Long-Run and Short-Run Relationships between Petroleum, Ethanol, and Natural Gas Prices

By

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Abstract:

We provide new econometric evidence on relationships between petroleum prices and natural gas prices. A novel aspect of our approach is application of a permanent-transitory (P-T) decomposition to separate shocks into permanent effects due to long-run changes in underlying economic fundamentals, versus transitory shocks representing short-run temporary deviations from long-run equilibrium. We find important long-run equilibrium relationships between gasoline, diesel, and ethanol prices but not between any of these and natural gas prices. Results are consistent with limited ability to substitute between natural gas and petroleum energy sources over long time horizons. The short-run response of natural gas prices to transitory shocks originating in the petroleum and biofuel sectors are also minimal and die out quickly. This suggests limited scope for substitutability across natural gas and petroleum in the short run as well. Ethanol prices are little influenced by natural gas prices but much more influenced by changes taking place in the petroleum and biofuel sectors. The implication is that that prices received by ethanol refiners will be driven primarily by petroleum price movements rather than changes in the price of natural gas or of biofuel feedstocks.

Keywords: cointegration, ethanol prices, natural gas prices, permanent-transitory decomposition, petroleum prices

JEL Codes: Q04, Q11, O13

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1. Introduction

Petroleum products such as gasoline and diesel are refined from crude oil, ethanol is a biofuel produced primarily from corn in the U.S, and natural gas is a hydrocarbon-based fuel like crude oil but is a gas at normal temperatures. Each of these energy sources has different origins, production processes, and supply chains; and each has comparative advantages in different end uses. Petroleum products and ethanol are used primarily for transportation while natural gas is used for heating, electricity generation, and various manufacturing uses. Because of these differences, each of these energy sources has different supply and demand conditions that may cause their prices to fluctuate away from one another. Yet there are also important linkages across the markets for these products as well, and these linkages could lead their prices to be connected in important ways. Ethanol is used as a gasoline additive and is subject to a blend wall that restricts how much can be blended with gasoline. Gasoline and diesel are both refined from crude oil and so production can switch more easily from one to the other. The supply chains for petroleum products and natural gas are largely separate but there is at least some potential for substitutability on the demand side. For example, electricity generation plants have some capability to switch between natural gas and residual fuel oil (a petroleum based product); major transportation companies (e.g., truck fleets, taxi fleets, and municipal bus lines) can switch to natural gas-powered vehicles; and consumers can purchase electric-powered vehicles. There may also be connections between ethanol and natural gas prices because the demand for corn generates a derived demand for fertilizer, much of which is produced using natural gas.

The degree of substitutability in both production and consumption between these alternative energy sources should be a major determinant of price linkages. Therefore, studying the nature and extent of linkages between these prices provides useful insights into the extent of substitutability and the degree to which prices of different energy sources can be expected to equilibrate with each other over time. In particular, an understanding of the dynamic relationships between petroleum prices, ethanol prices and natural gas prices may help predict ethanol price changes and explain how ethanol prices will respond to shocks in the petroleum and natural gas markets. In turn, this will have important implications for biofuel policies and the future demand for agricultural feedstocks used in biofuel production.

A number of existing studies have examined the relationship between crude oil prices and natural gas prices (e.g., Villar and Joutz, 2006; Brown and Yücel, 2008; Hartley, Medlock III and Rosthal, 2008; and Ramberg and Parsons, 2012). These studies have generally found some evidence of a long-run equilibrium relationship between crude oil and natural gas prices, but there are conflicting views on the strength of the relationship and whether it is stable over time. Furthermore, none of these studies have included either ethanol prices or refined petroleum product prices in the analysis and so may be missing important insights, particularly regarding the role of ethanol prices given expanding biofuel production. Some of these studies are also becoming dated and do not include data since 2010 when there appears to have been a major downward shift in natural gas prices relative to petroleum prices (Figure 1).

In this paper we provide new econometric evidence on the relationships between petroleum prices and natural gas prices. However, we expand the analysis by incorporating ethanol prices and the prices of refined petroleum products (gasoline and diesel). We also incorporate more recent data that includes the 2010-2014 period in which natural gas prices appear to have deviated from previously observed relationships with petroleum products. A novel aspect of our approach is that we use a permanent-transitory (P-T) decomposition to separate shocks into permanent effects due to long-run changes in underlying economic fundamentals, versus transitory shocks that represent only short-run temporary deviations from long-run equilibrium relationships. We find that the P-T decomposition provides some interesting new insights into the long-run and short-run relationships between petroleum, ethanol, and natural gas prices.

2. The Relationship between Petroleum, Ethanol, and Natural Gas Prices

If different fuels were perfectly substitutable we might expect their price per Btu to follow each other closely. Figure 1 shows U.S. prices per million Btus for gasoline, ethanol, and natural gas over the January 1990 through June 2014 period.[1] The figure shows that price/Btu for natural gas was lower than for gasoline over almost the entire sample, but the two prices diverge markedly starting in 2006 when natural gas prices began to fall relative to gasoline prices. The two prices also exhibit considerable co-movement prior to 2006 but display little obvious connection afterwards, especially since 2009. The price per Btu for ethanol is considerably higher than for both gasoline and natural gas over the entire sample period, although it appears to have become closer to and more connected with the price per Btu of gasoline since 2006. Clearly, there are systematic divergences between prices per Btu for different fuels and these divergences persist over long time periods.

