/2023. IES FSV. Charles University.

This paper can be downloaded at: http://ies.fsv.cuni.cz

Fueling Financial Stability: The Financial Impact of U.S. Renewable Fuel Standard

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September 2023

Abstract:
Oil price shocks, which materialize in petrol prices, put severe inflationary pressures on countries that rely largely on fossil fuels, causing financial instability. The Renewable Fuel Standard (RFS) program, implemented in the USA in 2005, sanctions blending corn-based ethanol with fuel and can offset oil price shocks. RFS is a technological innovation that protects against inflationary pressures while being ecologically beneficial. We examine how global oil price changes affect US petrol costs and the resulting savings for US families by assessing the program's effectiveness. Our findings show that blending ethanol into petrol serves as a buffer against global oil price shocks, delivering an average $0.185 per gallon savings from 2019 to 2022. This translates to $22.8 billion in annual savings for American consumers. As the global debate shifts towards sustainable energy and climate change mitigation, our findings highlight the practical benefits of diversifying energy sources, which promote both environmental sustainability and economic stability in the face of volatile commodity price shocks.

JEL: C22; E63; Q42; Q41;
Keywords: Financial stability, Commodities, Energy markets, Technological Innovation, Ethanol, U.S.A.

1. Introduction

Recent years witnessed high volatility in commodity prices, most notably electricity and oil prices have bounced off profoundly following the global economic crisis and recovery around the Covid pandemic. These price fluctuations of commodities influence financial stability through various channels, such as production inputs leading to inflationary pressures (Schwartz 1998, Kilian and Zhou 2023) or even directly the stability of banks (Batten 2018). For instance, Kinda et al. (2016) find that commodity price shocks increase the share of non-performing loans in periods of economic distress, thus impacting the banking sector, which is crucial for financial stability. Thus shocks to commodities prices are of great interest to regulators and policymakers.

This paper investigates how U.S. regulation in the domestic gasoline market contributes to lower prices and thus relieves inflationary pressure which would be otherwise causing financial instability[1](Boufateh and Saadaoui 2021). Our study considers the technological energy transition, emphasizing the role of renewable fuels' role in shaping crude oil and gasoline prices, especially ethanol blending. We show that diversifying energy sources can mitigate price volatility and reduce customers' prices at the pump. Since the gasoline demand is highly inelastic, price shocks from oil and gasoline prices propagate instantaneously into the economy. In 2005, U.S. policymakers introduced the Renewable Fuel Standard program (RFS) as a technological advancement, blending corn-based ethanol into gasoline. This initiative is not only a technological innovation but is also a strategy to mitigate price risks, thereby enhancing the financial system's stability. Our study assesses the program's efficacy by examining how global oil price fluctuations impact U.S. gasoline prices. Concurrently, we assess the savings this program brings to U.S. households which also contributes towards a higher level of financial stability.

The field of energy economics and finance has studied how shocks in commodity prices, such as energy or fossil fuels, affect the broader economy. This includes impact on the macroeconomy (Kinda et al. 2016), the stock market (Qin et al. 2020), inflation (Ding

[1] European Central Bank (2023) defines financial stability as "a condition in which the financial system – which comprises financial intermediaries, markets and market infrastructures – is capable of withstanding shocks and the unraveling of financial imbalances"

et al. 2023) and economic policy uncertainty (Coronado et al. 2018). Yet, there's a gap in research specifically addressing the direct effects of these price shocks on financial stability. Typically, studies in this domain explore how price changes correlate with key macroeconomic factors, some closely tied to financial stability. These factors include economic growth, stock market performance, sentiment indicators, exchange rates, and inflation. However, a recent trend in the literature also examines the implications of climate change and the transition to renewable energy on financial stability (Dafermos et al. 2018, Giuzio et al. 2019, Battiston et al. 2021, Zhang et al. 2022). Similarly, Shahbaz et al. (2019) suggest that commodity prices Granger-cause financial instability, although this relationship is time-varying and unstable in the short term.

