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A Review of the Evidence on the Relation Between Crude Oil Prices and Petroleum Product Prices†

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Abstract

We review a large body of the empirical literature focusing on the relation between petroleum product prices and oil prices and discuss the evidence on the direction of causality between crude oil prices and petroleum product prices. In addition, we survey the literature on the much-debated question of whether petroleum product prices respond differently to increases versus decreases in oil prices, which Bacon (1991) labeled the "rockets and feathers" phenomenon.

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1. Introduction

This survey is the first of a two-part series that reviews the extant empirical evidence regarding the behavior of petroleum product futures prices. Herein we review the literature focusing on the relation between petroleum product prices and oil prices. In the companion review (Ederington et al., 2018a), we turn to the general distributional characteristics of petroleum product prices, the influence of fundamental factors such as refinery outages and weather on product prices, the way that price discovery occurs for petroleum product prices, the predictive accuracy of petroleum product futures prices for future spot prices, and the impact of speculation on petroleum product prices.

Crude oil is the “main ingredient” in refined petroleum products. Two primary hypotheses regarding the causal relation between oil prices and petroleum product prices have been presented in the literature. The first argues that the primary causal relation runs from oil prices to product prices (see the survey of Frey and Manera, 2007; U.S. Energy Information Administration, 2014) and rests on the hypothesis that the marginal price of a barrel of a petroleum product should, in principle, be determined by the highest marginal cost of oil used. An alternative is that causality runs in the opposite direction (Verleger, 1982, 2011; Baumeister et al., 2018). The direction of causality has important implications for the regulation and organization of these markets and the facilitation of trade. Numerous authors investigating the links between oil price changes and product price changes have taken the direction of causation as a given and assumed that the dominant channel is from oil prices to product prices. However, recent evidence suggests that causality may run from product prices to oil prices. Whether there is a causal link running from product prices to oil prices has received limited although increasing attention (Asche et al., 2003; Kaufmann et al., 2009; Kilian, 2010; Bilgin and Ellwanger, 2017; Baumeister et al., 2018). The evidence supporting the first hypothesis rests generally on the analysis of data measured at a monthly or weekly frequency, whereas support for the alternative hypothesis rests generally on the behavior of data measured at a quarterly or longer frequency.

One important part of the dialogue about the short-term connection between oil prices and petroleum product prices is the speed and magnitude of product prices' response to changes in oil prices. This response is often referred to as the "rockets and feathers" phenomenon, a phrase coined by Bacon (1991) to describe the fast rise response in gasoline prices to increases in oil prices and the slow fall as oil prices decline. This question forms the basis of a long, ongoing debate about whether gasoline prices (and other product prices) respond more strongly and quickly to oil price increases than to oil price decreases. Prices of refined petroleum products such as gasoline and heating oil have long been a focal point of interest to individual consumers, industrial producers and consumers, as well as public policy makers and academics. When gasoline prices are rising, there is much popular consternation. Allegations of collusion on the part of retail sellers as well as predatory pricing are common. For instance, hearings conducted by the U.S. Senate Committee on Energy and Natural Resources emphasized the mission "To explore the effects of ongoing changes in domestic oil production, refining and distribution on U.S. gasoline and fuel prices."[1] No doubt as a consequence of the regulatory and antitrust attention focused on this industry, a large empirical literature studying gasoline prices has developed.

Herein we review the evidence regarding causality and the ways that petroleum product prices respond to increases or decreases in oil prices. As part of our review, we also examine the

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[1] Held in 2013. Refer to https://www.energy.senate.gov/public/index.cfm/hearings-and-business-meetings?ID=DC9017CC-BEAA-4EA6-A7DD-9EC1F3102D27.

empirical evidence on which market-determined oil price serves as the principal benchmark for product prices.

Section 2 presents a review of the empirical evidence on the causal relation between oil prices and petroleum product prices and the issue of the benchmark oil price. Section 3 reviews the literature on the asymmetric response of petroleum product prices to changes in oil prices. Section 4 presents a summary.[2]

2. Petroleum product prices

2.1. Crude oil prices and product prices

Heating oil, gasoline, and fuel oil are all refined from crude oil. The prices of petroleum products are inextricably linked to the price of crude oil by the technology and economics of refining. Propane is a byproduct of the refining process and is also extracted from natural gas or oil wellhead gas at processing plants.

Crude oil is traded in a global market, as is gasoline (Kaminski, 2012; Zavaleta et al., 2015). Indeed, Zavaleta et al. (2015) conclude that "Econometric evidence supports the hypothesis that the U.S. and European markets for oil and refined products are integrated" (p. 206).[3] A question that has surfaced in recent years is "which oil price is the primary world benchmark price?" The two benchmark oil prices which receive the most attention are: West Texas Intermediate (WTI) and Brent Blend. In this section, we discuss the empirical evidence regarding the connection

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[2] For a review of the literature focusing on the behavior and determinants of oil prices see Ederington et al. (2011), https://www.eia.gov/workingpapers/pdf/factors_influencing_oil_prices.pdf.

[3] An important driver in these markets is trading by commodity traders (see Pirrong, 2014). For instance, Gunvor, a leading commodities trader, states in its 2016 group summary report that "Gunvor's blending, storage and logistics capabilities enable us to take advantage of arbitrages that arise from often-significant price differentials that exist between or even within various countries."

between oil prices and product prices, and the evidence regarding whether the WTI or Brent price has the greater influence on product prices, with special emphasis on U.S. gasoline prices.

The U.S. Energy Information Administration (EIA) estimates that, in 2017, the cost of crude oil contributed 50% to the retail cost of a gallon of gasoline in the United States, down from 57% in December 2014. The remaining cost includes 19% taxes, 17% distribution and marketing costs, and 14% refining costs. The corresponding figures for diesel are 45% crude oil, 20% taxes, 17% distribution and marketing costs, and 18% refining costs.[4] State-imposed fuel taxes differ, contributing to differential prices across states.

Of course, changes in any of the contributing factors mentioned in the prior paragraph could potentially change gasoline or other product prices. Aside from the crude oil price, several additional factors could cause movements at the state level. Inventories are one factor. The theory of storage (Kaldor, 1939; Working, 1949) predicts that price volatility and price level are inversely related to inventory levels. State and federal requirements can vary regarding blending of reformulated gasoline with ethanol and/or fuels with different levels of low Reid Vapor Pressure (RVP). These requirements have the potential to create supply bottlenecks. For instance, the Energy Independence and Security Act of 2007 (EISA) imposes specific renewable fuel blending standards which increase over time.[5] This increase can also cause bottlenecks. A separate but related issue is the cost of ethanol relative to conventional gasoline and reformulated gasoline. Irwin and Good (2014) point out that "The recent drop in gasoline prices has been large enough to potentially threaten the competitiveness of ethanol in gasoline blends."[6]

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[4] These data are updated monthly by the EIA. Please refer to http://www.eia.gov/petroleum/gasdiesel/ for the most recent figures.
[5] http://www2.epa.gov/laws-regulations/summary-energy-independence-and-security-act.
[6] http://farmdocdaily.illinois.edu/2014/11/do-falling-gasoline-prices-threaton-ethanol.html.