Of course, there clearly is not perfect substitutability between fuels and so there are good economic reasons why per Btu prices do not equate. Residual fuel oil and natural gas can be substituted for each other in electricity generation, but only up to a point--different fuels have different designated supply chains and end uses. Similarly, different fuels have different costs of extraction, storage, and transportation. For these reasons, any long-run equilibrium relationship between petroleum fuels and natural gas prices would be unlikely to match their energy content

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[1] Standard Btu conversion rates are used. Price per Btu for diesel follows gasoline price very closely and so is not shown on the graph.

equivalence exactly. An equilibrium relationship between per Btu prices of ethanol and gasoline may seem more likely since these are, on the surface, more easily substitutable. Despite its lower energy content compared to gasoline, however, ethanol is subject to production mandates and subsidies. Furthermore, substitution with gasoline is constrained by the blend wall restriction on how much ethanol can be included in gasoline mixtures. So any equilibrium relationship between ethanol and other fuel prices should not necessarily be expected to reflect underlying energy content exactly either.

Although petroleum, ethanol, and natural gas prices per Btu clearly do not equalize, this does not mean there is no relationship between these prices at all. In this study we take a broader econometric approach to identifying possible equilibrium relationships that may take forms other than simple energy equivalence.

3. Empirical Approach

Consider a vector of *n* log energy prices represented by $\mathbf{y}_t = (ln\,P_{1t}, ln\,P_{2t}, ..., ln\,P_{nt})$.[2] Details on variables and data sources included in the analysis are discussed in the next section. Here we focus on model structure, estimation, and identification procedures. To model $\mathbf{y}_t$ we want a flexible framework that can capture rich dynamic interactions between the included prices without imposing a lot of theoretical structure. However, we also want to allow any long-run equilibrium relationships between prices to be identified and estimated, and to characterize and evaluate both long-run and short-run relationships between different prices. A convenient framework that satisfies these needs is the vector error correction model (VEC):

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[2] Log transformations are commonly used in price modeling because they are consistent with the statistical properties of most price data and facilitate interpretation of coefficients in terms of proportional relationships between prices.

$$(1) \qquad \mathit{\Delta}\mathbf{y}_t = \boldsymbol{\mu} + \boldsymbol{\alpha}\,\mathbf{z}_{t-1} + \sum_{i=1}^{q} \boldsymbol{\Gamma}_i \mathit{\Delta}\mathbf{y}_{t-i} + \boldsymbol{\varepsilon}_t$$

where $\mathbf{z}_{t-1} = \boldsymbol{\beta}'\mathbf{y}_{t-1}$ is the (r x 1) vector of lagged equilibrium errors from $r \leq n-1$ unique cointegrating (long-run equilibrium) relationships between prices in the system; $\boldsymbol{\beta}$ contains the cointegrating vectors representing long-run equilibrium parameters characterizing long-run equilibrium relationships between prices; the $\boldsymbol{\mu}$, $\boldsymbol{\alpha}$, and $\boldsymbol{\Gamma}_i{}'$s are unknown parameters to be estimated, q is the lag order for the dynamics; and the VEC errors $\boldsymbol{\varepsilon}_t$ are serially uncorrelated but may be contemporaneously correlated. The advantages of the VEC representation for our application are that it is straightforward to estimate using Johansen's maximum likelihood methods, it treats all variables as endogenous, it allows for variables to be integrated of order one I(1) and possibly cointegrated (long-run equilibrium relationships), and it also allows for rich dynamics in the way that the prices interact with one another over time in both the long-run and the short run.

The VEC errors $\boldsymbol{\varepsilon}_t$ represent unpredictable shocks to the variables in the system but analyzing and interpreting the effects of these shocks is hampered because they are contemporaneously correlated and represent the joint effects of many different fundamental economic influences on prices. To provide a structural interpretation of the effects of different shocks we need to impose additional identification assumptions. The conventional way of solving this problem is to orthogonalize the shocks and impose a recursive ordering, leaving the dynamics of the system unrestricted. This approach to identification in VEC models is now standard and will not be discussed further here (see, for example, Hamilton 1994).

A disadvantage of the conventional recursive approach to identification for our purposes is that it produces orthogonalized structural shocks that remain mixtures of permanent and transitory effects. It is therefore incapable of decomposing shocks into those that have permanent effects and those that have transitory effects, thereby identifying separate long-run and short-run dynamic relationships between the prices. To overcome this problem we follow Gonzalo and Ng (2001) and impose an alternative identification scheme that separates $\boldsymbol{\varepsilon}_t$ into orthogonal permanent and transitory shocks. The dynamic effects of these permanent and transitory shocks can then be simulated to evaluate the effects of both permanent and transitory shocks on future price paths.