Besides the link between shocks in commodity prices and consequences for financial stability, our investigation also relates to energy transition and climate change discussion as we analyze the impact of renewable fuels, more specifically ethanol, on these gasoline prices. We scrutinize a standard diversification argument that the diversification of sources in the supply chain decreases the impact of exogenous shocks.

We add to this discussion by modeling how U.S. market reacts to shocks in the global oil market represented by the West Texas Intermediate (WTI) oil and how the shocks propagate to U.S. gasoline prices. We estimate that blending of ethanol in U.S. gasoline cushions the shocks and we calculate statistically significant net benefits for the U.S. consumers. Our procedure estimates the discount per gallon to be, on average, \$0.185 between 2019 to 2022. Considering an average yearly U.S. consumption of 2,940,000 Mbbl of gasoline, or 123,480 million gallons of gasoline, this would add up to total savings of \$22.8 billion per year for U.S. consumers. Compared to the 2021 GDP of \$22,996 billion, the savings represent almost 0.1% of the U.S. nominal GDP. Our estimate is more conservative compared to other studies and used methodologies.

2. Literature review

Oil prices and, consequently, gasoline prices are important drivers of inflation in the U.S., particularly at the onset of oil price spikes (Kilian and Zhou 2022a). The theme of gasoline prices and household inflation expectations is rich in volume and remains an important topic in the contemporaneous literature (Coibion et al. 2020, Binder and Makridis 2022, Kilian and Zhou 2022b) and inflation links directly to financial stability (Bordo et al. 1998, Schwartz 1998, Bordo et al. 2002). More specifically, Kilian and Zhou (2022b) quantify that shocks to gasoline prices account for 42 % of the variation in households inflation expectations, taking a more conservative estimate to the one made by Coibion et al. (2020) who estimate 74 % correlation between the expectations and prices of oil. Kilian and Zhou (2022b) estimate that a 10% increase in the nominal gasoline prices increases the inflation expectation of the U.S. households by 0.3 percentage points, however, this effect diminishes over the period of 5 months. Kilian and Zhou (2022b) further show that although this effect is time-varying, the cumulative effect in inflation expectations was entirely caused by gasoline expectations from 2009 to early 2013, which falls within our dataset.

Schwartz (1998) then links the inflationary pressures with financial stability and works of Frankel (2014), Jacks and Stuermer (2015) and Shahbaz et al. (2019) link the commodities prices and financial stability through price volatility. More concretely, Shahbaz et al. (2019) investigated the relationship between commodity prices and financial instability in the U.S. Their research, spanning from January 1991 to September 2015, utilized monthly data from six commodity indices and US financial instability metrics. Initial results from the bootstrap full-sample Granger causality test indicated that commodity prices influenced financial instability. However, these short-term results were inconsistent. To address this and account for potential regime shifts, Shahbaz et al. (2019) employed a dynamic Granger causality method with bootstrap and rolling window techniques. This refined approach revealed fluctuating causal links between commodity prices and financial instability. Most notably, they found that rising commodity prices predominantly led to financial instability, with a pronounced effect during the 2007–2008 global financial crisis, where the global financial crisis reinforced commodity volatility, thus creating a feedback loop between commodities and financial instability.

Our paper is related to commodities and financial stability literature as well as the relatively new topic of biofuels, more concretely, their role as technological innovation in tackling climate change, which poses a new source of risk to the financial system (Batten et al. 2016) and as such is reviewed more comprehensively by Batten (2018). Dafermos et al. (2018) introduces climate change impacts in the context of financial stability. They find that climate change deteriorates firms' capital and liquidity, leading to higher default rates and, thus, the transmission of uncertainty to the financial system's stability.

