“Analyzing the Downstream Impacts of U.S. Biofuel Policies”

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June 16, 2021

Abstract

Researchers have shown that U.S. biofuel policies raise grain prices, improving the welfare of grain producers. But, the downstream implications of those policies haven't received much attention. Indeed, by creating new demand-side competitors for feed inputs these policies also risk destructive effects on cattle producers in particular, who use corn as a major input component. We investigate the effects of biofuel policies on cattle markets along several dimensions, focusing on price dynamics and herd size. We find that, following adoption of the Renewable Fuel Standard (RFS) in the United States, (1) a one standard deviation increase in the crude oil price leads to a several hundred thousand head reduction in the U.S. Beef herd, and (2) steer production profitability exhibits both statistically and economically significant declines.

Keywords: Price Analysis, Biofuel Policy, Cattle, Futures Markets, Government Policy

Econ Lit Codes: Q14, Q18, Q48

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1 Introduction

Biofuel policy in the United States began with the Energy Tax Act of 1978, which provided a tax exemption for ethanol fuel blends at 100% of the gasoline tax (Kesan et al. 2012). During the 1990s, Congress expanded that support, first with the passage of the Clean Air Act (CAA) of 1990, followed by the Energy Policy Act of 1992, directing appropriations toward research into the production and commercialization of alternative fuels. Congress continued this support with a series of reforms in the later part of the decade (FAO 2008). These reform address commercial fuel blending, particularly with regard to Methyl-tert-butyl ether (MTBE). MTBE raises octane levels in gasoline and reduces fuel emissions. In response, in 2001, California announced a ban on MTBE. As a result, in 2003, California, the nation's largest commercial vehicle market phased out MTBE in favor of ethanol (McCarthy and Tiemann, 2006). Soon other states placed restrictions on the use of MTBE, resulting in a significant decline in the demand for MTBE as a fuel oxygenate and a significant increase in the demand for ethanol (Duffield et al., 2015). Following these environmental mandates, Congress directly intervened in the renewable energy market to promote biofuel production and adoption.

The American Jobs Act of 2004 introduced the Volumetric Ethanol Excise Tax Credit (VEETC), a tax credit of 51 cents per gallon of ethanol for commercial sellers. In 2005, Congress enacted the Renewable Fuel Standard (RFS-1). RFS-1 required 4 billion gallons of renewable fuel by 2006. In 2007, Congress expanded the mandate of the RFS-1 with the passage of the Energy Independence and Security Act of 2007, which stated that by 2009 domestic refiners must blend the fuel that Americans consume with 9 billion gallons of ethanol, with scheduled yearly increases to a 36 billion-gallon target by 2022 (Brown and Brown, 2012). This expansion is known as the RFS-2 (Yacobucci, 2012). Various observers rationalize government-imposed RFS mandates as pursuing a variety of objectives, including reduction of GHG emission and reduction of the US dependence on foreign energy sources (Moschini, Cui and Lapan, 2012).

The most obvious effect of U.S. Renewable Energy Policy is that Americans now pour about thirty-six percent of the U.S. corn crop into their gasoline tanks (USDA, 2021). This new source of demand raises grain prices (see, e.g., Wright, 2014 & de Gorter et al., 2015) and more closely links them to energy markets. Carter et al., (2017) estimate that RFS policy increased the price of corn by 31% through 2019; Smith, (2019) extends the analysis of Carter et al., (2017) by including data from the 2016-2017 crop year as well as incorporating wheat and soybeans. He estimates the cumulative increase to the corn price over the life of the RFS-2 at approximately 30%.

However, the downstream impacts of biofuel policy on other agricultural markets remains effectively unexplored in the literature, even though feed (primarily corn) makes up approximately 60% of cattle production costs (Lawrence et al., 2008; Holgrem and Feuz, 2015). Industry advocacy groups routinely express concerns about the additional costs imposed by U.S. biofuel policies. The National Cattlemen Beef Association (NCBA), has filed three notable RFS volume waiver petitions to request suspension of annual biofuel mandates, on the basis of economic hardship (NCBA, 2012; Feinman, 2013). The petitions sought to exempt refiners from blend requirements, especially during natural disasters such as the 2012 drought, since blending commercial fuels results in higher feed costs for cattle producers during such periods. In 2008, Former Texas Governor Rick Perry pursued a volume waiver, requesting a 50% reduction in mandated biofuel volumes. He argued that the program's unintended consequences will lead to real economic damage to livestock producers and higher food prices (Schor, 2008). In 2012, a coalition of livestock farmers petitioned the EPA to reduce mandated biofuel volumes stating that, along with extreme weather conditions, the RFS will lead to significant herd liquidation (O'Malley and Searle, 2021). In addition, ten U.S. states submitted RFS waivers stating that the program could lead to higher food costs and grain supply depletion. In each instance, EPA did not grant a waiver, concluding that the impacts of the program on livestock farmers did not meet their definition of severe economic harm (NLR, 2012).

In this article, we estimate the economic harm RFS-1 & RFS-2 causes domestic cattle producers along several dimensions. Specifically, we study how biofuel policies more closely link energy prices and U.S. cattle herd size, and how real returns fell permanently following RFS-1 implementation. In the next section, we provide an overview of the existing literature on the relationship between biofuel policy and food commodities. In section 3, we offer background information on the cattle industry. Sections 4 and 5 detail our data and analytical methods and results. Section 6 concludes.

2 Relevant Literature

Carter et al., (2011) and de Gorter et al., (2015) attribute the doubling of food commodity prices between 2008-2012 to the systemic change in U.S. biofuel policies–in particular, the introduction of the RFS-1, RFS-2, and MTBE ban. However, it is important to note that there is some contention surrounding the impact of biofuels on food commodity prices[1]. Nevertheless, several studies in the literature identify biofuel policy as an important contributing factor among many to the price boom of the late 2000s.

Studies examining the relationship between food prices and the demand for biofuels traditionally follow a time series or general equilibrium approach, but in general results are consistent across methods. We focus on the time series approach employed by Carter et al., (2017) and Smith, (2019) to analyze the impact on livestock markets. However, we briefly

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[1] For example, others attributed the price boom to, e.g., increased demand for more resource-intensive foods in rapidly-developing nations (von Braun, 2007), financial speculation (see, e.g., Reguly, 2008)—even though the evidence supporting that view is–at best– mixed, and a combination of factors, including weather-related production shortfalls (Condon et al. 2015), U.S. monetary policy, and a leveling-out of crude oil production (Trostle, 2008).

discuss both methods here.

The first method relies on computable general equlibrium models to demonstrate the impacts of biofuel policies across the economy. For example, Chen and Khanna, (2013) use the BEPAM[2] to analyze the contribution of the RFS and other complementary policies (the VEETC and import tariffs) to corn and soybean prices along with sugarcane imports in the US in 2022 relative to a counterfactual scenario with no government intervention in the biofuel sector. They estimate a 4.7% increase in the corn price per billion gallon increase in ethanol production. In addition, they find in the absence of sugarcane tariffs, which were implemented to suppress competition with Brazilian sugarcane ethanol manufacturers, that 3.3 billion liters of ethanol would have been imported. (Hertel et al., 2010) use a different computable general equilibrium model built upon the standard Global Trade Analysis Project (GTAP) framework. They estimate a smaller effect of U.S. biofuel policies on the price of corn: approximately 1.3% per billion gallons of ethanol produced. However, they also find that acreage planted to coarse grains in the United States would rise by 10% as a result of biofuel policy mandates, while forest and pastureland areas of the United States would decrease by 3.1%. Therefore, even with potentially smaller price changes for corn consumers, ethanol expansion under RFS-2 has significant effects on the landscape of agricultural production in the United States. (Lapan and Moschini, 2009) build a simplified two-country general equilibrium model, where the energy and food sectors are linked. This competitive model assumes an upward sloping supply of corn with multiple uses: feed, energy, food, and export. They show that the ethanol mandate policy approach yields higher welfare than the ethanol subsidy. (Cui et al., 2011) adapt and extend Lapan and Moschini's model to make it more suitable for simulating the consequences of alternative policies. The extension recognizes that firms produce other products when they refine oil, in addition to gasoline (distillate fuel oil,jet fuel, etc.). The authors aggregate all non-gasoline output into