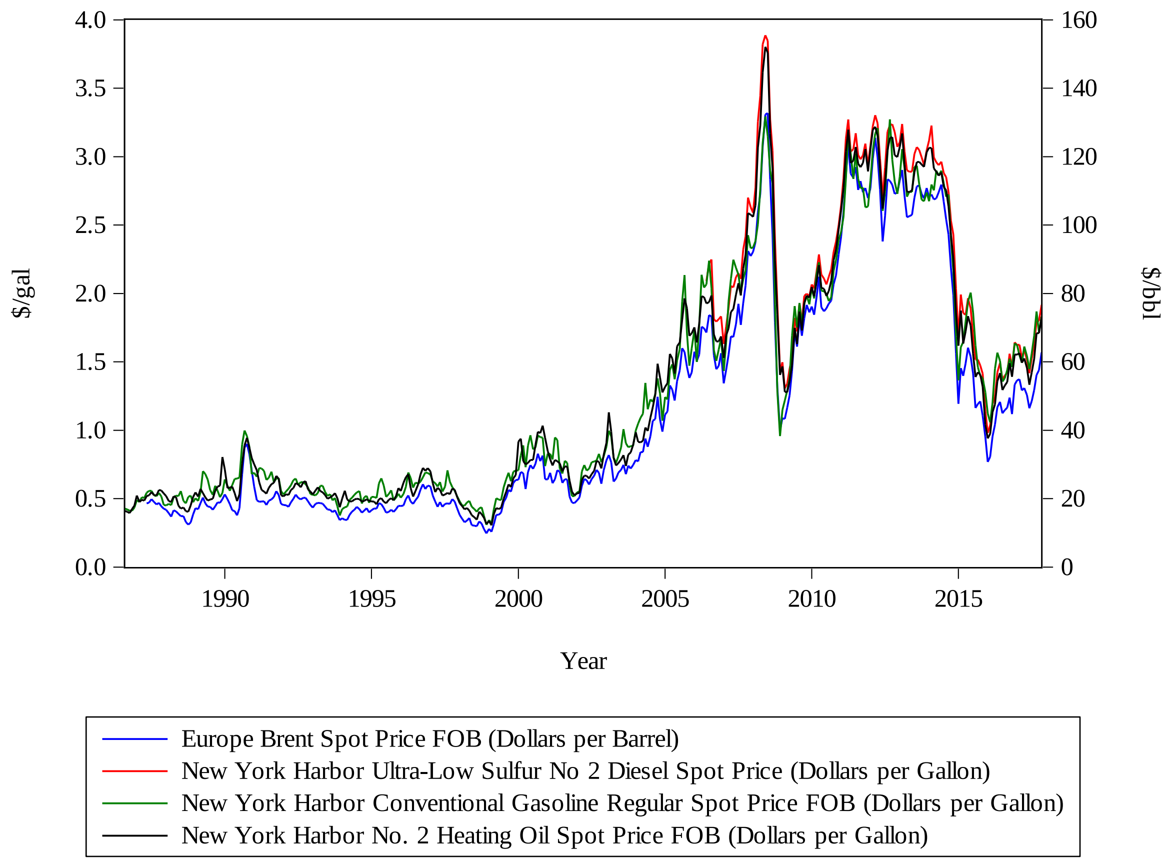
Another potentially important factor that could affect product prices is the incidence of regional refinery utilization and outages. Planned and unplanned outages can affect supply and cause price disruptions. The data suggest that refiners build inventory in anticipation of planned outages to avoid supply disruptions. Antitrust law prohibits refiners from communicating (and coordinating) outages. However, Section 804 of the EISA required the EIA to prepare a semi-annual analysis of planned refinery outages and their impact on petroleum product supply and price. The EISA further stipulates as follows: "On a determination by the Secretary, based on a report or alert under paragraph (3) or (4) of subsection (b), that a refinery outage may affect the price or supply of a refined petroleum product, the Secretary shall make available to refinery operators information on planned refinery outages to encourage reductions of the quantity of refinery capacity that is out of service at any time."[7] Finally, supply can be affected by pipeline disruptions due to natural disasters such as weather-related events. An extreme example followed Hurricane Katrina when the Colonial Pipeline, which includes 5,500 miles of pipeline delivering products such as gasoline, heating oil, and aviation fuel, was taken offline because electricity was not available to power pumps. We discuss the empirical evidence about these issues in Part 2 of this survey (Ederington et al., 2018a).

A large part of the empirical literature on product prices focuses on gasoline prices and the response of retail or wholesale gasoline prices to oil price changes. Additionally, a segment of the literature has attempted to address geographical variation in gasoline prices and the impact of competition.

[7] See EPA Laws and Regulations (http://www2.epa.gov/laws-regulations/summary-energy-independence-and-security-act).

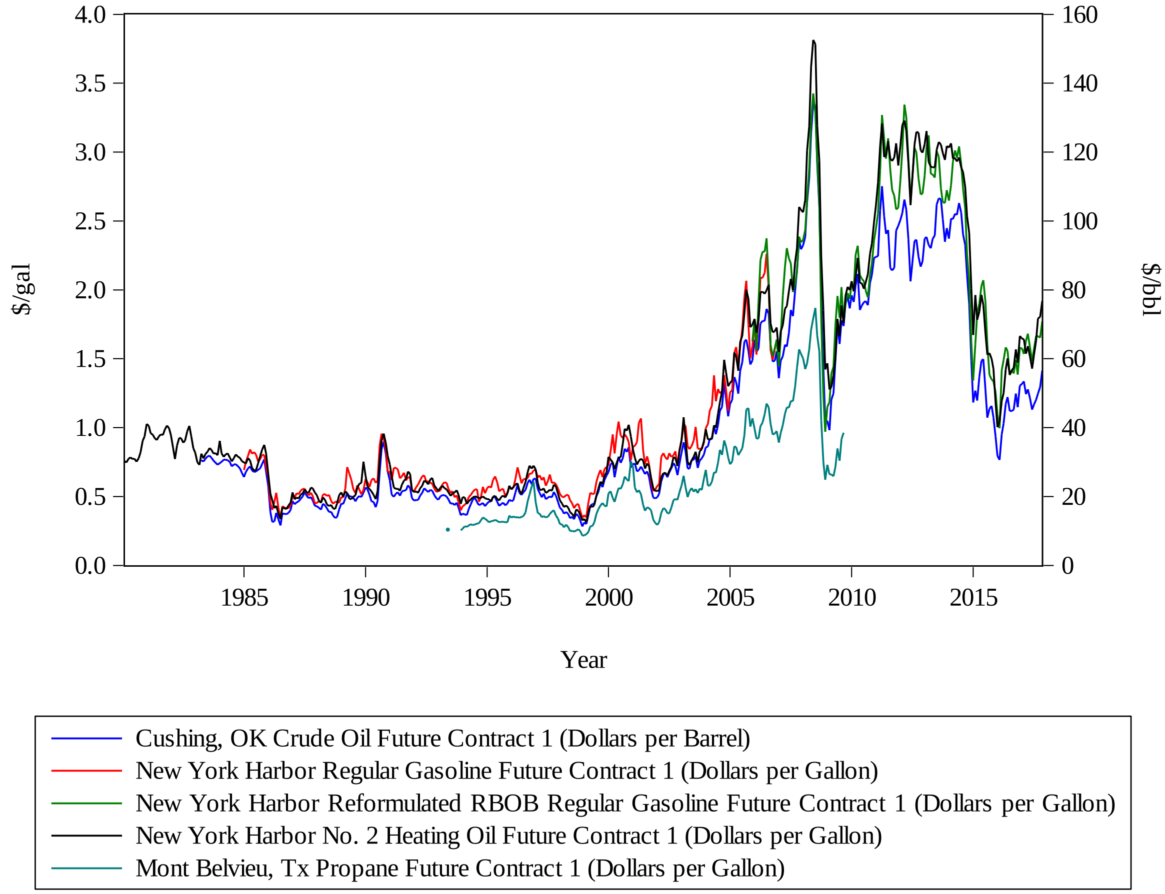
Figures 1 and 2 provide a first look at the relation between petroleum product prices and oil prices. Movements in oil prices are closely mimicked by gasoline prices, and both tend to follow the same visual trend, suggesting the presence of a long-term relation. One view, and the theme of a large body of research, is that changes in petroleum product prices are driven by changes in oil prices and that a long-term equilibrium relation exists between oil prices and product prices. We will return to this proposition below.

Figure 1
Spot Prices: Brent, Diesel, Gasoline, Heating Oil



Source: U.S. Energy Information Administration

Figure 2
Futures Prices (front month contract): WTI, Reg. Gasoline, RBOB, Heating Oil, Propane



Source: U.S. Energy Information Admiistration

Although the price series displayed in the figures appear to move together, some authors have presented evidence that movements in product prices follow movements in oil prices when the periodicity of data observations are measured over short horizons (days or weeks), whereas long measurement horizons support the reverse, that product demand drives oil prices. On the short horizon front, many researchers have presented evidence suggesting that the response size and adjustment speed of product prices to changes in oil prices depends upon whether the oil price has increased or decreased. Some have argued that faster product price adjustment in response to oil price increases than to oil price decreases is evidence in favor of the so-called “rockets and feathers" (asymmetric response) phenomenon originally studied by Bacon (1991). That segment of the literature, which we will turn to in Section 3, focuses on whether product price changes (in particular gasoline price changes) follow oil price changes, and whether those prices respond symmetrically to increases versus decreases in oil prices.

An alternative hypothesis is that the demand for petroleum products and the resulting prices drive the price of oil. Verleger (1982) has argued that spot market prices for petroleum products are the primary determinants of crude oil prices. Baumeister et al. (2018) describe the economic dynamics as follows: "A common view is that refiners view themselves as price takers in product markets and cut their volume of production when they cannot find crude oil at a price commensurate with product prices. In time, this reduction in the demand for crude oil will lower the price of crude oil and the corresponding reduction in the supply of products will boost product prices (see Verleger, 2011)" (p. 1). In essence, this hypothesis posits that refiners wish to maintain profit margins and therefore adjust their demand for oil in response to changes in the prices of petroleum products. In a study of oil price forecasting predicated on the Verleger thesis, Baumeister et al. (2018) find some evidence in support of the hypothesis, albeit for a model that deviates somewhat from the strict hypothesis. A recent contribution to the literature is Bilgin and Ellwanger (2017), who examine quarterly data and find evidence that "shifts in the global fuel demand accounted for the bulk of oil price fluctuations over the last decades." (p. 3). Most studies, however, have tended to emphasize the connection between changes in crude oil prices and wholesale or retail gasoline (or product) prices, under the assumption that changes in oil prices drive changes in product prices. An example of the latter are investigations of the relation between gasoline prices and the two primary oil benchmark prices, the Brent price and the WTI price (U.S. Energy Information Administration, 2014), which we comment on later.