One of the first biofuels studies by Hill et al. (2006) assesses energy costs of biodiesel and ethanol biofuels, respectively corn ethanol and soybean biodiesel. They find that no biofuel can replace oil without affecting food supplies and subsidies to make them profitable. Other avenues of research consider price effects across biofuels and food prices (Rajagopal et al. 2007, Mueller et al. 2011) or transmission mechanisms, particularly between corn, ethanol, gasoline, and oil prices (Serra et al. 2011). A comprehensive systematic review of the literature with an emphasis on ethanol blending and U.S. gasoline retail price was recently done by Janda et al. (2023).

Notably, the discussion over the benefits of ethanol changed during the food crisis in 2008 when it inclined more toward the negative sentiment. The affordability of food due to higher demand for corn has been discussed intensively in numerous articles during the food crises between 2008 and 2010 (Tokgoz et al. 2007, Abbott et al. 2008, Rosegrant 2008, Hochman and Zilberman 2018), or in a comprehensive review of the then available literature by Janda et al. (2012). Later, Hochman et al. (2014) show that for most crops, biofuels were not the most significant factor responsible for the price spike in food commodity prices. Hochman et al. (2014) note that price spikes can be mitigated by appropriate inventory-management policies or mechanisms that would allow poor countries to purchase food at predetermined prices.

Our approach not only estimates the protection of the U.S. gasoline market from global oil volatility, as a factor of protection of financial stability, due to the RFS program but also estimates the direct wealth effect for U.S. consumers, which constitutes another chanel through which the financial stability may be enhanced. Concerning ethanol savings price estimates in the literature, the meta-analysis of Hochman and Zilberman (2018) estimates an average of \$0.12 per gallon of fuel savings in 2005 U.S. dollars. However, the study finds large heterogeneity among the included studies. In a similar fashion to Hochman and Zilberman (2018), Khanna et al. (2021) compares the most recent results, but their study focuses on the effects of biofuels on food commodity prices, greenhouse gas emissions, and indirect land use change-related issues rather than the economic benefits of biofuels for transportation. Nevertheless, they conclude that the ecological effects of ethanol are smaller than generally believed. A recent study by Janda et al. (2023) offers a comprehensive review of ethanol's wealth effect on U.S. consumers.

Since our paper uses well-known methodological concepts of Ordinary Least Squares (OLS) linear regressions (Wooldridge 2015), we focus on exploring the economic underpinnings and model specification rather than on repeating of well-known OLS derivation. We explain in detail the crucial parts of the model along the way.

3. Results

We combine two intertwined linear models. First, we model the price dynamics of WTI crude oil prices[2], a benchmark for the U.S. crude, using data about OECD oil production and shocks to OECD inventories, which are prominent drivers of the price of crude (Ye et al. 2005, 2002) as well as biofuels (Hochman et al. 2011). Using the estimated parameters, we predict the future price of WTI crude from January 2019 to June 2022. Assuming that the RFS program finished in 2018, we can deduct the volume of blended ethanol and gauge the effects this would have had on the crude oil price. Thus, we create a counterfactual analysis in a similar manner as Kilian and Zhou (2022b). The price of crude oil strongly determines the retail gasoline prices across the U.S. This motivates the second model, which then describes the connection of the retail gasoline prices with WTI crude oil prices and calculates the scenario without ethanol blending.

3.0.1. Modeling WTI price To understand the relationship between ethanol blending and gasoline prices, we follow the methodology described in Verleger (2014, 2019). The idea of Verleger's approach is that biofuels remove a significant part of the demand for crude oil from the global market. Secondly, ethanol blending potentially provides a cushion that limits the adverse impact of global oil shocks, which translates to inflationary pressures and then into financial instability. We assume that the markets operate within a "tight supply" environment, while the demand for crude oil is highly inelastic and the

[2] We use Crude Oil West Texas Intermediate Spot price series downloaded from EIA Open data library, ticker "WTIPUUS"

impact of U.S. blending is significant on a global scale (Ye et al. 2005). In the first step, we specify a model for WTI crude oil prices, and we show that the WTI prices predominantly drive the retail gasoline prices. Then, we use the learned parameters to estimate the effect of reducing the crude oil supply by subtracting the volume of used ethanol and predicting the future monthly prices. We use and model the data from January 2009 to June 2022.