To motivate the alternative identification approach consider the matrix $\mathbf{G} = [\boldsymbol{\alpha}_{\perp}, \boldsymbol{\beta}]'$ where $\boldsymbol{\alpha}'_{\perp}$ (defined by $\boldsymbol{\alpha}'_{\perp}\boldsymbol{\alpha} = \boldsymbol{0}$) is the orthogonal complement of the speed of adjustment parameters $\boldsymbol{\alpha}$ from the VEC; and $\boldsymbol{\beta}'$ is the matrix of cointegrating vectors. Transforming the VEC model using ***G*** gives:

$$\text{(2)} \qquad \mathbf{G}\Delta\mathbf{y}_t = \mathbf{G}\boldsymbol{\mu} + \mathbf{G}\boldsymbol{\alpha}\,\mathbf{z}_{t-1} + \mathbf{G}\sum_{i=1}^{q}\boldsymbol{\Gamma}_i\Delta\mathbf{y}_{t-i} + \mathbf{G}\boldsymbol{\varepsilon}_t\ .$$

By construction, the first *n* – *r* rows of ***G*** eliminate the lagged equilibrium errors $\mathbf{z}_{t-1}$ from the first *n* – *r* equations, causing these equations to be specified in terms of differences only. Also by construction, the remaining *r* rows of ***G*** form I(0) linear combinations of the $\mathbf{y}_t$ vector at all lags, causing the remaining *r* equations to depend on stationary linear combinations only. The result is that the transformed errors $\mathbf{u}_t = \mathbf{G}\boldsymbol{\varepsilon}_t$ form a P-T decomposition with the first *n* - *r* rows being permanent shocks and the remaining *r* rows being transitory shocks. We can interpret the permanent shocks as unpredictable innovations to the *n* – *r* fundamental common factors (or “common trends”) driving the long-run equilibrium values of variables in a cointegrated system (see Stock and Watson, 1988; Gonzalo and Granger, 1995; Proietti, 1997; and Hecq, Palm, and Urbain, 2000). The transitory shocks can be interpreted as temporary deviations from the *r* long-run equilibrium relationships that correct themselves over time (i.e., shocks to the equilibrium errors $\mathbf{z}_t$).

To facilitate analyzing the effects of shocks we write (2) explicitly in terms of the permanent and transitory shocks:

$$(3) \qquad \Delta\mathbf{y}_t = \boldsymbol{\mu} + \boldsymbol{\alpha}\,\mathbf{z}_{t-1} + \sum_{i=1}^{q}\boldsymbol{\Gamma}_i\Delta\mathbf{y}_{t-i} + \mathbf{G}^{-1}\mathbf{u}_t \ .$$

In principle we could use (3) to trace out the dynamic effects of permanent and transitory shocks to the system. However, this task is complicated by the fact that although $\mathbf{u}_t$ is a P-T decomposition the elements of $\mathbf{u}_t$ will generally be contemporaneously correlated. Gonzalo and Ng (2001) suggest solving this problem by imposing a recursive ordering on the permanent and transitory shocks. To accomplish this consider a matrix **H** such that $\mathbf{u}_t = \mathbf{H}\mathbf{v}_t$ where $\mathbf{v}_t$ is a vector of orthogonal “structural” permanent and transitory shocks with unit variance. Cointegration requires that **H** be lower block triangular (transitory shocks cannot contemporaneously influence permanent shocks, otherwise they would not be transitory; see Gonzalo and Ng, 2001). If we further impose a recursive ordering among the permanent shocks (permanent components of $\mathbf{v}_t$ only influence permanent $\mathbf{u}_t$ shocks ordered equal or lower in the system) and a recursive ordering among the transitory shocks (transitory components of $\mathbf{v}_t$ only influence transitory $\mathbf{u}_t$ shocks ordered equal or lower in the system), then **H** is lower triangular and satisfies $\mathbf{H}\mathbf{H}' = Cov(\mathbf{u}_t) = \mathbf{G}\,Cov(\boldsymbol{\varepsilon}_t)\mathbf{G}'$. The matrix **H** can be estimated easily by computing the Cholesky decomposition of $\widehat{\mathbf{G}}\,Cov(\widehat{\boldsymbol{\varepsilon}}_t)\widehat{\mathbf{G}}'$ where $\widehat{\mathbf{G}}$ and $Cov(\widehat{\boldsymbol{\varepsilon}}_t)$ are estimated using the VEC model (1).

The complete P-T decomposition defined on orthogonalized shocks with unit variance is given by:

(4) $$\Delta \mathbf{y}_t = \boldsymbol{\mu} + \boldsymbol{\alpha}\,\mathbf{z}_{t-1} + \sum_{i=1}^{q} \boldsymbol{\Gamma}_i \Delta \mathbf{y}_{t-i} + \mathbf{G}^{-1}\mathbf{H}\mathbf{v}_t$$

where, as before, $\mathbf{z}_{t-1} = \boldsymbol{\beta}'\mathbf{y}_{t-1}$. All components of this model can be estimated from the VEC model (1). After estimation, (4) can be used to simulate the dynamic effects of different orthogonal permanent and transitory shocks on each of the prices. Results can be displayed as impulse response functions (IRFs). For some purposes it will also be useful to decompose the forecast error variance of prices into components due to the permanent versus transitory shocks (FEVD). By construction, the first $n - r$ elements of $\mathbf{v}_t$ will be orthogonal permanent shocks and the last r elements will be orthogonal transitory shocks. IRF and FEVD results may be sensitive to the ordering of shocks within each category (permanent and transitory), but the application can often provide guidelines on what ordering makes sense (essentially a just-identifying assumption). In the application below we show how assumptions about the relationship between markets for different energy products can be used to provide a structural interpretation for the orthogonal permanent and transitory shocks.