Controlling for other factors, a $1-per-barrel change in the price of crude oil results in a $0.024-per-gallon change in the price of wholesale and retail gasoline ($0.024 is 1/42 of $1; there are 42 gallons in one barrel).[8] The evidence suggests that the adjustment occurs with a lag and that about half of the change in crude oil price is reflected in retail prices within two weeks of the price change, all other market factors being equal.[9]

2.2. Empirical examinations of oil price/product price relations

2.2.1. Overview

The empirical literature on the general relation between oil prices and petroleum product prices documents that gasoline prices and crude oil prices move together in the long-term. Similar results have been documented for heating oil prices and oil prices. The statistical methods employed in these analyses typically involve the estimation of bivariate time-series relations. Studies using data observed at different frequencies and for different time periods, as well as for various regions of the world, generally find a long-term relation between an oil benchmark price and product prices. The usual approach has been to associate product prices in the United States with the WTI price and product prices in Europe with the Brent price. In Section 2.3, we discuss recent empirical results concerning the benchmark oil price.

2.2.2. Time series behavior

As we emphasized in Section 1, two alternative hypotheses have emerged regarding oil prices and product prices: 1) oil price changes drive product price changes, and 2) product demand (and prices) drive oil price changes. Although these hypotheses might seem to be mutually exclusive, we are more agnostic. It seems that in the long-term, both oil prices and product prices

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[8] U.S. Energy Information Administration (2014). What drives U.S. gasoline prices? https://www.eia.gov/analysis/studies/gasoline/pdf/gasolinepricestudy.pdf.

[9] Ibid.

should be determined by the supply of crude oil and the demand for products. However, the question of which leads in the short-term is partially a question of which tends to shift more in the short-term: supply or demand. But it also depends on speed of adjustment. A change in product demand might result in a change in crude oil demand quickly so that no lag between gasoline prices and crude oil prices would be observed, or conversely, there may be a lag before the demand for crude is affected. Likewise, a change in the supply of crude might affect gasoline prices almost immediately or with a lag.

The examination of the time-series relation between petroleum product prices and oil prices is prevalent in the literature. These statistical approaches have been in the form of single-equation models as well as multivariate models, but they generally account, correctly, for the nonstationarity of the price variables in a vector error correction model (VECM). The basic bivariate model allowing for cointegration is of the form $\Delta P_t = \alpha\,(B'\,P_{t-1} - c) + \sum_{k=1}^{K-1} \Gamma_k\, \Delta P_{t-k} + e_t$, where P is a vector containing the relevant price series, Δ represents the first difference, and K represents the number of lags. The term in parentheses is the error correction term. In this setting, α is a 2 x 1 vector of long-term adjustment coefficients, and Γ holds the coefficients of the lagged differences. We can think of the system as having two equations, one in which the change in the price of the first product appears on the left and one in which the change in the price of the second product appears on the left.[10] Numerous authors have documented a long-term price (cointegrating) relation between crude oil and its refined products (Girma and Paulson, 1999; Gjølberg and Johnsen, 1999; Asche et al., 2003, Hammoudeh et al., 2003). In addition, a large body of literature examines how

[10] See Greene (2008) or Hamilton (1994) for a discussion of the vector error correction model.

product prices respond to oil price increases and decreases. This research typically involves tests confirming that product price changes follow oil price changes. We will return to a discussion of that literature in Section #..

Two (or more) time series are considered to be cointegrated when they each possess a unit root and a linear combination of the variables is a stationary process (Green, 2008). The studies in this branch of the literature generally do not attempt to test relations using alternative oil price benchmarks to determine the most appropriate benchmark for a given set of product prices. Rather, for example, U.S. data on product prices are related to WTI prices and European data are related to Brent prices. In Section 2.3, we return to the question of the oil price benchmark. The literature is somewhat segmented. Many papers employ the type of model described above. Other studies modify the framework when addressing the question we will take up later regarding whether product prices adjust differently to increases in oil prices versus decreases in oil prices. Still others have adapted the structure to account for stochastic error variances. In addition, many single-equation time-series models of various specifications have been studied.

Gjølberg and Johnsen (1999) analyze the relation between monthly prices for the period 1992-1998 (observed on the Northwestern European market) of crude oil (Brent) and six oil products (gasoline, naphtha, jet fuel, gas oil, light fuel oil 1%, and heavy fuel oil 3.5%). They estimate single-equation models treating crude oil as exogenous and conclude that crude oil determines product prices.

Asche et al. (2003) study the relations between crude oil and refined product prices within a multivariate time-series framework. The authors point out that treating crude oil prices as exogenous, say in a single-equation model, explicitly makes the assumption that the price of crude oil is what determines product prices and that product prices do not influence the price of oil. The authors employ a multivariate VECM. Studying monthly time series data for spot prices of Brent crude, gas oil, heavy fuel oil, naphtha, and kerosene from the Rotterdam market for the period January 1992 to November 2000, they find that the crude oil price is weakly exogenous, which has relevance for the hypothesis described earlier generally attributed to Vergler (1982). Their result implies that crude oil prices determine the other prices investigated. Conversely, the authors present results indicating that weak exogeneity is rejected for the other prices in the system and document a long-term relation between crude oil prices and each of the product prices except heavy oil. Finally, they find a long-term relationship between the prices of gas oil, kerosene, and naphtha, concluding that changes in demand for one of these products will influence the optimal refinery output mix.

Hammoudeh et al. (2003) examine daily spot and futures prices for crude oil, heating oil and gasoline for the period 1986-2001. The authors study five commodity trading centers within and outside the United States. Hammoudeh et al. (2003) find evidence of bidirectional causality between daily crude and gasoline prices, and a unidirectional causal relationship between crude oil and heating oil prices running from the former to the latter.

Lanza et al. (2005) investigate the relation between crude oil and product price dynamics using weekly and monthly data for the period 1994-2002, presenting a comparison among ten price series of crude oils and fourteen price series of petroleum products, considering four distinct market areas (Mediterranean, Northwestern Europe, Latin America, and North America). However, they do not attempt to distinguish which is the appropriate benchmark, assigning the Brent price to the Mediterranean and Northwestern Europe and the WTI price to the Americas. The researchers are primarily interested in models explaining regional oil prices, but they employ models that relate those prices to benchmark "marker" oil prices such as WTI or Brent, as well as to two product prices, low-sulfur fuel oil and gasoline. After accounting for the benchmark oil price (WTI or Brent), they find only weak evidence of a long-term relationship between product prices and the regional oil prices they study, and only for prices outside the Americas. However, they do not present tests of the relations between product prices and the benchmark oil prices.

Chouinard and Perloff (2007) estimate reduced form models for retail and wholesale gasoline prices utilizing monthly observations for the period from March 1989 to July 1997 for all contiguous 48 states and the District of Columbia. The authors examine both factors that may drive gasoline prices across time as well as across geographic areas and also account for factors such as taxes, refinery outages, various regulation effects, weather, controls for ownership of stations and vertical relations, refinery mergers, and crude oil prices. They draw two conclusions from the results: 1) "virtually the entire variation in national prices was due to changes in the crude oil price and cyclical fluctuations and not to changes in taxes, content requirements, and other factors" (p. 18); and 2) the primary determinants of price differentials across states are taxes, population density, and age distribution of a state's population. The authors also report results consistent with refinery and retail mergers' having an impact on prices across states.

Employing a joint vector autoregression (VAR) model of the global market for crude oil and the U.S. market for gasoline, Kilian (2010) estimates differing magnitudes, patterns, and persistence in response to demand and supply shocks in these two markets. The data examined are measured at a monthly frequency. The variables representative of the global market for crude oil are 1) the percent change of crude oil in world product, 2) a measure of global real economic activity (Kilian, 2009), and 3) the real price of crude oil. The U.S. gasoline market variables are 1) the real price of U.S. gasoline and 2) the percent growth rate of U.S. gasoline consumption. The variables are transformed in a variety of ways (Kilian, 2010).

Analyzing the impulse response estimates for supply and demand shocks in the global crude oil markets on real gasoline and crude oil prices, Kilian (2010) finds that 1) unexpected reductions in the supply of crude oil cause the real price of crude oil and gasoline to increase insignificantly; 2) an unpredicted expansion in the global demand for industrial commodities causes a persistent increase in the real price of crude oil and gasoline (smaller response); and 3) an unforeseen increase in oil demand is met with an immediate increase in real crude oil and gasoline prices (smaller response) that gradually declines.

The impulse response estimates for supply and demand shocks of the U.S. gasoline markets on real gasoline and crude oil prices provide evidence that 1) an unexpected disruption in U.S. refinery output causes real gasoline prices to spike and gradually decline, while real crude oil prices drop and gradually rise; and 2) an unexpected increase in U.S. demand for gasoline does not cause a significant response in real crude oil or gasoline prices. Collectively, demand and supply shocks from the global crude oil market and the U.S. gasoline market have differential implications on price shocks for crude oil and U.S. gasoline.