To accurately understand the dynamics of the WTI crude prices, we refer to a specification in Verleger (2019). The main idea behind the model follows the natural rate theory, where the level of OECD commercial inventories is decomposed into a normal level and short-term fluctuations, where the relative level of inventories (RLI), or rather a shock to inventories, is the difference between the real level and the normal level. Several other studies (Ye et al. 2002, 2003) document that relative inventory is a key determinant of short-term crude oil price fluctuations. On both the demand side as well as supply side, the respective price elasticities are rather small compared to inventory elasticity. On the demand side, people use fuels for transportation to drive to work or heat at home, regardless of price, just as it is difficult for refineries to adjust their production quickly. Hence, inventories also serve as the balancing mechanism between crude oil demand and supply (Ye et al. 2005).

For our purpose, similarly to Ye et al. (2005), we downloaded the data from the EIA website and define the RLI as

$$RLI_t = IN_t - IN_t^* \tag{1}$$

where IN_t is the actual OECD crude oil inventory level in a month t, and IN_t^* is the seasonal component. We construct a model explaining the ${IN_t}^*$ with a time trend and dummy variables for 11 months in a year to remove seasonality and time trend. The estimates of monthly OECD inventory levels across the full sample from January 2010 to June 2022 are available upon request. The model is well-specified and captures about 35% of the variation in inventories. Calculating the RLI from Equation 1 as the difference between the in-sample prediction and real values (the model's residuals, in fact), we also interpret RLI as shocks to inventories not explained by seasonal and trend components. We find a strong inverse relationship between RLI and the *WTI price*, which also reacts in real-time.

We aim to predict *WTI price* with the *RLI* variable. We also add three variables that substantially improve the original of Verleger (2019). We include monthly OECD oil production, VIX index and U.S. Consumer Price Index (CPI). The OECD production provides information about the supply side. The VIX index is a forward-looking "fear index" of the stock market. There is ample evidence of connectedness between oil and financial markets (Zhang 2017). Thus, incorporating a financial market-related variable is economically meaningful. Instead of deflating the WTI prices by the U.S. CPI, we find that the model has higher predictive power when using nominal prices and the CPI index separately, similarly to Bec and De Gaye (2016). We add the U.S. CPI in the form of first differences, thus, in fact, a month-on-month CPI. That way, the CPI variable is stationary, and the model avoids spurious correlation with the WTI price through time trend, which is a component of the CPI through high correlation with the gasoline price. We define the model explaining the *WTI prices* in month t in Equation 2.

$$WTI\ price_t = \beta_0 + \beta_1 RLI_t + \beta_2 OECD\ production_t + \beta_3 VIX_t + \beta_4 \Delta US\ CPI_t + \epsilon_t \tag{2}$$

Note that we directly model the nominal *WTI price* instead of the maybe more typical first differences in prices. Despite the unit root present in the *WTI price* series, modeling the price directly markedly improves the model's forecasting ability, which we introduce in the next part.

We estimate the model from Equation 2 in time period from January 2010 to December 2018 and predict the future monthly values from January 2019 to June 2022. Table 1 shows that the model considering *RLI*, *OECD production*, *VIX index* and *U.S. CPI* is economically meaningful and explains the WTI crude oil prices well. The goodness of fit measure R^2 of 88% is rather high and suggests that our model captures the variation in WTI prices very well. Table 1 reports full regression outputs.