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[2] Biofuel and Environmental Policy Analysis Model

a single good called petroleum by-products. Consistent with Chen and Khanna, (2013), Cui et al., (2011) estimate that corn prices should rise by 3.75% per billion gallons of ethanol produced. (Moschini et al., 2017) build a multi-market model of the U.S. supply of corn, soybeans, oil, along with the domestic and rest-of-world demand for food products and transportation fuels. They simulate their model under a no-RFS scenario, 2022 RFS-2 scenario, and optimal (second-best) mandates scenario. Compared to the no-RFS scenario, they find that current 2022 RFS-2 mandates increase corn prices by 3.6% per billion gallon of ethanol produced. At the low end, Gehlhar et al., (2010) found in a general equilibrium analysis that for every billion gallons of ethanol produced the price of corn will rise by 0.4–0.7%. In fact, their report suggests that the ethanol policy mandates and tax credit subsidies of the VEETC and RFS would result in greater household welfare by as much as $ 28 billion in increased consumption. However, this report is focused on consumer welfare impacts as they claim that the RFS-2 would impact food prices considerably less than it would impact farm commodity prices in the long term (i.e. by mandate objectives of 2022).

The second method we address relies on the time series approach developed by (Carter et al., 2017). They adopt a partially identified structural vector autoregression model to estimate the effect of the RFS on corn prices. (Smith, 2019) updates their model for corn with data through the 2016-17 crop year, and also applies the model to soybeans and wheat. Their models rest on the fact the RFS is a persistent rather than a transitory shock to agricultural markets. This distinction is important because persistent shocks have longer-lasting price effects than transitory shocks, and are signified by a structural break. Markets for storable commodities can respond to a transitory shock, such as poor weather conditions, by drawing down inventories, mitigating its effects. In contrast, inventories cannot insulate market participants from a persistent shock. (Carter et al., 2017) decompose the shock to crop inventories and spot prices owing to the increase in the demand for corn and soybeans by including impulse response functions for corn and soy futures prices and inventories. Their results show that inventory demand shocks increase the futures prices. Their findings for the impact of U.S. ethanol policies aligns with the general equilibrium analysis results: they estimate that every billion gallons of ethanol produced raises the price of corn by 5.6% (95% CI– 0.009, 0.17). To account for the short-term and long-term response to shocks, Carter et al., (2017) include in their model the convenience yield, allowing them and Smith, (2019) to isolate RFS' persistent impact on agricultural commodities.

3 Cattle Market Background

To facilitate our discussion, we provide an overview of the modern beef industry, and offer important definitions as well as a timeline of production. We begin by defining the production inputs, and describe the production function for cattle producers. We then then describe input costs, focusing on feed, and the typical feed input mix of producers. We conclude with an overview of the beef supply chain. Finally, for context, we conclude this section with a brief summary of the beef cattle supply chain as well as general trends in cattle markets over the last few decades.

The cattle production function is made up of equipment and infrastructure, weather conditions, feed, supplemental nutrients, and veterinary resources. Equipment and infrastructure includes, for example, fencing, corrals for cattle handling and machines for forage production, and transporting cattle to market. Weather conditions affect cattle performance, e.g., extreme heat reduces an animal's ability to gain weight and leads to heat stress. Veterinary services ensure herd health and reproduction. And successful production of beef cattle necessitates good quality feed. In fact, feed is the principle component of all models of the production function for cattle (Heady et al., 1963; Lalman et al., 1993; Van Amburgh et al., 2008; Holgrem and Feuz, 2015). Specific feed rations depend the type of operation and the time of the year. For example, in the winter producers might opt for a low-energy ration composed of primarily fibrous hay supplemented with more high-energy silage[3] and essential minerals (e.g. calcium, phosphorus, and potassium). On the other hand, in the spring and summer producers may adopt a more high-energy diet composed of feed grain to promote efficient weight gain in the herd. In terms of total digestible nutrients[4] (TDN), up to 70% of such a feed mix would come from feed grains (Lalman et. al., 1993; NRC, 2000) like corn, sorghum, barley, and oats. In the United States, corn is far and away the primary choice, accounting for more than 95% of total feed grain production and use (USDA, 2020). Byproducts of ethanol production (i.e. distillers grain) can be substituted for feed grain, and are primarily used in the Midwest and Great Plains[5]

As a result, feed represents the primary cost for a beef producer, accounting for 60% of the cost of production (Lawrence et al., 2008; Holgrem and Feuz, 2015). And since corn is the primary feed grain, its price changes play a dominant role in the cost of beef production. In fact, (Tonsor and Mollohan, 2017) show that the corn price is inversely related to cattle margins: as the price of corn increases, returns to cattle producers decrease. Therefore, the cattle market is highly susceptible to corn price volatility. Figure 1 shows the price of corn from 1983-2021. The period of corn price doubling is clearly visible, and while it does stabilize around 400¢/bushel toward the end of the 2010s, in nominal terms it remains well above prices observed during the 1980s and 1990s. Compounding this feed input cost rise is the significant increase in the cost of crude oil over the past 40 years. Figure 1 also shows the West Texas Intermediate (WTI) futures price over the same time frame. For the first half of the period, oil prices were relatively stable below $50 dollars a barrel. However, beginning in the early 2000s, they spiked and have remained elevated compared to their historical level. This translates into a higher cost of transportation for beef producers, packers, and

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[3] "Silage" refers to grasses grown for forage and harvested at a relatively high moisture level; the most common types of silage include alfalfa and corn in the United States.

[4] "Digestible nutrients" is the proportion of feed that an animal can metabolize into their system

[5] Cottonseed, a byproduct of the ginning process for cotton, can also serve as a feed grain substitute (perhaps in times of high grain prices) since it is an adequate source of protein.

distributors. The long beef cattle production cycle (relative to annual crops, for example) increases the role of uncertainty with respect to investment,[6] and when coupled with higher feed and transportation costs places pressure on the domestic herd size. The second panel of Figure 1 shows that, since the late 1970s, the U.S. beef herd size fell from approximately 39 million head to 60-year low in 2014 of just over 29 million head. The industry attributes this steady decline to a variety of factors including drought years, market uncertainty, and packing capacity (Northen Ag. Network, 2020), with the high cost of feed as perhaps the main cause for cow herd shrinkage.