It is important to note that orthogonalization of the permanent and transitory shocks via Cholesky decomposition does *not* preclude certain shocks from influencing some prices contemporaneously (unlike in conventional Cholesky decomposition). This is because in conventional Cholesky decomposition $\mathbf{G}^{-1}$ is an identity matrix but under the P-T decomposition this matrix can transmit orthogonal permanent and transitory shocks contemporaneously to all prices in the system. In this sense the P-T recursive structure is not as rigid as the conventional recursive structure typically applied in structural VEC analysis.

3. Variables and Data

In this paper we analyze a four variable VEC model which includes gasoline price, diesel price, ethanol price and natural gas price. Gasoline and diesel prices are included because they are the most important refined petroleum products used in the U.S. transportation system. Ethanol price is used because it is the most important U.S. biofuel. Natural gas price is included because of its importance for heating and electricity generation. It will be of interest to investigate how these different energy prices are related to one in both the short-run and the long-run.

Monthly U.S. data from January 1990 to June 2014 are used in the analysis. Gasoline prices (PGAS) are regular gasoline spot price, FOB New York Harbor in \$/gallon. Diesel price (PDIE) is the spot price FOB Los Angeles California for No. 2 diesel in \$/gallon. Ethanol prices (PETH) are the average ethanol rack price, FOB Omaha, Nebraska in \$/gallon. Natural gas price (PNAT) is the U.S. City Gate price in \$/MCF. Normalized gasoline, diesel, and ethanol prices (January 1990 = 1) are shown in Figure 2. Not surprisingly, gasoline and diesel prices follow one another very closely. Ethanol price movements also follow fluctuations in gasoline and diesel prices, but appear to be growing at a slower rate than the petroleum prices. Normalized prices for gasoline and natural gas (January 1990 = 1) are shown in Figure 3. These prices seem to follow one another well over the first part of the sample but, starting around 2008, they drift apart with gasoline prices rising while natural gas prices are falling significantly. We investigate and characterize the dynamics of these relationships in the empirical work below.

All prices were transformed using logarithms and tested for unit roots using the augmented Dickey-Fuller, Phillips-Perron, and Dickey-Fuller GLS test with trend. Results are reported in Table 1 and provide support for the hypothesis that all series are I(1), possibly with drift. These findings are consistent with considerable existing evidence.

We also tested for cointegration among the prices using Johansen trace tests. Results are reported in Table 2 and support two cointegrating relationships (two common factors are driving the permanent component of all prices). Hence, a VEC with two cointegrating vectors is estimated. The cointegration tests show that gasoline prices, diesel prices and ethanol prices all have long-run equilibrium relationships with one another but there is no cointegration between natural gas price and any of the other prices. This will have important implications for the analysis which follows and is contrary to some existing evidence which supports the existence of a cointegrating relationship between petroleum prices (crude oil) and natural gas price (see Brown and Yücel, 2008; and Ramberg and Parsons, 2012). However, these studies use weekly prices while we use monthly and their data sets do not include the 2010-2014 period when petroleum and natural gas prices diverge significantly (see Figure 3).

4. Estimation and P-T Decomposition Results

We estimate the VEC using Johansen's maximum likelihood method. Lag length selection criteria (FPE and AIC) support three lagged differences in the VEC (i.e., q = 3) and a joint LM test for no autocorrelation in the residuals of the 3 lag model cannot be rejected (p-value = 0.759 against first order autocorrelation and 0.336 against second order autocorrelation). Full VEC estimation results are of little intrinsic interest by themselves and so are not reported. However, results for the two cointegrating vectors ($\boldsymbol{\beta}$ matrix) are:

$$ln(PDIE_t) = 0.069 + \underset{(43.58)}{1.032}\, ln(PGAS_t) \tag{5a}$$

$$ln(PETH_t) = 0.445 + \underset{(17.63)}{0.468}\, ln(PGAS_t) \tag{5b}$$

where numbers in parentheses are consistent t-statistics. Two cointegrating vectors in this four variable model suggests two I(1) common factors , so there are two permanent shocks driving the long run equilibrium values of all prices. If a shock to one of these factors causes a permanent 1% increase in gasoline prices the cointegration results suggest we should expect diesel prices to increase approximately proportionally (1.03%). However, the corresponding permanent increase in ethanol prices would be just 0.47%. Hence, the results do support the hypothesis that long-run ethanol prices grow at a slower rate than gasoline prices (about one half), as suggested by examination of Figure 2.