The model suggests that a statistically significant negative relationship exists between the relative level of inventories, the *OECD production* and VIX financial fear index. The CPI change (*d_us_cpi*) variable is positive, as an increase of the general level of prices intuitively increases the price of crude oil. According to our expectation, the OLS estimates

Dep. Variable:	wti_price	**R-squared:**	0.887		
Model:	OLS	**Adj. R-squared:**	0.883		
Df Model:	4	**Log-Likelihood:**	-370.75		
No. Observations:	108	**AIC:**	751.5		
Df Residuals:	103	**BIC:**	764.9		
Prob (F-statistic):	0	**F-statistic:**	202.7		

	coef	**std err**	**t**	**P>|t|**	**[0.025**	**0.975]**
const	191.2034	9.446	20.243	0.000	172.470	209.937
rli	-0.1281	0.006	-20.702	0.000	-0.140	-0.116
oecd_production	-4.2996	0.310	-13.870	0.000	-4.914	-3.685
vix	-0.5119	0.149	-3.424	0.001	-0.808	-0.215
d_us_cpi	4.2969	1.671	2.572	0.012	0.984	7.610

Table 1 **Using the model from Equation 2, we estimate parameters on a sample from 2010 to 2018 and use those values to estimate the effect of the RFS policy on WTI prices from 2019 onwards.**

all coefficients with negative values except the U.S. CPI with a positive one. This suggests that a positive shock to inventories, higher production, and higher uncertainty in the financial markets drive the price of *WTI crude* down in the same period, while positive inflation shocks drive the price up.

While using the estimated parameters, we consecutively predict the monthly WTI prices with no error correction using only exogenous variables. The predicted prices correlate strongly with the realized WTI prices with a correlation coefficient of 90% and mean error of the WTI price of the forecast of $8.42 and a maximum error of $11.65. Figure 1 shows the out-of-sample performance of the model.

The results suggest that the model predicts the overall dynamics quite well. However, our model is slightly more conservative and starts underestimating the price after a few months. It also lags behind during the swift price recovery after the Covid shock in 2021 and also the Russian invasion of Ukraine in 2022. Nevertheless, the model performs quite well in the overall trends over 42 future months for a set of parameters estimated on data prior to 2018 and never re-estimated.

Since our model depends on inventories and other exogenous variables, it can be used to assess specific impacts in the significant variables, as per Verleger (2019). Hence, we deduct the blending volume of ethanol from the *RLI*, because if the RFS program terminated at

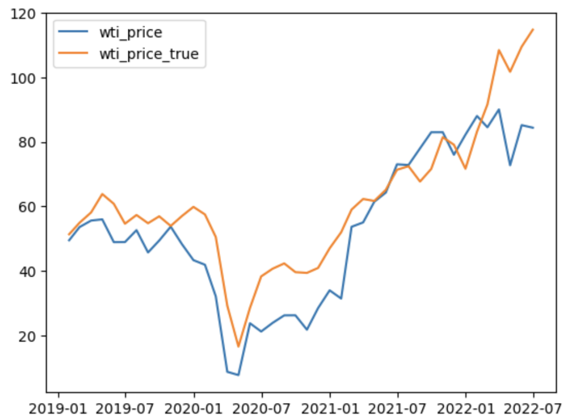

Figure 1 Out of sample forecast of the WTI prices. The blue series wti_price is our prediction, while the orange line wti_price_true is the actual WTI price.

the end of 2018, it is the volume of fuel that would have been missing in the reservoirs driving the price up. We estimate that the effect of U.S. ethanol blending on global *WTI price* is roughly \$3.45 per barrel over the years 2019 to June 2022. Reducing the volume of biofuels would have had a significant impact since global oil production was operating with no output constraints as per Verleger (2019).

3.0.2. Impact of RFS on gasoline prices The crude oil price model can be directly applied to create a model for retail gasoline prices, as crude oil is a key factor in determining gasoline costs. We use a straightforward approach to model changes in gasoline prices with changes in WTI crude oil prices, to which we add seasonal variables. The seasonal dummies significantly improve the model's explanatory power. The gasoline price is the U.S.-wide average taken from the EIA website. We denote this as Equation 3 written as follows:

$$\Delta gas_t = \beta_0 + \beta_1 \Delta P_t + \beta_2 \Delta P_{t-1} + \sum_{k=2}^{12} \beta_{k+1} D_k + \epsilon_t \tag{3}$$