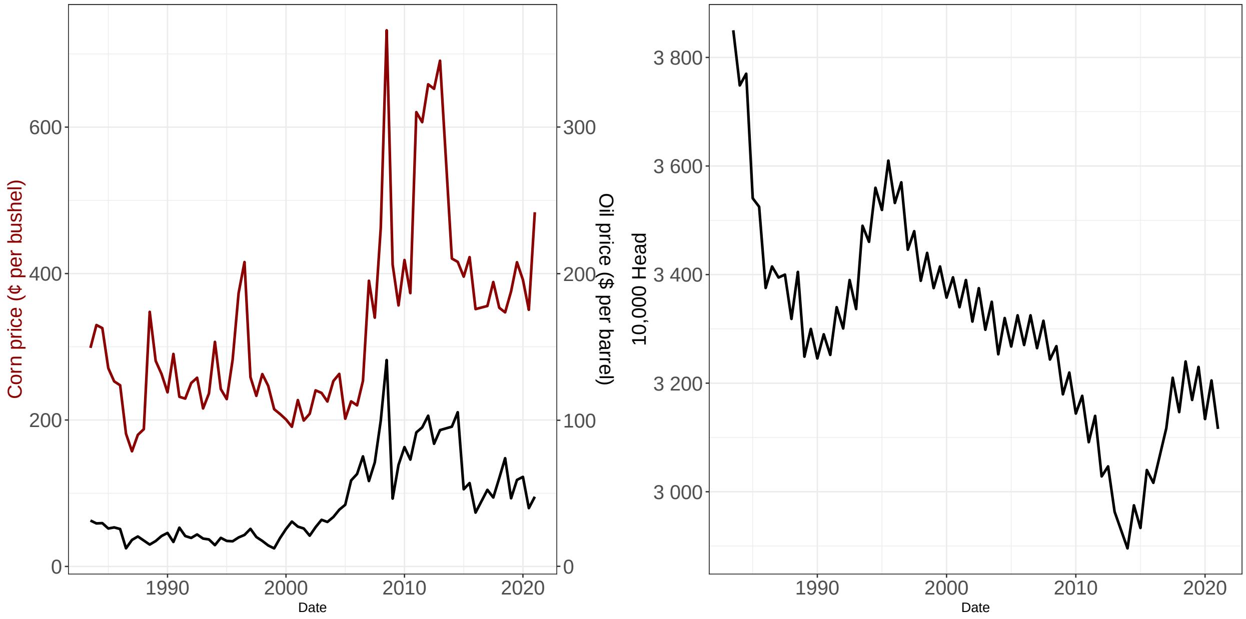

Figure 1: Beef Herd Size, Corn, and Crude Oil Prices 1983 - 2021
Source: USDA 2021 & Focus on Feedlots Newsletter, KSU 2020

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[6] The natural cattle cycle, a process in which the size of the national cattle herd—including all cattle and calves—increases and decreases over time. This typically lasts between 8 to 12 years, with the last full cycle beginning in 2004. The herd size grew slightly over the next three years before increasing feed and energy prices led the herd size contracting sharply to a record low in 2014 (USDA 2021).

One sign of the disparate impacts of biofuels policy on up- and downstream agricultural producers is the difference in land price paths, which capitalize the value of production according to economic theory (Doye and Brorsen, 2011). Figure 2 shows that while cropland values nearly doubled in real terms sine the late-1990's, pastureland values have increased by a much smaller factor–just a few hundred dollars per acre. U.S. Government support for agriculture, codified every five years in the Farm Bill, provides crop producers with significant support through subsidized crop and revenue insurance programs, but little in the way of support for livestock producers. For example, the 2018 Farm Bill allocates almost \$70 billion to crop insurance and commodity risk protection programs (CRS, 2019). Livestock producers do not receive the same level of support under the legislation. Even ad hoc programs, like direct assistance to producers to remunerate them for trade war damages is targeted to the producers of crops (Adjemian et al., 2019), not livestock.

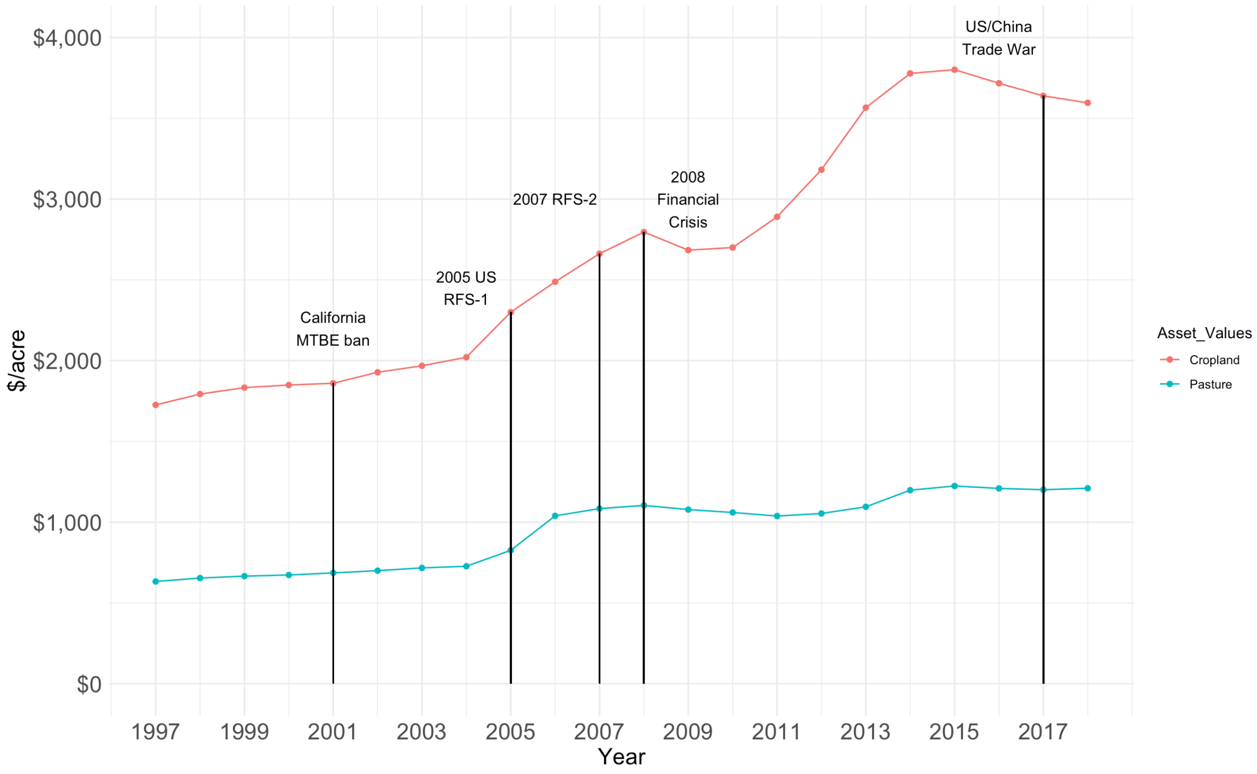

Figure 2: US Real Land Values 1997-2018
Source: NASS Land Asset Values Survey 2018

4 Data and Methods

Table 1: Summary Statistics: Structural VAR Herd Model

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Crude Oil \$/barrel	74	42.54	28.67	12.34	20.21	59.00	141
Corn ¢/bushel	74	323	128	157	232	385	732
Live Cattle \$/cwt	74	86.19	25.93	55.97	65.79	102	166
Herd Size 10000 head	74	3,308	186	2,896	3,206	3,399	3,850

Source: NASS & CME 2021

To examine the impact of U.S. biofuels policy on the cattle industry, we use biannual (January and July) herd data from the National Agricultural Statistics Service (NASS) for the U.S. beef herd from 1970 to 2021. These data are available through the NASS Cattle Inventory Report[7]. We match our herd data with the average of the nearby daily futures prices for relevant CME (Chicago Mercantile Exchange) commodity prices in the intervening period up to each inventory report. For example, the Cattle Industry Report is published at the first of the month in January and July. Therefore, we average the preceding six months of futures prices to correspond to the herd average provided by the report. For the nearby futures prices, we use the front-month closing price for corn, live cattle, and West Texas Intermediate (WTI) crude oil. By matching this way, we generate 74 observations for the time period July 1983 to January 2021. Table 1 presents summary statistics for these series. Over the period of observation, the average size of the U.S. beef herd was 33 million head, which is down from the early 1970s high of about 40 million. The corn price experienced dramatic changes over this same time period, rising to almost $ 8.00 per bushel following the RFS. Crude oil follows a similar trend, rising in the early 2000s to a record high in 2008-09 before collapsing with the recession only to bounce back in the 2010s. Live Cattle, however, remains steady relative to the other series with short cycles of highs and lows throughout the 2000s and 2010s.

Table 2 presents the summary statistics for the cattle market returns data. Feeding cost of gain[8] is reported in the Focus in Feedlots newsletter[9] produced by Kansas State University (KSU). Feeder cattle prices for Kansas are reported by the Livestock Marketing Information Center (LMIC)[10]. Feeder cattle are cattle on feed that have yet to reach marketable weight. Their prices are reported for different weight categories (e.g., 600 to 700 lbs., 700 to 800

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[7] The report was suspended in 2013 and 2016 due to sequestration

[8] An industry efficiency measure defined as the total feed cost divided by total gain in lbs.