Natural gas price is not cointegrated with the other prices and therefore has no long-run equilibrium relationship with them. This suggests that natural gas prices will eventually drift apart from the petroleum and biofuel prices (which will revert to their long-run equilibrium relationships over time). On the surface, this would suggest no long-run connection between natural gas and other energy prices, and hence no long-run substitutability between natural gas and petroleum or biofuels. However, even though the long-run equilibrium (permanent) component of natural gas prices is not perfectly correlated with the long-run equilibrium component of the other prices, this correlation is not necessarily zero either. That is, there may still be a tendency for the long-run equilibrium component of natural gas prices and other energy prices to move together over finite time horizons, even though they will eventually meander apart (no cointegration). The extent of this co-movement in long-run equilibrium prices will be an indicator of the extent of substitutability between energy sources and can be investigated by examining the influence that different kinds of permanent shocks have on the different energy prices.

Hypothesis tests revealed that the first common factor is associated primarily with changes in gasoline and diesel prices so we interpret this factor as an economic fundamental driving long-run change in the petroleum sector. Similarly, the second common factor was found to be associated primarily with natural gas prices so we interpret this factor as an economic fundamental driving long-run change in the natural gas sector. The factors may be correlated which allows natural gas prices to have a persistent connection with the other prices, even though natural gas prices are not cointegrated with these other prices (no long-run equilibrium relationship). For identification we need a recursive ordering for the permanent shocks. Here we order the first permanent shock first which restricts the second permanent shock (natural gas) to have no contemporaneous impact on the first common factor (petroleum). This is an identification assumption which allows a permanent shock to the long-run fundamentals underlying the petroleum sector to have a contemporaneous impact on the long-run fundamentals underlying the natural gas sector, but restricts a permanent shock to the long-run fundamentals underlying the natural gas sector to have no *contemporaneous* impact on the long-run fundamentals underlying the petroleum sector. Because it is more likely that natural gas fundamentals respond contemporaneously to petroleum fundamentals than vice versa, this seems like a reasonable identification assumption. Dynamics are left unrestricted so there are no further restrictions on the ways in which the two common factors can interact with one another over time.

Because there are two permanent shocks and four variables there will also be two transitory shocks, one representing shocks to the first long-run equilibrium relationship (5a) between gasoline price and diesel price, and one representing shocks to the second long-run equilibrium relationship (5b) between gasoline price and ethanol price. For identification we place transitory shocks to (5a) first in the recursive ordering. This implies that transitory shocks to the gasoline-ethanol price relationship do not contemporaneously influence the gasoline-diesel price equilibrium. Put another way, it implies that an increase in ethanol price relative to gasoline price does not have a contemporaneous impact on the relative price of gasoline and diesel. Since ethanol is a much smaller sector than the petroleum sector this seems like a reasonable identification assumption and is consistent with the idea that the first transitory shock originates in the petroleum sector and the second originates in the biofuel sector. Transitory fluctuations in all prices (including natural gas) may depend on both these transitory shocks. Dynamic interactions remain unrestricted.

We applied these identification assumptions, along with estimates from the VEC, to compute IRFs for the four types of shocks. The IRDFs are computed by simulating the decomposition (4) starting from a point of long-run equilibrium. The system is perturbed with a one-time shock to one of the orthogonal errors and the resulting time path for prices is computed. Then the simulation is repeated sequentially for each of the permanent and transitory shocks. Graphs of the resulting IRFs are provided in Figures 4-7. The size of the first permanent shock (petroleum) in Figure 4 is normalized so that it eventually increases gasoline price by 1% (see the convergence point for the gasoline price response in the Figure 4). The size of the second permanent shock (natural gas) is normalized so that it eventually increases natural gas price by 1% (see the convergence point for the natural gas price response in Figure 5). Notice first that the effects of both permanent shocks are consistent with the cointegration restrictions among gasoline, diesel, and ethanol prices (i.e., the long-run effect of both permanent shocks is to increase diesel prices by a factor of 1.03 and ethanol prices by a factor of 0.47 over the proportional increase in gasoline price). This is most obvious in Figure 4 but also occurs in Figure 5. Second, a shock to the first (petroleum sector) factor does have a permanent effect on natural gas prices, but long-run natural gas price only increases by about one-third of the long-run proportional increase in gasoline price (see Figure 4). A shock to the second (natural gas) factor also has a permanent effect on gasoline, diesel and ethanol prices, but this proportional effect is even smaller in relative terms with gasoline and diesel prices increasing by about one-fifth of the proportional increase in natural gas prices, and ethanol prices by only about one-tenth (see Figure 5). Consistent with these results, less than 5% of the unpredictable variation in gasoline and diesel prices is due to permanent natural gas shocks, and less than 3% of the unpredictable variation in natural gas price is due to permanent petroleum shocks. These results show that while there is some connection between long-run equilibrium movements in natural gas and other energy prices, the connection is weak, suggesting substitutability is weak. Nevertheless, unlike the inference from cointegration analysis only (which suggests no long-run substitutability) the P-T decomposition shows that there is a (weak) persistent connection between natural gas and other energy prices.

Transitory shocks originating in the petroleum sector are normalized to have an immediate 1% effect on gasoline prices (Figure 5) and those originating in the ethanol sector are normalized to have an immediate 1% effect on ethanol prices (Figure 6). Both shocks have minimal effects on natural gas prices and the effects that do occur die out quickly. Consistent with these results, less than 25% of the unpredictable variation in natural gas prices is due to the transitory shocks. Therefore, we conclude that transitory shocks to long-run equilibrium relationships among gasoline, diesel, and ethanol have only limited transitory effects on natural gas prices. Hence, the short-run connection between natural gas prices on one hand and petroleum and biofuel prices on the other is also weak.