The OLS estimation method yields estimates of the parameter values shown in Table 2. Some of the month dummies are again not significant, but we decide to keep them in order to be consistent with the RLI model. Nevertheless, the WTI price variables are highly statistically significant and have expected positive coefficients. Apart from that, the

Dep. Variable:	d_gasoline	**R-squared:**	0.689
Model:	OLS	**Adj. R-squared:**	0.646
Df Model:	13.	**Log-Likelihood:**	-379.40
Prob (F-statistic):	0	**F-statistic:**	16.04
No. Observations:	108	**AIC:**	786.8
Df Residuals:	94	**BIC:**	824.4

	coef	**std err**	**t**	**P>|t|**	**[0.025**	**0.975]**
const	1.2695	2.903	0.437	0.663	-4.494	7.033
d_wti_price	1.2065	0.171	7.048	0.000	0.867	1.546
d_wti_price_1	1.0799	0.172	6.268	0.000	0.738	1.422
m_2	3.9474	4.106	0.961	0.339	-4.204	12.099
m_3	10.9997	4.127	2.666	0.009	2.806	19.193
m_4	1.5693	4.146	0.379	0.706	-6.662	9.801
m_5	3.4523	4.152	0.831	0.408	-4.792	11.697
m_6	-1.9781	4.108	-0.482	0.631	-10.135	6.178
m_7	-5.6862	4.108	-1.384	0.170	-13.842	2.470
m_8	0.3590	4.127	0.087	0.931	-7.835	8.553
m_9	0.6586	4.111	0.160	0.873	-7.503	8.820
m_10	-9.2494	4.105	-2.253	0.027	-17.401	-1.098
m_11	-9.0786	4.120	-2.203	0.030	-17.259	-0.898
m_12	-7.0455	4.112	-1.713	0.090	-15.211	1.120

Table 2 Model explaining the difference in the gasoline price with the change in WTI price and its one-period lagged values. The m_x variables are calendar month dummy variables.

contemporaneous change in crude price has larger coefficients and thus is more influential for the gasoline dynamic. This model explains 69% of the variance of changes in retail gasoline prices.

Having a model for historical gasoline prices, we use it in the same way as the WTI crude price model to forecast future changes in gasoline prices and reconstruct them by summing from the latest observed value (December 2018). Figure 2 then shows how well the model uses our predicted WTI prices and subsequently fits the realized gasoline prices. Again, we observe shortcomings of the prediction at the beginning of the predicted period and during the Covid crisis and recovery in 2020.

Finally, we use the predicted series for *WTI price* and WTI price with the RFS mandate terminated in December 2018 and we let the model forecast the U.S. retail gasoline prices. Figure 3 then shows the difference between the gasoline prices based on model-predicted WTI prices with and without the ethanol policy in place. The no-ethanol scenario is almost

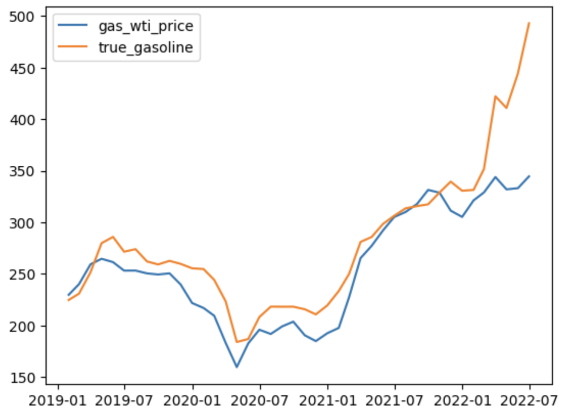

Figure 2 Performance of the model forecasting the gasoline prices compared to realized values. The series gas_wti_price is the gasoline price predicted with our forecast of the WTI prices using the model from Equation 3 and the orange series true_gasoline is the actual value recorded.

always markedly higher across the predicted sample. This suggests that RFS cushions the impact of shocks from the oil market on the gasoline prices, thus alleviating inflationary pressures which could translate into financial instability.