[9] Focus on Feedlots Newsletters

[10] LMIC website

lbs., and 800 to 900 lbs.). We use this information along with feeder weight reported in the Focus on Feedlots newsletter, Kansas State University, to compute the feeder price for each month. Fed (or finished) cattle prices for steers in Kansas are reported by the LMIC. The ”price ratio ”is the feeder to fed cattle price ratio. Again, feeder cattle are distinct from fed cattle in that fed cattle have reached maturity (approx. 1100 lbs.) and ready for market, while feeder cattle are still maturing but can be put on feed in feedlots for finishing. Feed conversion is also reported in the Focus on Feedlots newsletter, Kansas State University, where the ”feed conversion rate” is defined as the amount of feed input divided by the total mass of the fed cow/steer at finishing or its dressed (post-slaughtering) weight. In addition, the newsletter reports an inventory price for corn and alfalfa, as averaged over the previous 5 months–an appropriate measure for the feed cost of production. Simulated net returns per head of cattle producers are computed by subtracting feeding cost of gain and interest cost from gross returns (number of cattle marketed multiplied by the price). According to table 2, the average net returns are negative, but note that cattle sales are not constant over time. Sale weight, feeder weight, feeding cost of gain, and days on feed (for interest cost computation) are from the Focus on Feedlots newsletter, Kansas State University. We use the operating interest rate from the Kansas City Federal Reserve, a readily available interest rate for short-term assets.

Table 2: Summary Statistics: Net Returns and Feed Costs on Cattle

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Net Returns \$/head	252	−35.26	131	−521	−105	35.99	353
Feed Cost of Gain \$/cwt	252	74.73	20.63	43.01	54.11	85.76	134
Price Ratio	252	1.20	0.13	0.82	1.10	1.27	1.70
Feed Conversion	252	6.04	0.21	5.62	5.90	6.15	7.08
Corn Price \$/bushel	252	4.00	1.51	1.96	2.72	4.36	7.96
Alfalfa Price \$/ton	252	133	45.84	59.33	102.84	153	242
Feeder Price \$/cwt	252	124	35.60	72.76	96.76	146	240
Fed Price \$/cwt	252	103	24.78	63.15	84.36	121	171

Source: LMIC & KSU 2020

We investigate whether the observed variation (and decline) in beef herd size is attributable to changes in U.S. biofuels policy by (1) analyzing the counterfactual (no VEETC, RFS, or MTBE ban i.e. business-as-usual) time series for herd size, and (2) searching for structural breaks in the beef herd series, especially in and around the critical dates of 2001, 2004, 2005, and 2008. After identifying structural breaks in the herd size, we split our sample to estimate the relationship between beef markets and energy before and after relevant policy changes. We implement the procedure described in (Bai and Perron, 2003) for simultaneous estimation of possibly multiple breakpoints. The distribution function used for the confidence intervals for the breakpoints is given in (Bai, 1997), and the objective is minimize the triangular RSS matrix, which gives the residual sum of squares for a break segment. We then use the same procedure to search for breaks in the net returns to feed and fed cattle producer data.

4.1 Structural VAR Model

We estimate the impact of biofuel policies on beef herd size, corn, oil, and cattle prices with a recursive structural VAR model. Our model extends the approach of Carter et al., (2017) and Smith, (2019) to include cattle. First, we define $\mathbf{y}$, as a set of endogenous variables $\mathbf{y}_t = (\text{oil\_fut}_t, \text{corn\_fut}_t, \text{cattle\_fut}_t, \text{herd\_size}_t)$. The $VAR(p)$ process for this set of endgogenous variables is:

$$\mathbf{y} = A_1\mathbf{y}_{t-1} + \cdots + A_p\mathbf{y}_{t-p} + \mathbf{u}_t \tag{1}$$

A_i are (4×4) coefficient matrices for $i = 1, \cdots, p$ lags and $\mathbf{u}_t$ is 4-dimensional white-noise process. We select an autoregressive lag order of 2 from the Schwarz information Criterion (SIC) for our $VAR(p)$ process (Pfaff 2008). Equation (1) is then a reduced form model. We can then define a structural form model as:

$$A\mathbf{y} = \bar{A}_1\mathbf{y}_{t-1} + \cdots + \bar{A}_p\mathbf{y}_{t-p} + B\epsilon_t \tag{2}$$

ϵ_t are white-noise structural errors, and $\bar{A}_i$ are structural counterparts to the coefficients in Equation (1). B is the structural coefficient matrix for the error term. This matrix captures the impact of ”structural shocks” to our endogenous variables, or true independent innovations rather than correlations among the variables in the model. We impose restrictions on B to simulate the impact of the structural shocks. Our restriction matrix B is,

$$\begin{pmatrix} b_{1,1} & 0 & 0 & 0 \\ b_{2,1} & b_{2,2} & 0 & 0 \\ b_{3,1} & b_{3,2} & b_{3,3} & 0 \\ b_{4,1} & b_{4,2} & b_{4,3} & b_{4,4} \end{pmatrix} \tag{3}$$

which implies oil prices (b_1) impacts corn (b_2) and cattle (b_3) prices as well as beef herd size (b_4) contemporaneously; corn impacts only cattle prices and herd size, and oil prices at a lag; cattle prices only impacts herd size, and oil and corn prices at a lag. These restrictions allow model identification by the Cholesky decomposition, which uses a recursive method to solve for the elements of B (Sims, 1980; Sims et al. 1990). This is a logical set of restrictions given that 40% of the U.S. corn crop is used for ethanol production, and the life-cycle of the average fed cattle on market is approximately 2 years, much longer the growing season for corn.

5 Results

We find that positive crude oil and corn price shocks reduce the beef herd size for up to several years. In particular, our impulse response functions in figure 3 imply that a one standard deviation increase in the price of oil ($\approx$ \$26/barrel) can produce a 400,000 to 600,000 head reduction in the U.S. herd size ($\approx 0.3\%$ of the mean herd size over the period of observation). These results support the claim of the NCBA and other livestock industry groups that cattle liquidations can result from government intervention to promote the production and adoption of biofuels, if those policies raise the price of feed.

Other relevant impulse response results in figure 3 indicate that oil shocks affect corn prices, as expected. Specifically, our impulse response results imply that a standard deviation increase in the price of oil results in a 5.5% increase in the futures price of corn for almost eight periods or 4 years (assuming we divide the impulse response estimate for corn by the average price of corn during the 2008-12 food commodity price boom). This is consistent with the findings of Carter et al., (2017) and Smith, (2019). And, it implies that an expanding demand (or tight supply) for oil itself raises the cost of cattle production and pressures herd size downward, but also does so indirectly via its affect on the price of corn.