According to Kilian (2010), a shock to gasoline supply (refining shock) accounts for approximately 80% of the variation in gasoline prices in the short-term, and shocks to aggregate demand and oil-specific demand are responsible for approximately 95% of the variation in gasoline prices in the long-term. The supply side of gasoline appears to be the dominant factor in determining fluctuations in real gasoline prices, whereas the U.S. gasoline consumption is only modestly responsive to shocks in gasoline supply.

Ederington et al. (2018b) extend the analysis to a study of the relations between Brent oil futures prices and gasoline and heating oil futures prices for contracts traded on the NYMEX.[11] Their results show consistent evidence that causality runs from oil futures prices to product futures prices. The results are based upon weekly price data spanning a 28-year period. The authors also find some evidence of a marginally significant relation running from product futures prices to oil futures prices following 2005 when measured at the weekly frequency. However, an analysis of the response of oil futures prices to shocks to product futures prices reveals that the economic significance is small, so they cannot reject the hypothesis that the responses are equal to zero. The results carry through to a model that includes variables measuring fundamental supply and demand, which may themselves be jointly determined with prices. However, in an analysis of daily data during the post-2005 period, the authors also find evidence that product prices caused oil prices, suggesting that causality ran in both directions during that period when measured at the daily frequency.

2.3. Oil price benchmarks and petroleum prices

In testimony before a committee of the U.S. House of Representatives, Medlock (2014) made the case that petroleum products will be priced based upon the cost of the marginal internationally traded barrel of oil when there is no constraint on the trading of the refined product but there may be a constraint on the trading of the input (oil). If the Brent price is the appropriate

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[11] Futures contracts for oil, gasoline, and heating oil (ultra-low-sulfur diesel) are traded in liquid markets, facilitating price discovery and informationally efficient prices (Black, 1976; Jarrow and Larsson, 2012). The nearby oil contract is considered one of the most liquid contracts traded (Fett and Haynes, 2017), and its liquidity has been shown to be associated price efficiency (Raman et al., 2017). Reported spot prices for oil and petroleum products, on the other hand, are generally mechanically aggregated from surveys of trades (as assembled, for instance, by Platts and Thomson Reuters). In addition, contracts for immediate delivery in the crude oil market are quite rare, making the definition of a spot price problematic. Virtually all contracts are for delivery over a future month. What is normally reported as a spot price is the forward market price for delivery over the next month.

proxy for that barrel, we should see that wholesale gasoline prices are more closely aligned with the Brent price. The recent debate about the relaxing of U.S. export restrictions on crude oil and the implications for oil prices and U.S. gasoline prices is intimately linked to whether an increase in the global supply of oil would reduce global oil prices (reflected in the Brent price).[12] This brings us to the two benchmark oils that have received the most attention in the literature, WTI and Brent. Prior to 2010, the two prices were generally of the same magnitude, but a decoupling occurred in 2010 and has since persisted, although the gap has narrowed recently. Many commentators have attributed this to increased production in the United States and falling production in the North Sea, as well as infrastructure constraints in the United States. These developments have led some participants and reporting agencies to adopt the Brent price as the benchmark, including, for instance, the EIA in its Annual Energy Outlook publication. Figure 3 displays plots of regional U.S. gasoline prices along with the Brent spot price.[13]

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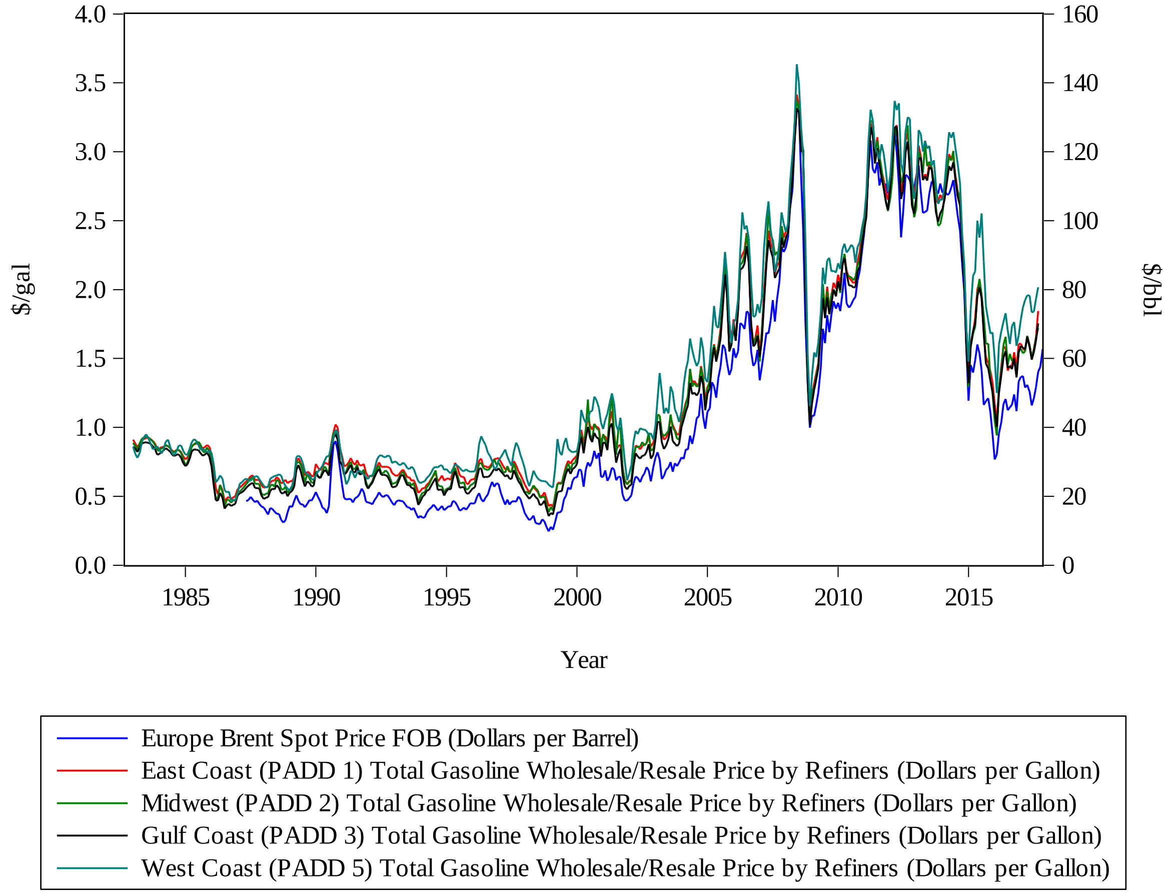
[12] "U.S. crude oil exports averaged 1.1 million barrels per day (b/d) in 2017 and 1.6 million b/d so far in 2018, up from less than 0.5 million b/d in 2016," according to the EIA https://www.eia.gov/todayinenergy/detail.php?id=36232.

[13] Report: http://www.eia.gov/petroleum/weekly/archive/2015/150122/includes/analysis_print.cfm. Per information from the website of the EIA (http://www.eia.gov/tools/glossary/index.cfm?id=P#PADD_def),
Petroleum Administration for Defense District (PADD): A geographic aggregation of the 50 states and the District of Columbia into five districts, with PADD 1 further split into three sub-districts. The PADDs include the states listed below:
•PADD 1 (East Coast):
•PADD 1A (New England): Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.
•PADD 1B (Central Atlantic): Delaware, District of Columbia, Maryland, New Jersey, New York, and Pennsylvania.
• PADD 1C (Lower Atlantic): Florida, Georgia, North Carolina, South Carolina, Virginia, and West Virginia.
•PADD 2 (Midwest): Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, Tennessee, and Wisconsin.
•PADD 3 (Gulf Coast): Alabama, Arkansas, Louisiana, Mississippi, New Mexico, and Texas.
•PADD 4 (Rocky Mountain): Colorado, Idaho, Montana, Utah, and Wyoming.
•PADD 5 (West Coast): Alaska, Arizona, California, Hawaii, Nevada, Oregon, and Washington.

Figure 3
Spot Prices: Brent, Gasoline by PADD



Source: U.S. Energy Information Administration

Recent EIA research (U.S. Energy Information Administration, 2014) shows that changes in Brent crude oil prices explain more of the variation in U.S. spot gasoline prices than do changes in WTI crude oil prices.[14] Prior to 2011, the Brent and WTI prices tended to be close. Following 2011, however, there were periods when the WTI price traded at a significant discount to Brent. The price gap has shrunk in recent years. The EIA study examines data from the period January

[14] Available at http://www.eia.gov/analysis/studies/gasoline/.

2000 to June 2014 and uses January 2011 as the breakpoint at which WTI prices first moved to a significant discount relative to Brent prices.

The models estimated by the EIA researchers posit a lagged relation between changes in oil prices and changes in spot gasoline prices for four regions: U.S. East Coast, U.S. Gulf Coast, U.S. West Coast, and U.S. Midwest. In addition, the authors control for regional gasoline inventories (specifically deviations from previous five-year averages as well as seasonal effects). Weekly averages of daily price data are examined. An error correction term computed following the convention of linear regression of one price on another price (see Engle and Granger, 1987) is included because the EIA researchers identify that the prices studied are cointegrated.