It is also interesting to note that a permanent natural gas shock has only a small effect on ethanol prices (see Figure 5) and these shocks only account for 13% of the unpredictable variation in ethanol prices. Therefore, the path of ethanol prices is little influenced by natural gas prices but much more influenced by changes taking place in the petroleum and biofuel sectors. This suggests that the fertilizer/natural gas link to ethanol (corn) production is weak.

5. Conclusion

This paper uses the Gonzalo and Ng (2001) P-T decomposition to analyze the dynamic effects of permanent and transitory shocks on gasoline, diesel, ethanol, and natural gas prices. We find important long-run equilibrium relationships between gasoline, diesel, and ethanol prices but not between any of these prices and natural gas prices. This is somewhat surprising because if these alternative energy sources are strongly substitutable, and if their Btu conversion rate remains approximately constant over time, then energy equivalence and full substitutability would imply these prices remain proportional to one another in the long-run. We find this proportional relationship holds for gasoline and diesel prices but not for the other energy price relationships studied. In the case of ethanol there *is* a long-run equilibrium relationship with gasoline and diesel prices, but ethanol prices grow more slowly than petroleum prices in the long run, rather than remaining proportional. This suggests restricted substitutability between gasoline and ethanol. In the case of natural gas there is *no* long-run equilibrium relationship with the other prices. Nevertheless, there remains a persistent but subdued longer-run connection between natural gas prices and the other prices due to correlation between their respective permanent components. These results are consistent with some, though limited, ability to substitute between energy sources over long time horizons.

We explain the long-run petroleum-ethanol price relationship in terms of the unique role that ethanol plays in the gasoline market. Ethanol is a required gasoline additive but is subject to a blend wall which places an upper bound on the proportion of ethanol that can be mixed with gasoline. This means there is substitutability between ethanol and gasoline but the substitutability is limited. The connection is strong enough to keep ethanol prices in a long-run equilibrium relationship with gasoline (and diesel) prices but not strong enough to induce long-run proportionality, as we might expect if gasoline and ethanol were perfectly substitutable.

Our results suggest there is limited substitutability between natural gas and petroleum/biofuel use applications, even in the long run. Therefore, although permanent shifts in these prices are not completely unrelated, the prices certainly do not remain proportional in the long run as we might expect under complete substitutability. There is little evidence to suggest natural gas prices will have a major connection with either petroleum or ethanol prices over very long time horizons.

The short-run response of natural gas prices to transitory shocks originating in the petroleum and biofuel sectors are minimal and die out quickly. This suggests there is very limited scope for substitutability across natural gas and other energy use applications in the short run. Ethanol prices are little influenced by natural gas prices but much more influenced by changes taking place in the petroleum and biofuel sectors. The implication is that that prices received by ethanol refiners will be driven primarily by petroleum price movements rather than changes in the price of natural gas, and changes in the price of natural gas may influence fertilizer prices paid by corn producers but will have little impact on the incentive to divert corn to ethanol production (which is determined primarily by shocks originating in the petroleum sector).

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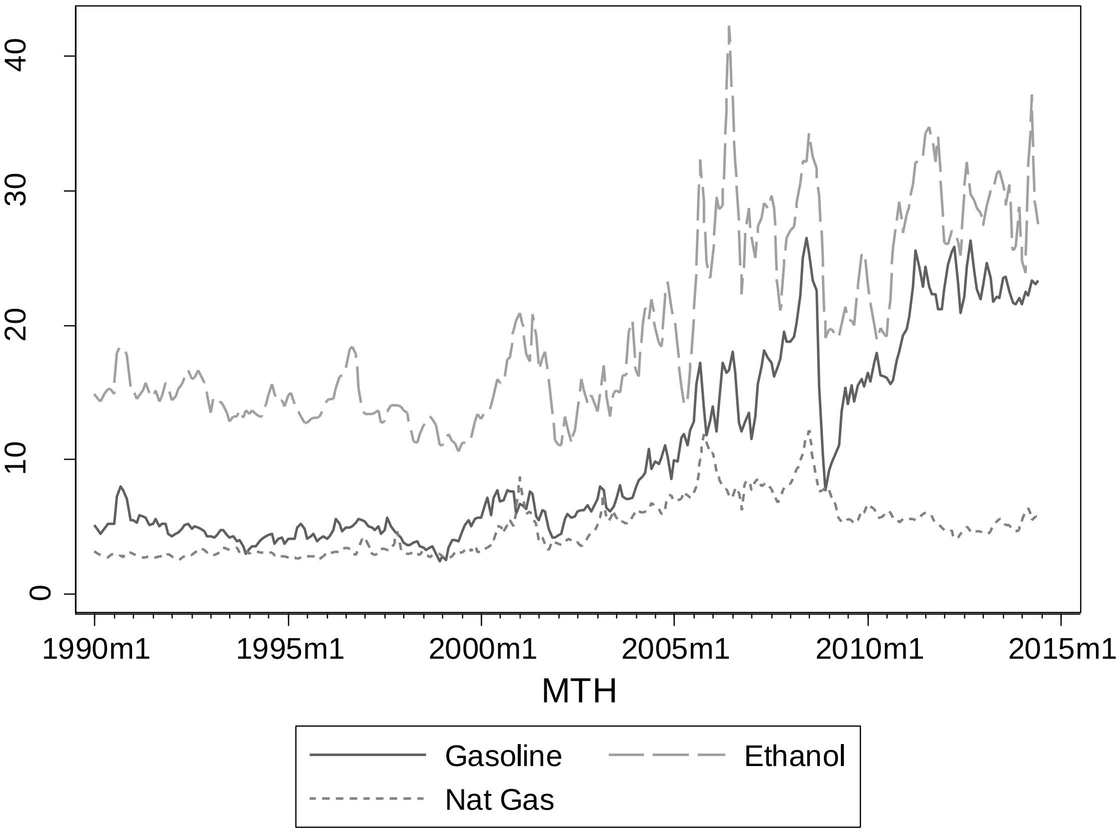