Method 1: Recursive identification

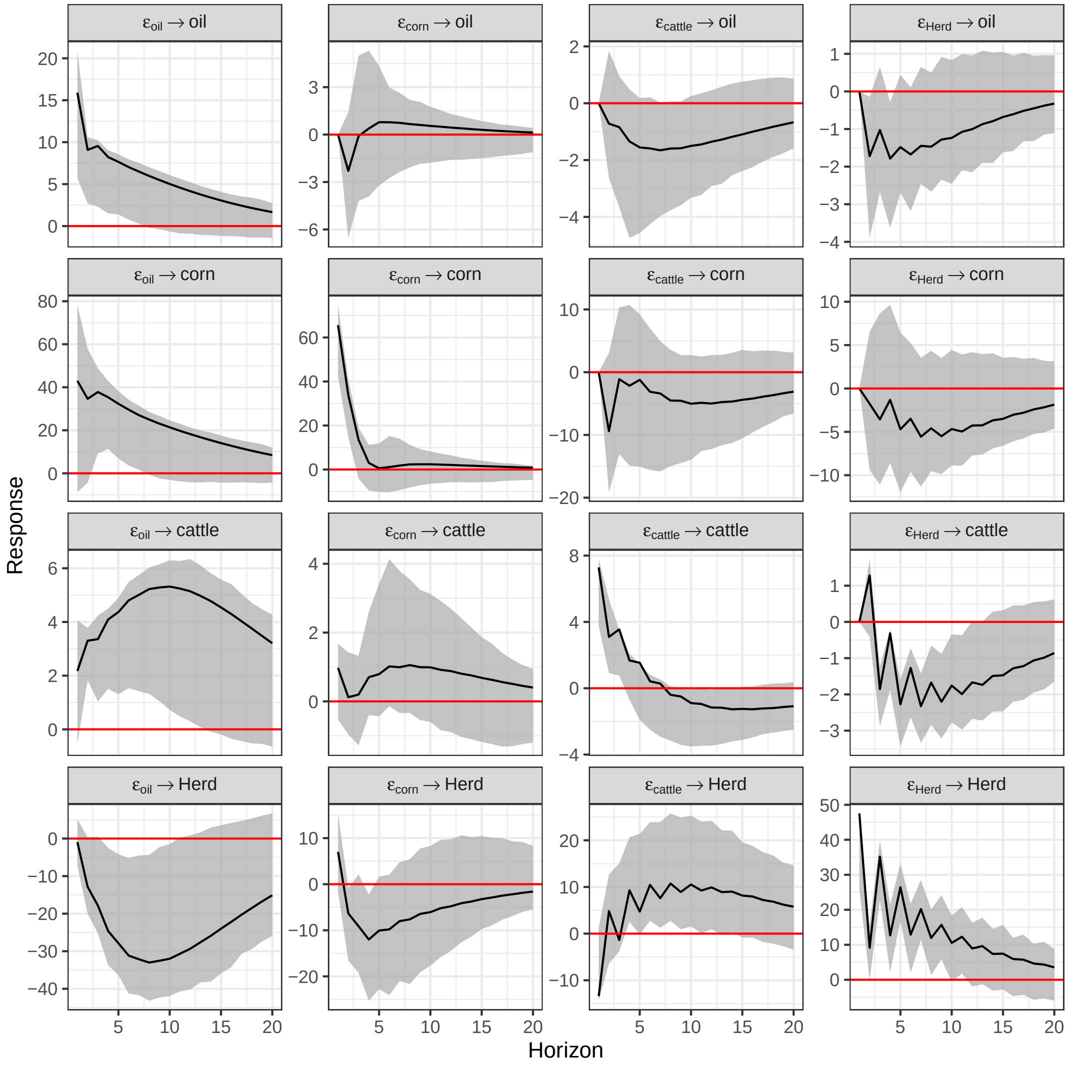

Figure 3: Impulse Response Functions (IRF): Simulated Shocks to SVAR components under Recursive Specification, 1983-2021

Source: Author calculations based on data sourced from NASS and CME 2021

Note: IRFs are generated from the estimated **B** matrix for 30 steps ahead. Grey 95% Confidence bands are generated using moving-blook bootstrap method with 500 runs.

5.1 Counterfactual vs. Actual

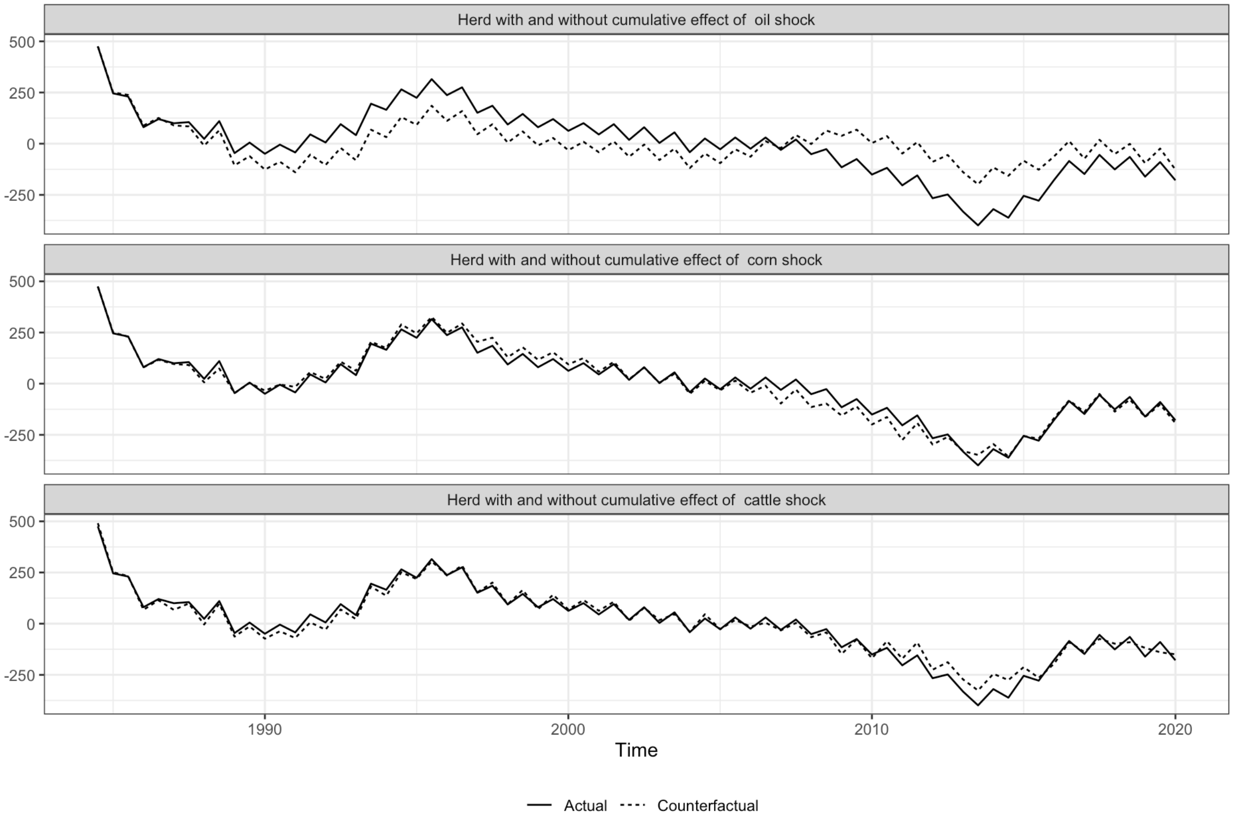

Figure 4: Evolution of de-meaned Beef Herd Size with and without corn,energy, and own-price shocks

Source: Author calculations based on data sourced from NASS 2021

Note: Counterfactual constructed from Recursive Identification Results

Similar to Smith, (2019), we present in Figure 4 the de-meaned beef herd series with and without the effects of shocks to crude oil, corn (the primary feed input), and own price. Corn and crude oil have the largest cumulative impact on beef herd beginning in the early 2000s. The first panel shows the historical decomposition for oil on herd size over our sample time period. Beginning in the mid-2000s, the observed herd size is above the counterfactual series, implying that the cattle herd benefited from depressed oil prices (recall Figure 1)–

which lowered industry production costs–until the mid-2000, when the U.S. government enacted significant policies to promote biofuel production and adoption. Beginning at that time, the counterfactual herd size series runs substantially higher than the observed series implying that the the spike in oil prices during the 2000s lowered the U.S. herd size, as cattle producers were forced to both pay higher prices for the oil they used in production and compete with ethanol producers for feed inputs. Figure 4 offer suggestive evidence that the transition in the crude oil market from low to high prices may have coincided with a structural break in the beef herd. Using the Bai-Perron procedure, we identify structural breaks in the beef herd series at July 1988, January 1994, July 1999, and July 2008. Test results are given in Table 3.