The resulting statistical analysis leads the EIA researchers to several conclusions:

> "1. For both the 2000-2010 and 2011-2014 periods, the equations in which the Brent price was used as the independent variable have more explanatory power than the equations in which WTI was the independent variable. This holds true for all regional markets, including the Midwest.
>
> 2. The equations that use Brent as the independent variable lose very little explanatory power from period one (2000-2010) to period two (2011-June 2014), while equations with WTI as the independent variable lose considerable explanatory power from period one to period two.
>
> 3. Introducing the Brent-WTI spread to equations in which WTI is the independent variable significantly improves the explanatory power of the equations, while introducing this spread to equations that use Brent as the independent variable does not significantly improve the explanatory power" (p. 8).

These results provide evidence that Brent crude oil prices are more important than WTI prices in determining U.S. gasoline prices. The recent debate about relaxing U.S. export restrictions on crude oil and the potential impact on U.S. gasoline prices therefore revolves around whether an increase in the global supply of oil would reduce global oil prices (reflected in the Brent price), which the EIA's analysis suggests could lead to a decrease in domestic spot gasoline prices. This same conclusion has been drawn by others, such as the private consultancy IHS (2014), which in a recent study of oil markets concludes that:

> "The shift of the U.S. crude market to free trade will have the effect of lowering U.S. gasoline prices. That is because as new crude supply is added to the global market the international price of crude will fall, putting downward pressure on U.S. gasoline prices. At the same time, free export of U.S. crude oil would actually increase domestic crude prices, which will rise to meet higher international price levels, generating additional U.S. output and adding to international crude supply" (p. IV-24).[15]

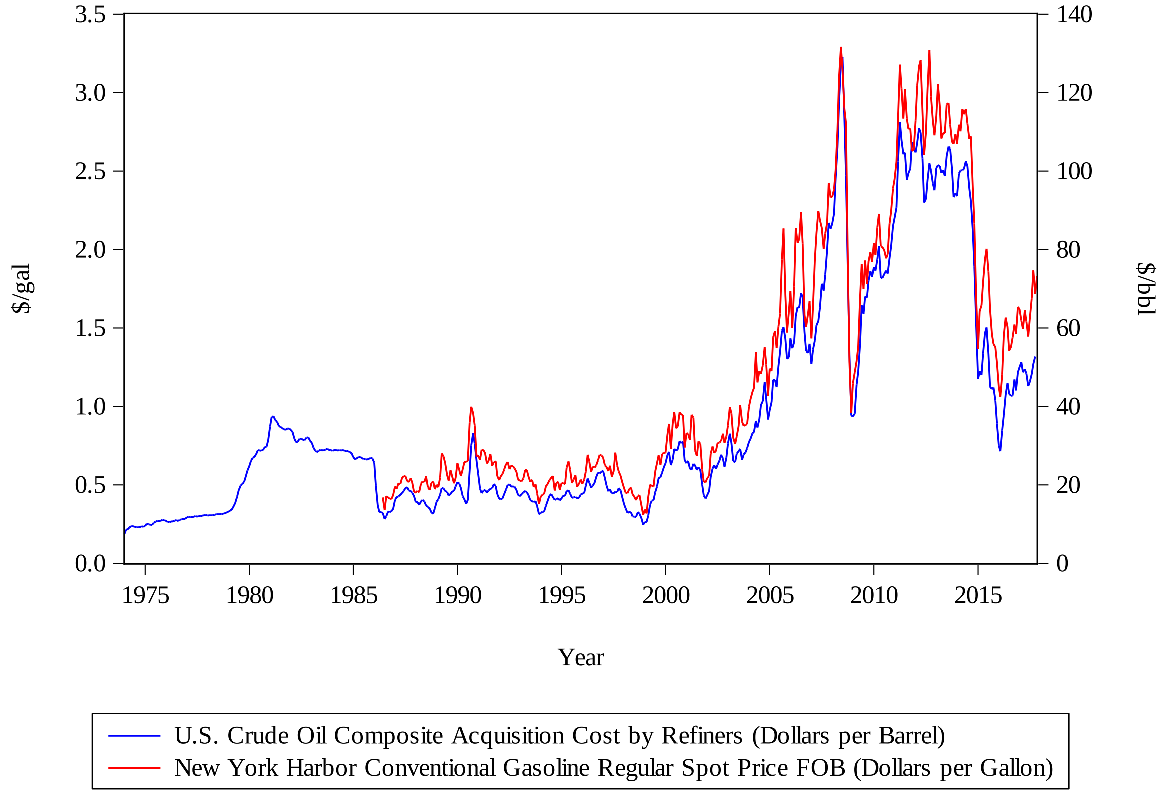
In a related study, Borenstein and Kellogg (2014) examine why low crude prices in Petroleum Administration for Defense District (PADD) 2 did not affect PADD 2 gasoline and diesel prices. The authors conclude from their empirical results that this happened partly because refiners in the Midwest were operating at or near capacity, that there was no buildup of refined product inventory despite the buildup of oil inventory, and that the Midwest was a net importer of refined products from the Gulf Coast. The implications are that the marginal gallon of refined product in the Midwest during the period studied was imported and that the cost of producing it was based on a different and higher oil price from the then-existing WTI price. If the price of the

[15] IHS Energy (2014), U.S. crude oil export decision: Assessing the impact of the export ban and free trade on the U.S. economy, IHS Energy / IHS Economics Report.

marginal barrel of oil refined in Gulf Coast refineries during the sample period accurately reflected the world price of oil, and if the Brent price largely represented that world price, then this study's conclusions would be consistent with the EIA study's statistical analysis.

Not all agree that Brent is the best benchmark (Pirrong, 2010; Purvin and Gertz, 2010). Fattouh (2011) suggests that neither the WTI nor the Brent price is the best, and Baumeister et al. (2018) state that "U.S. traders have switched toward benchmarking a weighted average of WTI and Brent prices" (p. 16). They suggest using the refiners' acquisition cost as a benchmark because it would reflect transportation costs. Figure 4 presents a plot of refiners' acquisition cost and gasoline prices. Refiners' acquisition costs are available from the EIA on a monthly basis but are not the focus in most empirical studies. A recent study by Mann and Sephton (2016) examines the time-series dynamics of the WTI, Brent, and Oman spot prices. The authors conclude that when there is a disruption in oil prices all three series move to restore a long run relationship between the three series in at least one regime for both pairings suggesting there is no global benchmark for crude oil.

Figure 4
Refiners Acquisition Cost and the Spot Price of Gasoline



Source: U.S. Energy Information Administration

Although numerous papers have examined the relation between oil prices and petroleum product prices, they typically focus on only one oil price and do not attempt to contrast the influence of the Brent price over the WTI price. Typically, studies of U.S. petroleum product prices, such as gasoline, use the WTI oil price as the base input, whereas studies of product prices in Europe use the Brent price.

We next turn to a companion issue that continues to be debated in the literature: Do gasoline prices respond differently to increases versus decreases in oil prices?

3. Asymmetric responses of product prices to oil price changes

3.1. Overview

An offshoot of the literature concluding that changes in oil prices drive changes in product prices goes a step further and examines the companion question of whether gasoline prices (and petroleum product prices) respond faster and/or more completely to increases than to decreases in the crude oil price. Bacon (1991) first coined the phrase "rockets and feathers" to describe this phenomenon in his study of the response of U.K. gasoline prices to changes in oil prices. The question has attracted much attention because of the conjecture that a delayed response to a decrease in oil prices could be evidence of collusive behavior, which would of course be of interest to regulatory bodies. The primary question is whether gasoline prices respond faster and more fully to positive changes in oil prices while responding more slowly and less fully to decreases in gasoline prices. Nevertheless, a number of papers addressing the asymmetric response question do not focus on prices per se but on the difference between the oil and gasoline price, a margin, principally in an attempt to test whether collusive behavior or predatory pricing are at work to preserve high profit margins.

Several authors have surveyed this literature, including Geweke (2004), Radchenko (2005b), Grasso and Manera (2007), Eckert (2013), and Owyang and Vermann (2014). Although many of the papers addressing this topic conclude that product prices (largely focusing on retail and spot gasoline prices) respond in an asymmetric fashion to oil price changes, not all reach this conclusion. Grasso and Manera (2007) survey 23 studies based upon U.S. and OECD country data and find that 16 of the 23 studies report evidence consistent with asymmetric price adjustments. Perdiguero-García (2013) also examines studies in this area and concludes that out of roughly 400 reported tests, about 60% suggest that product prices exhibit asymmetric price adjustment to oil price changes.

Studies of whether petroleum product prices respond asymmetrically to oil price changes do not all reach the same conclusion, and the conclusions are often related to the country of origin for the data examined (see for example, Venditti, 2013). In addition, Bagnai and Ospina (2018), using monthly retail prices, and Fosten (2012), using weekly retail prices, find evidence that gasoline prices respond asymmetrically to changes in oil prices but that the relation may have changed over time.