Figure 1. Fuel Prices per Million BTU, January 1990 to June 2014

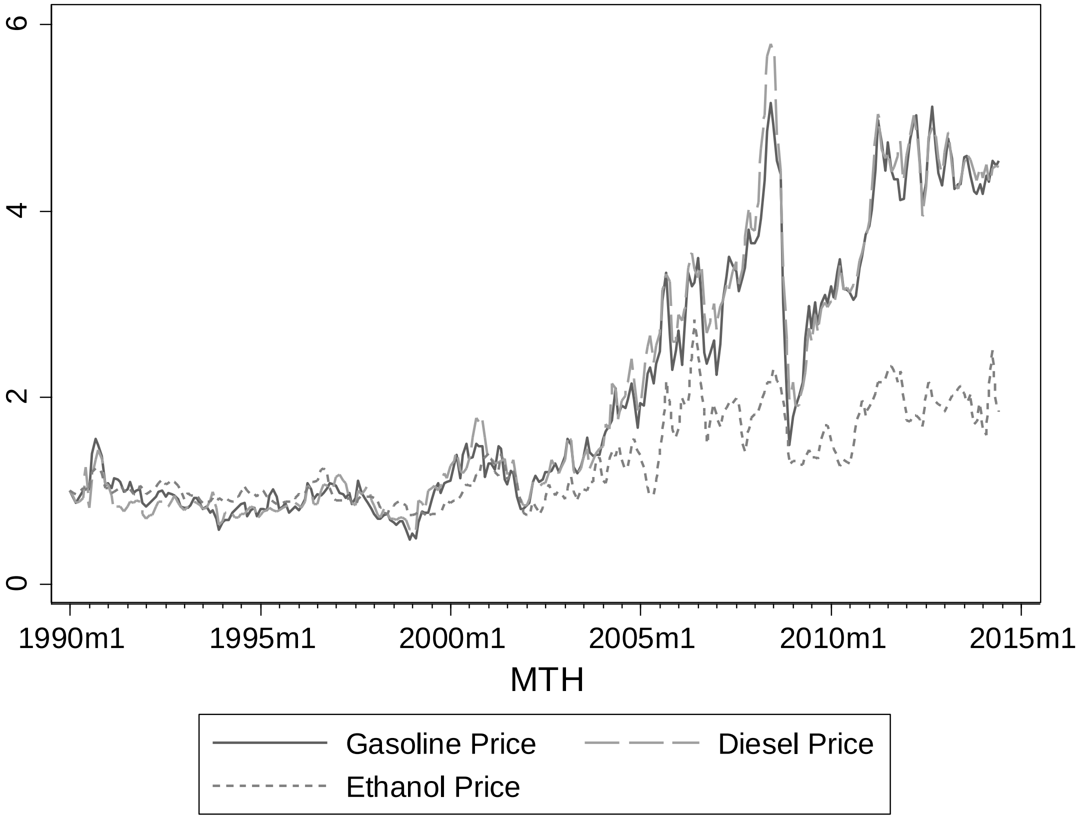

Figure 2. Normalized Gasoline, Diesel, and Ethanol Prices, January 1990 to June 2014