Table 3: Structural Break Test Beef herd Series

Break Point	10% value	90% value	RSS	BIC
July 1988	January 1988	July 1992	974825.4	960.6
January 1994	January 1993	July 1995	870396.5	960.6
July 1999	January 1999	July 2000	759681.6	958.9
July 2008	July 2007	January 2009	678299.5	959.0

Notes: Computed using procedure described in Bai and Perron (2003)

Figure 5 visualizes the identified structural breaks. These breaks coincide with significant events in the evolution of the U.S. beef herd. The 1988 break aligns with the start of the US-EU beef dispute over the use of hormones in the production process. The E.U. ban on the importation of hormone treated beef, resulted in the U.S. placing retaliatory tariffs on E.U. imports to the (AFB, 2019); unsurprisingly, the domestic herd rises beginning then. The 1994 break in the figure corresponds to the peak of the beef cattle price cycle, when feedlots swelled with an oversupply that resulted in a decline in the cattle price (Hughes, 2001). The 1999 break represents the year California sought its first waiver for the blending of MTBE in its commercial fuels, marking the beginning of the domestic shift towards ethanol as the sole oxygenate used in the blending of commercial fuels. Finally, the 2008 break directly corresponds to the implementation of RFS-2 legislation (Duffield et al., 2015). From the standpoint of our analysis, the 1999 and 2008 break are of primary interest. These dates relate to fundamental shifts in U.S. biofuel policies, while the two previous breaks correspond to trade issues and market cycles for cattle. Therefore, we split our sample into two periods: (1) July 1983 to July 2000; (2) January 2001 to January 2021. For robustness, we compare our results to intentionally splitting our sample in 2004, coinciding with the adoption of the VEETC and immediately preceding the RFS-1 and RFS-2 implementation. This latter split generates results (available in the Appendix) consistent with our headline findings.

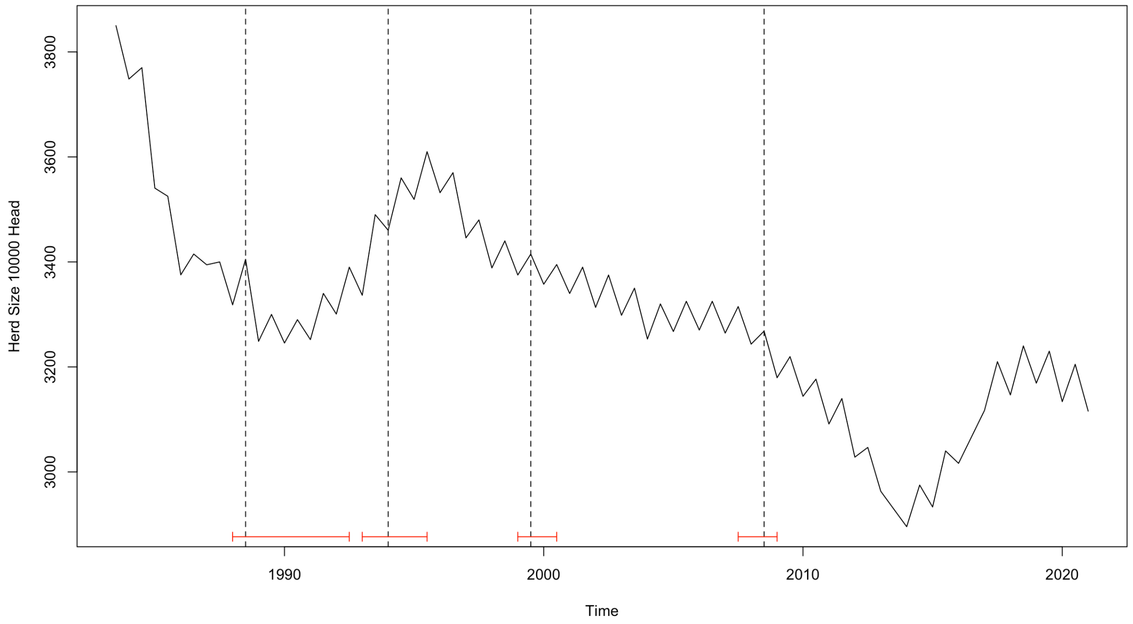

Figure 5: Structural Breaks U.S. Beef Herd 1983-2021
Source: Author calculations based on data sourced from NASS 2021

5.2 Sample Split: Pre and Post 2000

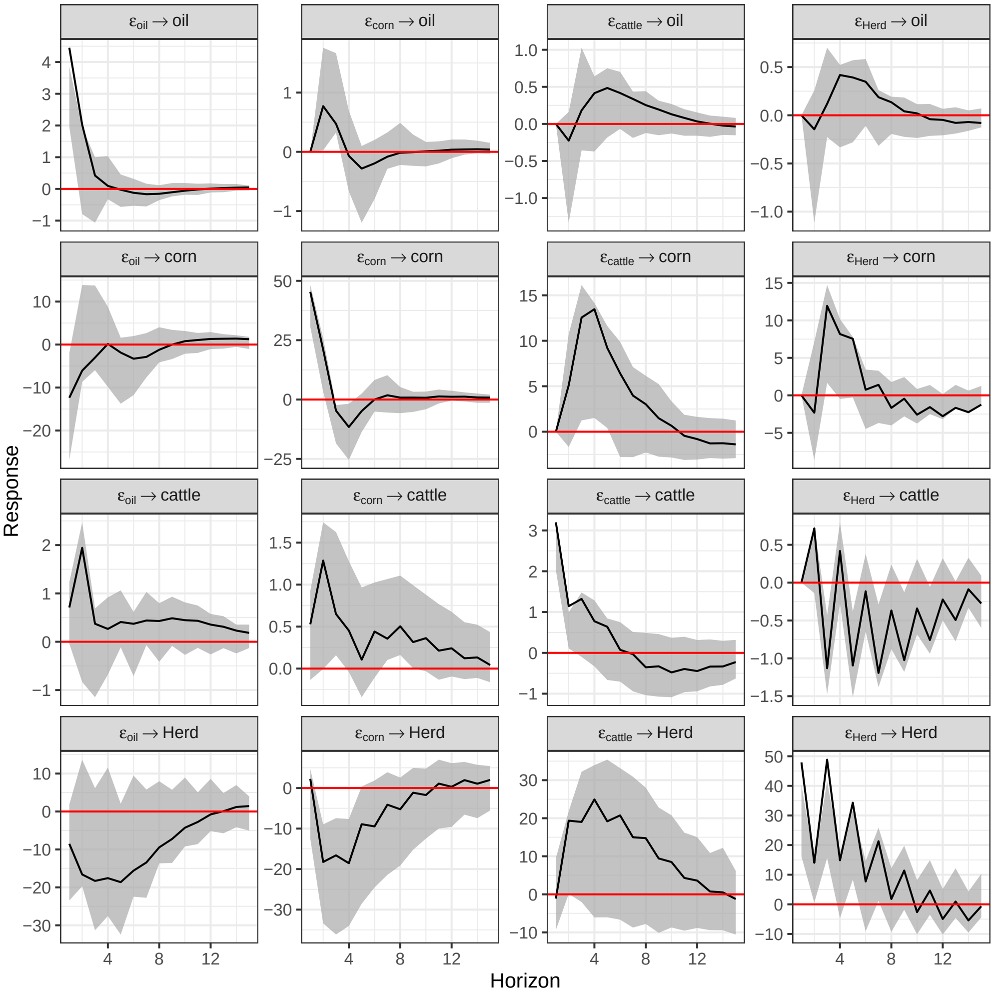

Figure 6: Sample Split pre-2000 impluse response function under recursive specification
Source: Author calculations based on data sourced from NASS and CME 2021
Note: IRFs are generated from the estimated **B** matrix for 15 steps ahead. Grey 95% Confidence bands are generated using moving-blook bootstrap method with 500 runs.

Figure 6 presents the impulse response functions generated for data in the period July 1983 to July 2000. Unlike the total sample response functions in Figure 3, shocks to the crude oil prices, although suggestive, do not translate to significant decline in herd size (at the 95% level) before the MTBE ban and subsequent adoption of the RFS-1. On the other hand, corn price shocks have clearly significant, negative impacts on herd size even prior to the MTBE ban–as expected since corn is the primary cost of feed.