Studies conducted in the early 1990s involved only *empirical* tests of whether petroleum product prices responded asymmetrically to oil price changes. Starting around 1997, those studies were followed by the development of economic hypotheses designed to answer the question of why the phenomenon might be observed, which were then subjected to testing. We begin by first highlighting the principle hypotheses that have been offered in the literature for why an asymmetric response might be observed.

3.2. Hypotheses regarding an asymmetric response

Several alternative hypotheses have been offered for why an asymmetric price response might be observed. One argument is that the response is due to limited inventory. Borenstein et al. (1997) suggested that an unexpected decrease in demand causes firms to cut production and sell from inventory, resulting in the need for only a small decrease in price initially. However, an unexpected increase in demand cannot be met quickly from production or inventory (because of its limited size), so an increase in prices is used to dampen down the demand increase.

Borenstein et al. (1997) also offer an alternative explanation. Assume that firms have imperfect knowledge about rival firms' prices and costs and are cautious about giving misleading signals about their own intentions. When oil prices fall, the existing product prices (say gasoline prices), established before the decrease in oil costs, become what they refer to as a focal point for any subsequent price changes. Some have referred to this hypothesis as "focal price collusion" (see also Lewis, 2011). This hypothesis suggests that firms will be reluctant to cut prices to avoid sending the signal to rivals that they are commencing a price war to capture market share. A firm in this setting will reduce its price only if there is a significant drop in sales, indicating that other firms are themselves cutting prices. Product prices will tend to stay near the original pre-drop price even though oil prices are falling. Alternatively, if oil prices increase (i.e., costs increase), the event will result in an immediate price increase response, because this would not be interpreted by rivals as indicative of a price war and margins would decrease otherwise.

Borenstein and Shepard (2002) present a model that includes both costly adjustment of production and costly inventories. They show that wholesale gasoline prices respond with a lag to crude oil cost shocks and that futures prices for gasoline adjust incompletely to crude oil price shocks.

A third alternative offered by Borenstein et al. (1997) and Johnson (2002) is that, because of price dispersion and the volatility of oil prices and retail prices, consumers have difficulty assessing the options available in the market. In other words, consumers encounter search costs. The authors posit that when prices rise, consumers tend to search for sellers with lower prices, thus putting demand pressure on rivals to adjust prices. When prices fall, consumers devote less effort to searching, which allows firms to temporarily capture a greater margin by not reducing prices as fast as costs. Lewis (2011), Tappata (2009), and Yang and Ye (2008) develop models in which search leads to asymmetric price adjustments. For instance, in Yang and Ye's (2008) model, consumers are characterized by differential search costs, and search intensity is determined endogenously. When a positive shock affects a producer's input cost (say, the price of oil), all searchers immediately learn the true state, leading to a full adjustment in the output price in the next period. When a negative shock to the input price occurs, it takes longer for learning to occur, and the search intensity increases gradually, leading prices to fall slowly.

Noel (2007, 2009) suggests that the phenomenon may be due to price cycles brought on by price wars. He draws this conclusion based on price wars between retail stations in Canadian cities. The idea is that on the downward part of a price cycle, stations reduce prices by small amounts in order to increase market share. When the price reaches marginal cost, each firm considers raising its price substantially. When one does raise its price, the others follow, taking price quickly to a peak, after which the undercutting begins again. This asymmetric response is driven not by changes in costs but rather by the attempt to increase profits.

A final hypothesis is that the process of adjusting prices involves incurring costs, and if these costs are large, firms will not wish to change prices too often. As firms wait to adjust their prices, a lag between an initial oil price change and the resulting product price change can result.

3.3. Econometric methods

Statistical models used in the evaluation of asymmetric price responses of petroleum products to oil price changes have taken several forms (Geweke, 2004; Frey and Manera, 2007; Grasso and Manera, 2007; Venditti, 2013). However, the literature has generally converged on the use of an error correction model (ECM) structure that includes lagged changes in oil prices, sometimes allowing for a conditional autoregressive error process.[16]

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[16] See Bollerslev, T. (2009). Glossary to ARCH (GARCH) at http://econ.duke.edu/~boller/Papers/glossary_arch.pdf) for a review of ARCH- and GARCH-type models.

The extant approach to testing for asymmetric responses is the estimation of a model structured to account for 1) a long-term relation between the product price and the oil price, 2) a partial adjustment process to correct deviations from the long-term relation, and 3) short-term lagged relations. The model is then modified to separate oil price changes into positive changes and negative changes. For convenience, we will sometimes refer to the generic form of this model as the Asymmetric ECM. An illustrative approach is described next.

Assume that the long-term relation between the product price at time t (y_t) and the price of oil (x_t) is given by

$$y_t = \beta_0 + \beta_1 x_t \quad . \tag{1}$$

The intercept (β_0) represents the markup of the product price over the oil price. Additional control variables may be needed if the intercept is expected to change over time or to vary between cross-sectional observations (for example, if the study is "across" service stations with different characteristics). If costs are fully passed through, then the value of the coefficient linking the oil price to the product price (β_1) should be close to 1.

To test whether product prices fully and instantaneously adjust to changes in oil prices, lags of changes in the oil price are introduced, giving rise to a single-equation ECM. A simple version of the model is illustrated by equation (2),

$$\Delta y_t = \varphi \Delta x_t - \gamma (y_{t-1} - \beta_0 - \beta_1 x_{t-1}) + \varepsilon_t . \tag{2}$$

In equation (2), product price changes arise due to 1) deviations from the long-term equilibrium conditional on the adjustment coefficient (γ), and 2) recent changes in oil prices, coefficient (φ). Of course, the empirical specification of the model may include multiple lags of the change in oil prices.

Asymmetry of price changes is usually introduced by segmenting the oil price changes and the deviations from long-term equilibrium into cases where the changes or the deviations are positive and those where they are negative. Such a modification to equation (2) could take the form shown as equation (3),

$$\Delta y_t = \varphi^+ (\Delta x_t)^+ + \gamma^+ (y_{t-1} - \beta_0 - \beta_1 x_{t-1})^+$$

$$+\varphi^- (\Delta x_t)^- + \gamma^- (y_{t-1} - \beta_0 - \beta_1 x_{t-1})^- \ . \qquad (3)$$

The superscript (+) indicates that the associated variable takes the actual value if positive and is zero otherwise; the converse is true for the superscript (–). This differentiates the positive shocks from the negative shocks.

The null hypothesis that the product price responds symmetrically (that is, it responds the same to a change or deviation of the same absolute magnitude, whether positive or negative) implies the restrictions:

$$\varphi^+ = \varphi^- \text{ and } \gamma^+ = \gamma^- . \qquad (4)$$

A Wald test is typically used to test the null hypothesis.

How one estimates equation (3) depends on whether the price variables are stationary. When they are not stationary but are cointegrated, alternative estimation methods must be followed.

Oil prices and petroleum product prices are generally found to be nonstationary in most of the empirical studies we reviewed (that is, these series exhibit a unit root). If the product price and oil price both exhibit a unit root but are cointegrated (that is, a linear combination of the two prices is stationary), then the estimation methods proposed by Engle and Granger (1987) can be employed. Basic steps in estimating and testing the asymmetric response hypothesis involve the following:

1. Regress y_t on x_t (estimate equation (1)) and compute the residuals $(\hat{u}_t)$ from this estimation.
2. Test whether the estimated errors exhibit a unit root. If the series are cointegrated, replace the long-term deviation terms in equation (3) (the terms $(y_{t-1}-\beta_0-\beta_1 x_{t-1})^+, (y_{t-1}-\beta_0-\beta_1 x_{t-1})^-$) with the estimated values $(\hat{u}_{t-1})$, distinguishing between positive and negative residuals.
3. Estimate the linear model to obtain estimates of the four parameters φ^+, φ^-, γ^+, and γ^-.
4. Compute the Wald test statistic for the null hypothesis $\varphi^+ = \varphi^-$ and $\gamma^+ = \gamma^-$.

Geweke (2004), Frey and Manera (2007), and Grasso and Manera (2007) present catalogs of the alternative econometric (dynamic) models that have been employed in the literature, but the approach just described has been used frequently. Three model specifications stand out in the literature: the asymmetric error correction model (AsyECM, described above); the error correction model with threshold cointegration (TAR); and TAR's alternative, the momentum threshold model (MTAR).[17] These models account for cointegration and allow tests for both long-term and short-term responses. Some authors have also estimated specifications that account for GARCH-type error processes. Alternative formulations of the model within a nonlinear autoregressive distributed lag (NARDL) framework have also been employed (Bagnai and Ospina, 2018; Fosten,

[17] For development of the asymmetric error correction model, see Granger and Lee (1989); for a discussion of the TAR and MTAR models, see Enders and Granger (1998) and Enders and Siklos (2001).

2012; Atil et al., 2014). It can be shown, however, that the NARDL model can be equivalently expressed as an AsyECM.