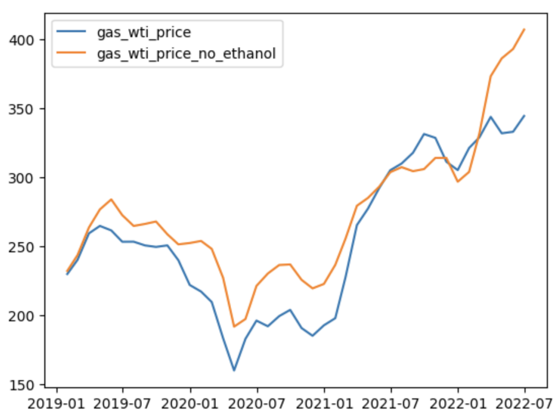

Figure 3 Out of sample forecasts of the gasoline prices with ethanol deducted from the supply

From this, we can also directly calculate the wealth effect for U.S. consumers. The mean of the ethanol discount is \$0.185/gallon and the monthly median is \$0.170/gallon.

The ethanol discount is statistically significant, with a t-test value of the sample mean differences being zero of -1.712. More detailed yearly estimates are in Table 3.

year	2019	2020	2021	2022
discount	13.3	33.2	2.2	32.0

Table 3 This table summarizes the average monthly discount over calendar year of retail gasoline prices in USD cents due to ethanol blending.

We estimate consistent ethanol discounts for the years 2020 and 2022, while the model predicts almost no effect in 2021. The model is rather straightforward, and the Covid shock and subsequent recovery was a so-called black-swan event, where the linear specification has naturally limited options to account for it. We assume a constant effect of WTI prices and monthly seasonal components based on the realization of the prices before 2019. We hypothesize that they would be markedly different should we include this period in the estimation period, yet it would limit our forecast period.

4. Conclusion

The intricate link between commodity price shocks and financial stability remains an unexplored area of research in the context of technological change represented by biofuels. Our study evaluates the role of U.S. regulations in the domestic gasoline market, particularly the Renewable Fuel Standard program (RFS), in mitigating the adverse effects of global oil price fluctuations. In this way the expansion of renewable fuels constributes to the increase of U.S. and global financial stability. By integrating corn-based ethanol into gasoline, this initiative showcases technological innovation and serves as a strategic buffer against price volatilities, fortifying the financial system's resilience against inflationary pressures.

We find that ethanol blending driven by the Renewable Fuel Standard (RFS) program has a direct and statistically significant negative (i.e., lowering) effect on gasoline prices at the pump, generally a source of increased inflationary expectations of U.S. households. We estimate the savings between 2019 and 2022 to be monthly on average $0.185 per gallon of gasoline. Although we do not directly quantify the "protection" effect on financial stability, we see that the total savings in the U.S. economy amount to roughly $22.8

billion, representing about 0.1% of the U.S. nominal GDP. If we consider that those savings can be reinvested in the economy with a multiplier effect, the net benefit to the U.S. consumer and to the financial stabilization of U.S. economy is, in fact, even higher. Those results are consistent with the findings in the reported literature, which report a wide impact of ethanol on gasoline prices in the U.S. We also present a general approach to estimating retail price impacts of public policies through interaction with global markets using parsimonious linear models.

Acknowledgments

This paper is part of a project GEOCEP that has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 870245. The research leading to these results was financially supported by the Czech Science Foundation (grant number 19-26812X). The authors are grateful for the research assistance to Vendula Letovska and to David Prochazka for feedback at the 2023 ACFA conference. Karel Janda and Jan Sila acknowledge the research support provided during their long-term visits to the Department of Agricultural and Resource Economics, University of California, Berkeley. Jan Sila is also grateful to the University of Auckland, New Zealand, for the research support during his visit. The views expressed here are those of the authors and not necessarily those of our institutions. All remaining errors are solely our responsibility.

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