Figure 7 depicts the impulse response function for the post-2000 era. Unlike in Figure 6, shocks to crude oil prices generate a significant decline in the domestic herd size, representing an important shift in energy and livestock markets. Our results, especially with regard to corn and oil, are consistent with the impulse response functions generated by of Carter et al., (2017) and Smith, (2019). In Figure 6, prior to the break, the impulse response of herd size to oil is not significant at the 95% level. However, in Figure 7, after the break, oil has a clear, significant negative impact on herd size. Furthermore, the oil shocks correspond to significant increases in the corn futures price after the break, consistent with the results of Carter et al., (2017) and Smith, (2019). For robustness, the impulse response function for the own-price and herd size on itself is unchanged before and after the break. This suggests that the adoption of the VEETC, RFS-1, and RFS-2 established a stronger link between cattle and energy markets. A sudden increase in the price of oil drives down the herd size in the short run. In addition, according to Figure 7, a positive corn price shock has a stronger (at the mean) and more persistent negative impact on herd size after the break than before it, lasting more than 8 periods (4 years), while before the break the confidence bands cross the vertical axis at about 4 periods, or around two years.

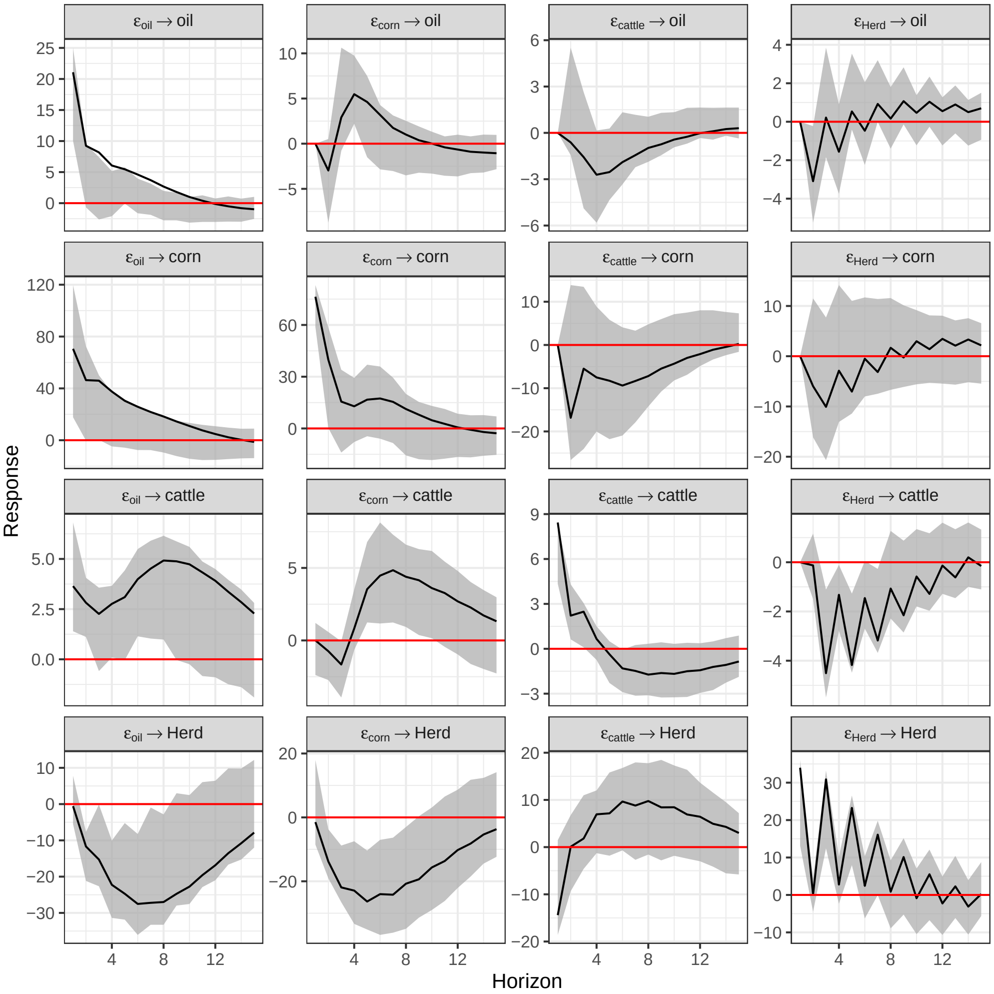

Figure 7: Sample Split post-2000 impulse response function under recursive specification

Source: Author calculations based on data sourced from NASS and CME 2021

Note: IRFs are generated from the estimated **B** matrix for 15 steps ahead. Grey 95% Confidence bands are generated using moving-blook bootstrap method with 500 runs.

5.3 Structural Break: Net Returns

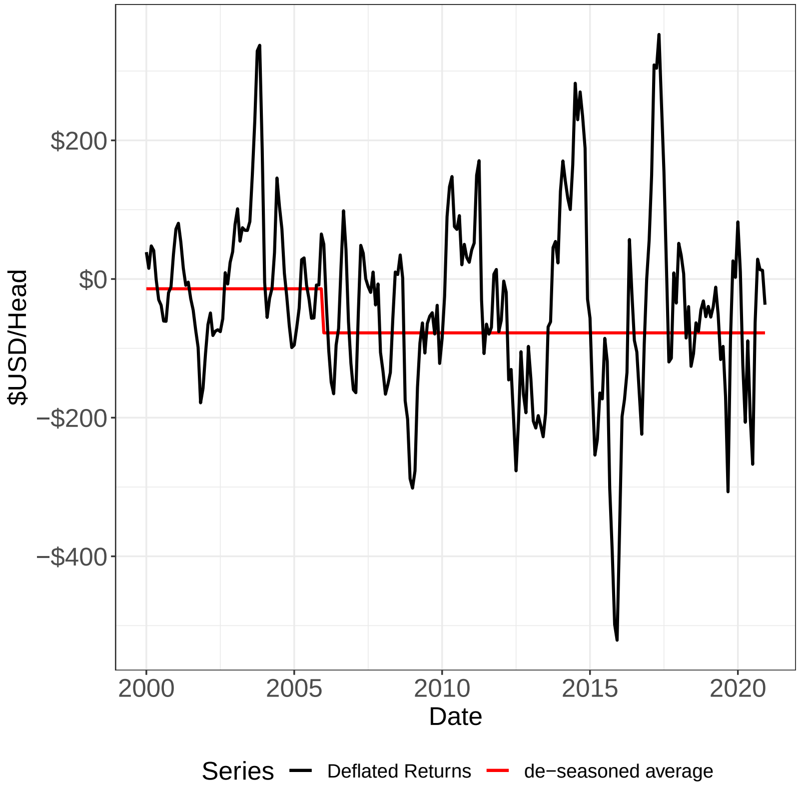

Figure 8: Deflated Net Returns $ per head
Author calculations based on data sourced from KSU and LMIC 2020

Finally, we consider the impacts to producer profitability using our simulated returns series. Following the Bai-Perron procedure, we identify a break point of October 2004 on the net returns to cattle (Bai and Perron, 2003). We then test the date of January 2006, the first month of the year after the RFS was passed. Table 4 details the test results. Since 2006, the average simulated return per head to steer producers at representative Kansas feedlots has decreased by approximately $77 per head. Figure 8 shows the deflated series of net returns along with the de-seasonalized average value of the series. We interpret this finding to mean that, in addition to making the domestic cattle herd more sensitive to crude oil and corn price shocks, U.S. biofuel policy has also adversely impacted cattle producer revenue.

Table 4: Structural Break Test Cattle Net Returns

Date	Test Statistic	$\lvert t \rvert$-value	p-value
October 2004	-73.70418	2.574709	0.0106
January 2006	-77.65414	2.306100	0.0220

Notes: Computed using procedure described in Bai and Perron (2003)

6 Conclusions

By expanding ethanol production, U.S. biofuel policy increased the demand for feed grains (especially corn) and raised their prices. But those policies also risked destructive effects on downstream entities by creating new demand-side competitors for feed inputs. Cattle producers, who use corn as a major input component, were most exposed. Our results confirm that–post-RFS implementation–sudden, unexpected changes to the prices of corn and oil pressure ranchers to reduce the domestic herd size. We also show that U.S. biofuel policies had both economically and statistically significant negative impacts on feedlot net returns.