An important alternative to the test described above stems from work done on the response of general economic activity to oil price changes. Kilian and Vigfusson (2011a, 2011b) examine the econometric issue of testing whether economic activity responds asymmetrically to positive and negative oil price shocks. Econometrically, the issues are the same as those faced in tests of asymmetric petroleum price responses to oil price changes. Kilian and Vigfusson (2011a, 2011b) argue that traditional tests for asymmetric response, such as those described above, are weak because of a threshold nonlinearity in the regression. They suggest that a structural model of the transmission of oil price shocks should be used in conjunction with examination of the impulse response function (IRF) that corresponds to a positive or negative shock to oil prices. These authors propose a test of the equivalence of IRF for positive and negative shocks. However, they do not provide evidence regarding the test's power to reject the null when it is false. Venditti (2013), discussed in the next section, implements Kilian and Vigfusson's (2011a, 2011b) methods in tests of asymmetric response of gasoline prices to oil price changes. Hamilton (2011) has argued that structural models impose unnecessary restrictions on the contemporaneous relationship between oil prices and other variables, and that if asymmetries are significant, reduced-form models should be able to detect them. Unsurprisingly, the majority of papers written on this topic have used an approach similar in nature to equation (3) and the Wald test described earlier.

3.4. Empirical evidence on asymmetric responses

Because this literature is vast, we highlight only a few select studies, in particular two that challenge the view that gasoline prices respond in an asymmetric fashion. Published studies differ along several dimensions: 1) the country being investigated; 2) the level of aggregation, such as cities (Borenstein et al., 1997; Eckert, 2002; Chesnes, 2016), states (Deltas, 2008), and countries (Galeotti et al., 2003); 3) the sample period and the frequency of the price observations; 4) the stage of the transmission (i.e., whether the analysis is between oil prices and spot gasoline prices or retail prices, oil prices and spot prices, or spot prices and retail prices); and 5) the statistical model estimated as part of the analysis. An important element is the structure of the dynamic econometric model employed, which tends to vary across studies.

Geweke (2004) reviews the statistical models that have been employed. Grasso and Manera (2007) explore the sensitivity of the empirical conclusions on asymmetric price responses to three popular models that have been used in the literature using a common set of data. The models estimated are the asymmetric ECM, described earlier, the threshold autoregressive ECM, and ECM with threshold cointegration. The threshold autoregressive ECM is akin to estimating equation (2) with a dummy interaction variable that takes the value 1 if the fuel price exceeds a specified threshold. The ECM with threshold cointegration accounts for the error introduced when the long-term relation is above or below a threshold. The authors estimate each model using monthly gasoline price data from France, Germany, Italy, Spain, and the U.K. for the period 1985–2003 and find that each of the models captures a lag in the reaction of retail prices to changes in spot wholesale gasoline and crude oil prices, as well as some evidence of asymmetric behavior. However, the type of market and the number of countries that are characterized by asymmetric oil–gasoline price relations vary across models.

Perdiguero-García (2013) addresses the heterogeneity issue by analyzing how the fundamental characteristics of the study (the points mentioned above, which tend to differ across studies) are related to the conclusion that an asymmetric price adjustment is found. Examining 403 different results about the response of gasoline prices to oil price changes, he finds that roughly

60% report that asymmetry exists. He follows Frey and Manera (2007) in defining types of asymmetries, including a contemporaneous impact, a distributed lag effect, a cumulative impact effect, the reaction time, and an adjustment due to deviations from the equilibrium long-term relation (as described for the simple model illustrated earlier). Perdiguero-García (2013) tests whether the conclusion of asymmetry is related to the type of asymmetry examined, to the type of dynamic model estimated (error correction, autoregressive distributed lag, partial adjustment models, or regime switching models), and to whether a multivariate model is employed (vector autoregression, vector error correction). Most of the studies use a single-equation ECM. He accounts for the country, the length of the sample period, the frequency of the data measurements, and the stage of transmission (crude-spot, crude-wholesale (rack), spot-wholesale (rack), spot-retail, crude-retail, and wholesale-retail), but does not control for the benchmark, whether WTI or Brent or an alternative. Because the sample studies examine both gasoline and diesel fuel price responses, he also controls for this fact, although roughly 96% of the studies examine gasoline price data.

Several results emerge from Perdiguero-García's work (2013). The results presented in the papers he examined indicate that asymmetric price adjustment is less likely when monthly data are examined. This is perhaps not a surprise. Kilian (2010) shows that monthly data may hide asymmetries, as also emphasized by Bachmeier and Griffin (2003) and Bettendorf et al. (2003).[18] The type of basic model is not a discriminating factor, but asymmetry is less likely if the model

[18] Balaguer and Ripollés (2016) report (in their Table 1) that the half-life response of retail gasoline prices to oil prices changes for a representative set of studies that employ data measured at either a daily or a weekly frequency, varying from 2.2 weeks to 17.73, but these results vary across countries as well as across model specifications. The authors conclude: "Nevertheless, considering that fuel stations in the investigated markets are completely free to adjust their prices daily after frequent oil price shocks, these empirical results seem rather surprising" (p. 282), suggesting that aggregation issues as well as model specification issues may be problematic.

employed includes a feature controlling for regime changes. Similarly, the result is less likely the longer the sample period studied. Perdiguero-García also reports some evidence that the use of more micro-level data may be important, but this seems to depend upon the model employed.[19]

Godby et al. (2000) empirically explore the behavior of gasoline and oil prices and suggest that only oil price changes that are larger than some threshold level lead to a revision of gasoline prices. Similar results were obtained by Radchenko (2005a), who points to possible nonlinearities in retail gasoline prices and the role that different kinds of oil price fluctuations play in the gasoline price response.

Borenstein et al. (1997) and Chen et al. (2005) also estimate models that account for thresholds in the error-correction term. For instance, in Chen et al. (2005), there are two regimes that are distinguished by whether the error correction term is positive or negative. Borenstein et al. and Chen et al. both find evidence of asymmetric response. Douglas (2010) extends the model to incorporate multiple regimes determined by estimation. In contrast to the two-regime model (see equation (3) for a simple form), he posits that the data are driven by a model in which the retail price response to a change in the input price can be different across multiple regimes. This allows him to test the asymmetric response conclusion's sensitivity to the two-regime case. Based on the response of weekly U.S. retail gasoline price data to changes in the New York Harbor Conventional Gasoline Regular Spot Price for the period 1990-2008, his data suggest that the model should allow four different regimes. He finds little evidence of asymmetry for the vast majority of the observations he studies and concludes that the asymmetry is being driven by a small number of outlying observations.

[19] Frey and Manera (2007) perform a similar analysis but use the F statistics for the tests of the asymmetry coefficients. The sample is small, however, and spans studies in agricultural, alimentary, and gasoline markets.

In a further challenge, Venditti (2013) uses the impulse-response test described earlier, as proposed by Kilian and Vigfusson (2011a, 2011b), to reexamine the question of whether fuel prices respond asymmetrically to oil price changes. The author examines weekly gasoline and gasoil prices and oil prices for the United States, the euro area, and the four largest euro-area countries (Germany, France, Italy, and Spain) for the period January 1999 to September 2009 as well as WTI prices for the United States and Brent prices for Europe. Retail as well as wholesale fuel prices are examined. The author points out that "The wedge between the spot price of crude oil and retail prices accounts for refining and shipping costs, distribution costs and margins, while the difference between wholesale and retail prices includes only distribution costs and margins" (p. 469). He also tests for asymmetry in response using the ECM framework as described above. Based on the traditional asymmetric ECM approach, the author finds evidence that U.S. retail prices adjust asymmetrically to changes in both spot oil prices as well as wholesale fuel prices, but only weak evidence for the European countries. Based on the Kilian and Vigfusson (2011a, 2011b) impulse-response test, evidence of an asymmetric response depends upon the product. Tests of the IRF for a shock (positive or negative) of one or two standard deviations present no evidence of an asymmetric response in retail gasoline prices for the United States or any of the European countries. In contrast, this is not true for gasoil in the United States. Nor is it true for the impacts of shocks to wholesale prices of gasoline or gasoil on retail gasoline and gasoil prices, both of which show an asymmetric response in retail prices for the United States. Both approaches point to the presence of asymmetries in the adjustment of retail prices, although for the euro area the evidence is mixed.

Ederington et al. (2018c) extend the analysis to an examination of changes in futures prices for petroleum products and changes in futures prices for oil. Test results favor the MTAR specification for the data they examine. Focusing on daily price data, the authors find evidence of an asymmetric response of gasoline futures prices to deviations in the long-term relation between those prices and oil futures prices (Brent) and to short-term negative versus positive changes in oil prices. As part of the analysis, they examine this behavior both during the period leading up to the end of 2005, the approximate date when many believe oil futures began to be viewed as an important portfolio asset for investors, and in the period after that through early 2016. Although an asymmetric response is found overall and during the two subperiods for a gasoline price model, a model relating heating oil futures prices to oil futures prices provides mixed evidence, and no support for the asymmetric response hypothesis during the second subperiod.