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7 Appendix

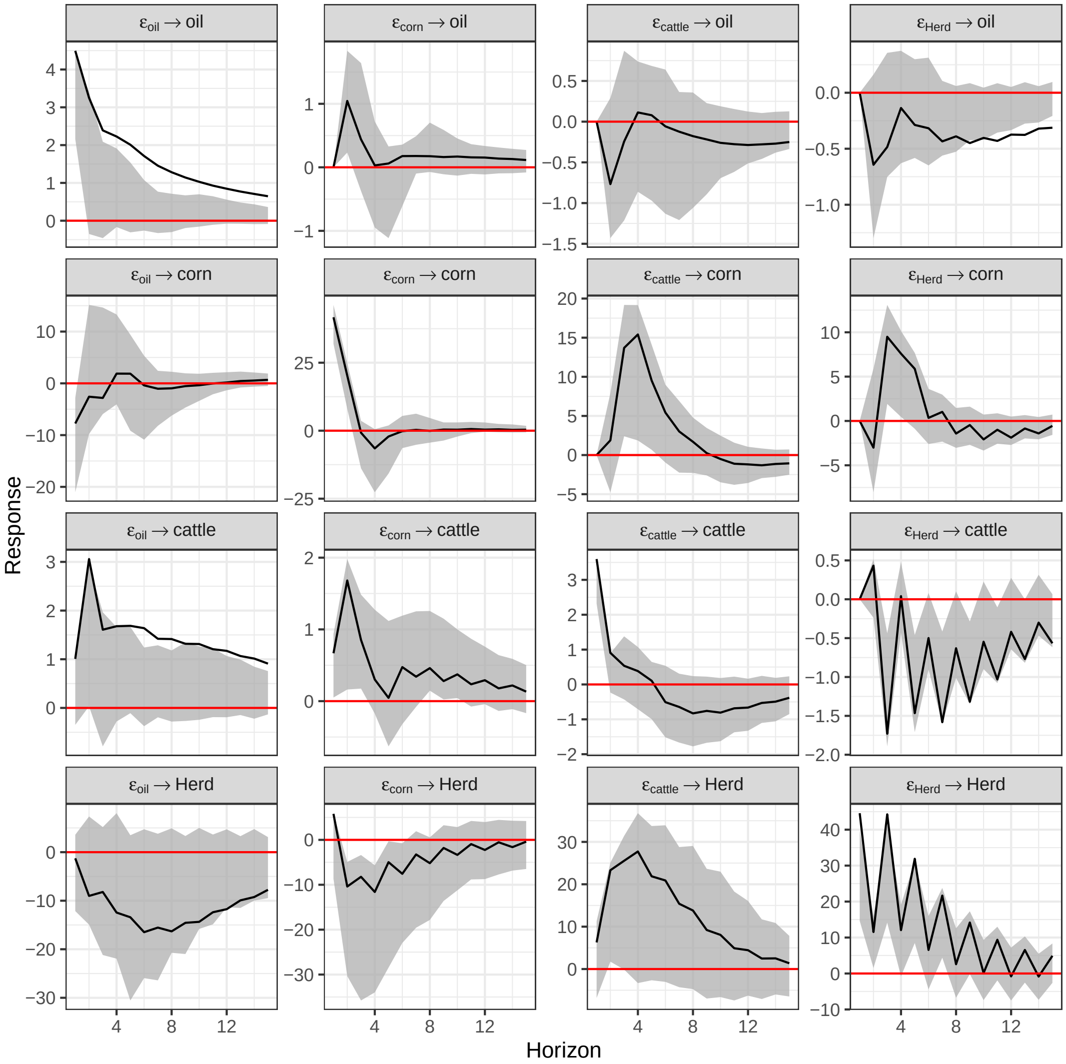

Figure 9: Sample Split pre-VEETC (2004) impulse response function under recursive specification

Source: Author calculations based on data sourced from NASS and CME 2021

Note: IRFs are generated from the estimated **B** matrix for 15 steps ahead. Grey 95% Confidence bands are generated using moving-blook bootstrap method with 500 runs.

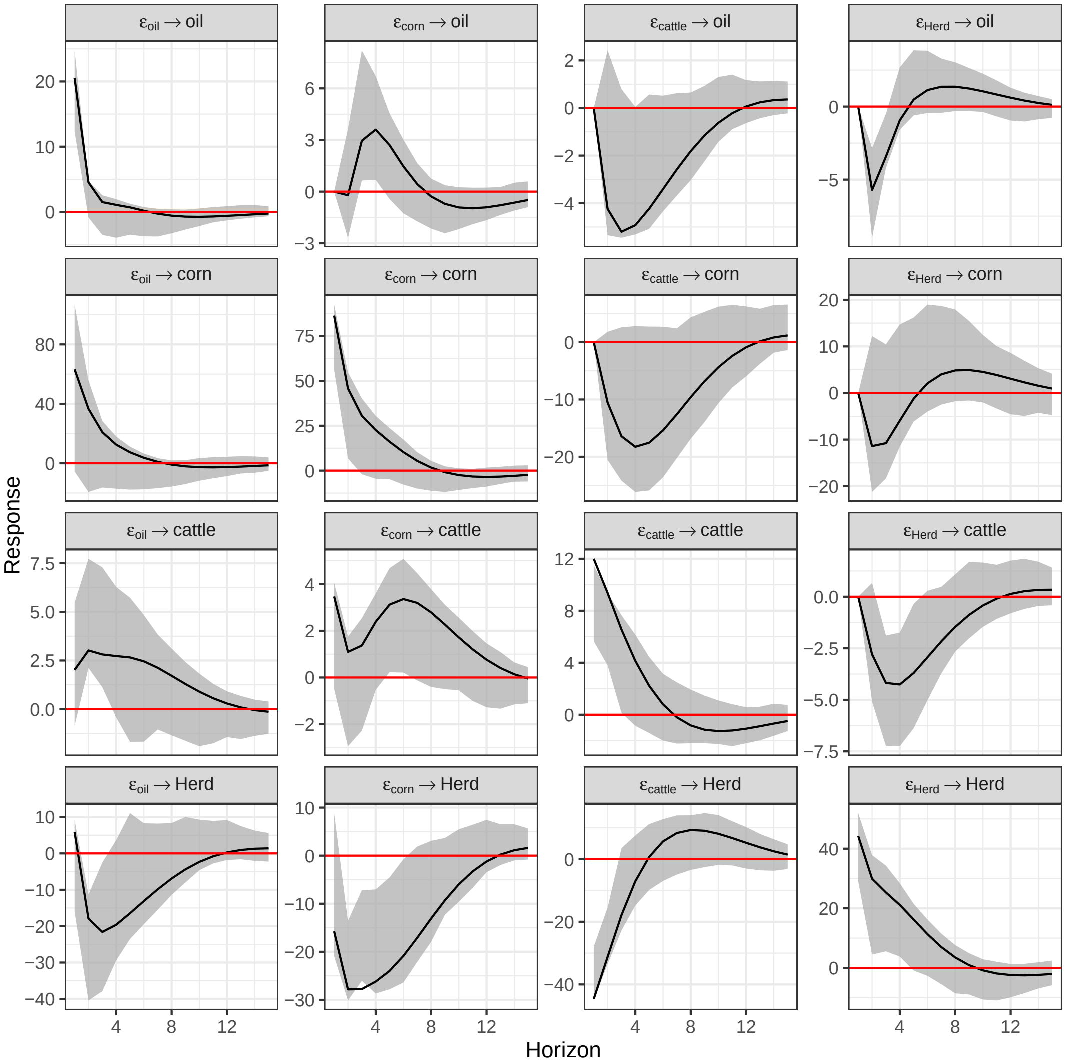

Figure 10: Sample Split post-VEETC (2004) impulse response function under recursive specification

Source: Author calculations based on data sourced from NASS and CME 2021

Note: IRFs are generated from the estimated **B** matrix for 15 steps ahead. Grey 95% Confidence bands are generated using moving-blook bootstrap method with 500 runs.