Bagnai and Ospina (2018), using monthly retail prices, and Fosten (2012), using weekly retail prices, find evidence that gasoline prices respond asymmetrically to oil price changes and that the relation may have changed over time. The authors estimate a general NARDL model allowing for asymmetric short- and long-term responses.[20] Fosten (2012) presents evidence suggesting that an asymmetric response behavior emerged only after the economic shock of 2008, and this conclusion is also supported by the results presented by Bagnai and Ospina (2018).

3.5. Long-term and short-term effects of oil price shocks

Radchenko (2005a) tests how the asymmetric price response differs between what he terms oil price shocks that have a long-term impact versus a short-term impact. Using weekly retail U.S. gasoline prices and WTI oil prices for the period March 1991 to August 2002, he estimates how retail U.S. gasoline prices respond to changes in crude oil and spot gasoline prices. The new element of his model is that he allows for two types of cost shocks to the gasoline market: long-

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[20] See Atil et al. (2014), who also examine monthly price data and find no long-term effect but do find a short-term effect.

term and short-term shocks. Controlling for the change in gasoline inventory and also for a shift in the federal gasoline tax,[21] he concludes that approximately 97% of changes in crude oil prices are viewed as short-term and that this may be the driving factor for lags in the response of retail gasoline prices.

3.6. Conditional effects

Extending the analysis of the asymmetric price response of gasoline prices to oil price changes, Radchenko (2005b) studies the effect of volatility in oil prices on the degree of asymmetry in the response of gasoline prices to oil price increases and decreases. He constructs several time series measures of the asymmetry between the responses of gasoline prices to oil price changes and several measures of oil price volatility. He finds that the degree of asymmetry in gasoline prices declines with an increase in oil price volatility. He thenargues that these results are more consistent with the view that oligopolistic coordination is an explanation for the observed asymmetry than other explanations.

Analyzing monthly data on the U.S. petroleum market for the period of January 1986 to December 2002, Kaufmann and Laskowski (2005) estimate the asymmetric ECM model described above. They find that when refinery utilization rates and the level of stocks are included in the model, the asymmetry between the price of crude oil and gasoline vanishes. However, when they estimate the same model for heating oil, they find asymmetries.

Kuper (2012) presents evidence suggesting that asymmetry in gasoline price dynamics is caused by changes in the net marginal convenience yield. Based upon the structural inventory model of Pindyck (2004), in which the convenience yield is related to volatility, he concludes that

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[21] The break date for the federal tax change cited by the author appears to be a typo, as the year is incorrect. It is not clear how this might have affected the results.

higher costs of marketing and storage lead to rising gasoline prices, whereas a drop in these costs lowers gasoline prices. In Pindyck's model, the optimal response by the refiner is either to adjust production to the shock to input price (the oil price) or to absorb the shock in inventory changes. The optimal response depends upon whether there are adjustment costs or a convenience yield. The author reasons that a lagged price adjustment in the short-term therefore requires sticky production and a net marginal convenience yield that decreases if the level of inventory increases. Kuper (2012) modifies a version of the sample model described earlier to include independently estimated lagged values of the net "market" convenience yield, computed using the standard no-arbitrage condition between spot prices and futures prices, and also includes a lagged change in the net convenience yield. The model is also structured to account for asymmetric behavior in the error variance. The author finds no evidence of an asymmetric response of gasoline price changes to oil price changes. However, he does find an asymmetric response of gasoline prices to the lagged change in the net marginal convenience yield as well as the lagged level of the net convenience yield on gasoline prices. The estimation results show that the effect is asymmetric; a higher net marginal convenience yield leads to lower gasoline price responses, whereas a lower net marginal convenience yield increases gasoline prices. The latter effect is greater, and the difference is significant. If the convenience yield is positively related to volatility, then these results are consistent with the findings of Radchenko (2005b) previously mentioned.

3.7. Station-level data and tests of the economic hypotheses

Most studies of an asymmetric gasoline price response are long on statistical verification of the phenomena but short on direct tests of the economic hypotheses mentioned earlier. Several studies have used station-level data under the assumption that locational and other advantages potentially provide an avenue for testing whether the asymmetric response is influenced by market power or costly consumer search.

Deltas (2008) finds that states with higher average seller margins on gasoline (the inference being that this implies fewer sellers) had a more asymmetric response and a slower speed of adjustment, consistent with a market power argument.

Studying weekly station prices for a geographically contiguous group of nearly 100 stations in California between July 2002 and May 2003, Verlinda (2008) concludes that stations with greater market power exhibited greater price response asymmetry.

Hosken et al. (2008) study weekly data for a panel of 272 stations over a three-year period in the Northern Virginia suburbs of Washington, DC. They conclude that, although the data they study are consistent with asymmetric pricing, the stations did not consistently pursue "rockets and feathers" pricing.

Chesnes (2016) conducted a micro-level study looking for evidence of asymmetric pass-through of oil price changes in the gasoline market in 27 cities. He concludes that asymmetry was present but that the type of fuel used in each city was important for determining the magnitude of the asymmetry. Specifically, cities selling predominantly conventional gasoline were less asymmetric in adjusting than cities where reformulated gasoline was sold.

Lewis (2011) develops a model in which consumers search based upon whether the expected value of finding a lower price than just observed exceeds their search cost. He develops two results. "For a given level of consumers' expectations: (1) equilibrium prices increase more quickly with wholesale cost as costs rise relative to expectations, and (2) prices exhibit less dispersion as wholesale costs rise relative to expectations" (p. 423). He tests predictions of the model using gas station level weekly price data, as well as testing the "focal price collusion" hypothesis. His results favor the search cost model.

Remer (2012) studies daily price data for more than 11,000 retail gasoline stations for a set of U.S. states (Maryland, New Jersey, Philadelphia, Virginia, Washington, and Washington, DC) over a single year from July 2008 to July 2009 and presents several results of interest. First, he finds that independent brand retailers charge lower prices than the major company stations, consistent with results found by Eckert and West (2004) and Hosken et al. (2008). Second, he shows that prices increase as the distance to the closest competitor increases, consistent with a market power thesis. However, he finds conversely that prices decrease as the number of competing stations that are not major brands increases. Remer's tests are based on equation (3), accounting for multiple lags as suggested in Borenstein et al. (1997). He also controls for a number of additional factors, including the number of stations within a geographic area surrounding the station of interest, whether the station is an independent brand, the number of independent brand competitors within a given geographic area, population size, firm fixed effects, and day-of-the-week effects. He tests two predictions of the search models of Yang and Ye (2008) and Tappata (2009) and concludes that his tests support the consumer search hypothesis.

Balaguer and Ripollés (2016) study daily retail price adjustments for a panel of service stations in Spain for the period June 2010 through November 2012. They examine two metropolitan areas with 283 and 185 stations respectively. The authors focus on retail prices' response to changes in wholesale prices. The authors employ panel estimation methods developed by Pesaran and Smith (1995) that account for heterogeneity across cross-sectional units. The results provide new evidence on the issue of aggregation. The authors conclude that:

"The null hypothesis of symmetry cannot be supported when data for micro units are used. More specifically, our results suggested the existence of the "rockets and feathers" phenomenon basically for the first week after a shock. However, after aggregation of our individual time series, we obtained no evidence of this phenomenon although the number of observations available was still within the standard for this type of study. This could explain why sometimes the presence of "rockets and feathers" has not been unambiguously concluded, even though it could actually be relevant. Hence, panel data information not only allows us to consider behavioral heterogeneity, but it also provides more degrees of freedom and sample variability to improve the efficiency of the corresponding estimates" (p. 289).

4. Summary

We review the evidence regarding the relation of petroleum product prices to wholesale spot prices and oil prices and the ways that product prices respond to wholesale fuel prices and oil price changes.Studies of the link between petroleum product prices and oil prices predominantly find evidence that the causal path flows from crude oil prices to product prices. However, there is limited evidence that the prices of petroleum products influence oil prices. Most studies pair petroleum prices in the United States with the WTI oil price and petroleum prices observed outside the United States (largely Western Europe) with the Brent oil price.

Comprehensive studies of gasoline price determinants find that virtually all variation in national gasoline prices over time is due to changes in the crude oil price and cyclical fluctuations, not to changes in taxes, content requirements, or other factors. The primary determinants of price differentials across states are taxes, population density, and age distribution of a state's population.

The proposition that world oil prices are the primary drivers of U.S. gasoline prices is supported by evidence from studies that account for inventory effects and that use the Brent price rather than the WTI price as the world proxy. The support for this proposition comes from tests of the direct empirical relation as well as indirect evidence from an analysis of differential effects across U.S. PADD regions.

Related to the preceding point, considerable attention has been given to the question of the size and speed of adjustment of petroleum product prices, principally gasoline prices (spot as well as retail) to increases versus decreases in oil prices. The evidence is mixed, but many studies focusing on gasoline prices find faster adjustment to increasing oil prices and slower adjustment to declining oil prices, often referred to as the “rockets and feathers” asymmetric response phenomenon. However, some studies find that the response is symmetric. These studies vary along numerous dimensions, including data measurement frequency, model specification, country from which the data are gathered, whether the data are measured at the retail or wholesale level, and which benchmark oil price is employed.

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