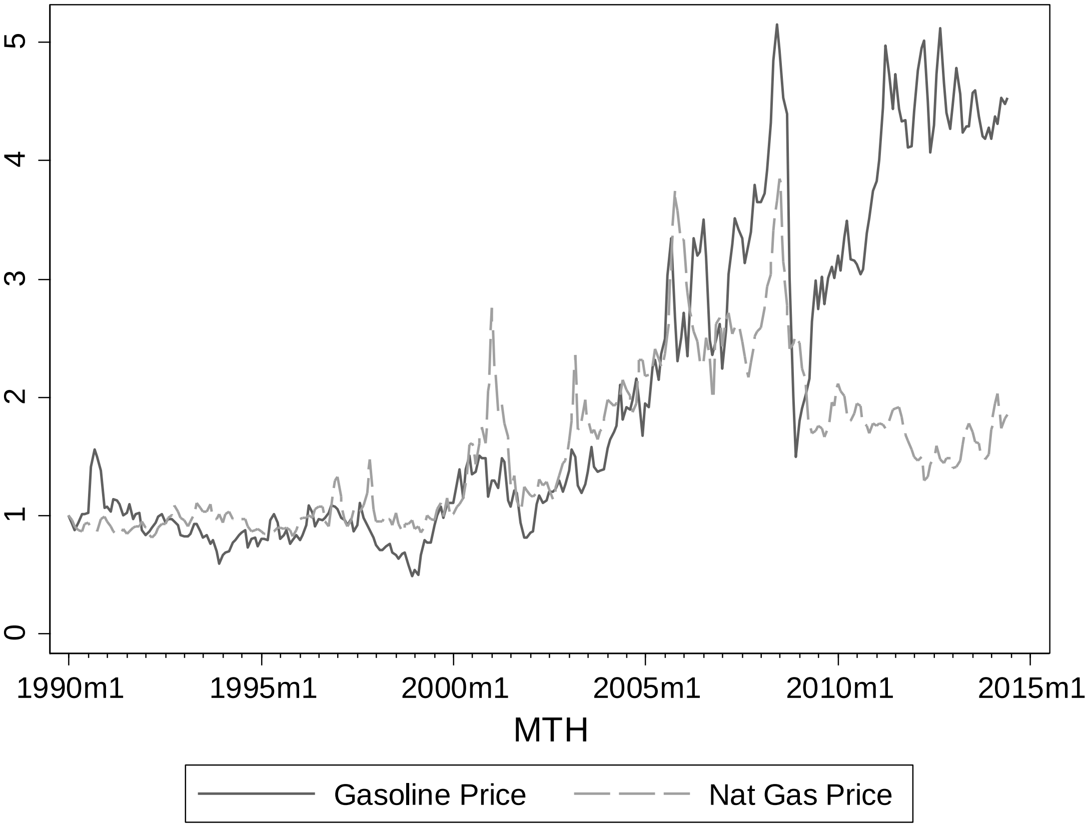

Figure 3. Normalized Gasoline and Natural Gas Prices, January 1990-June 2014

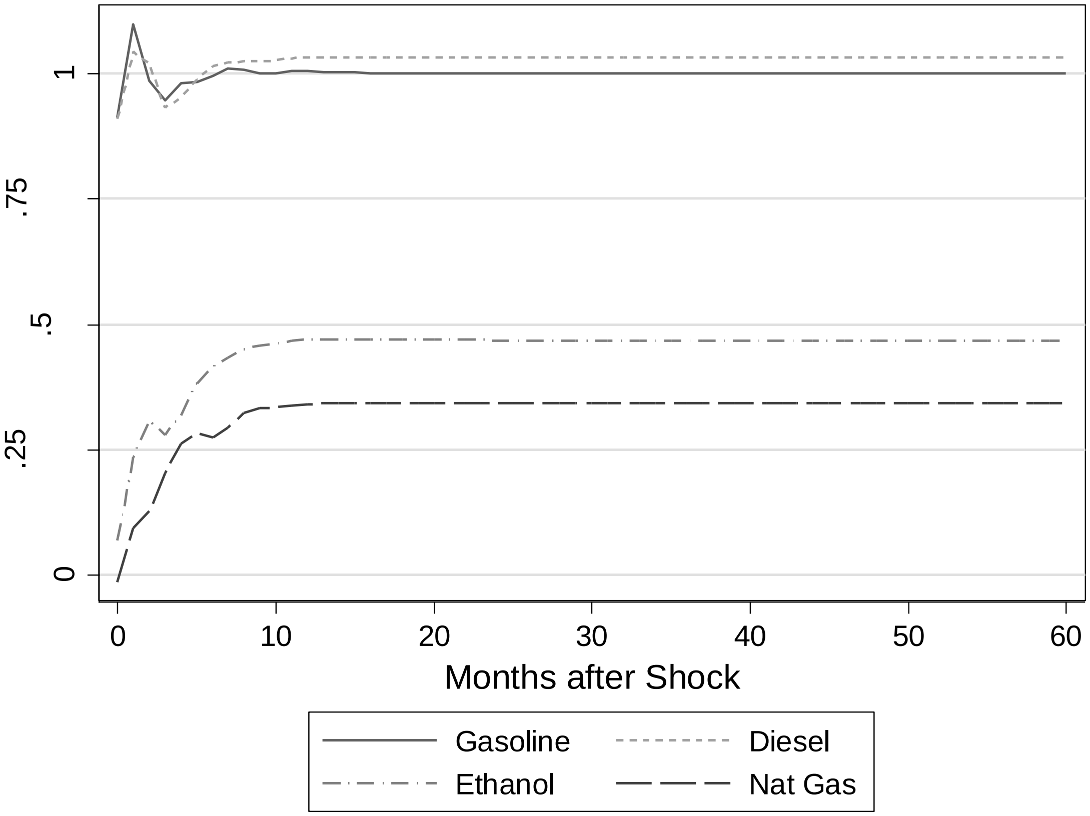

Figure 4. Impulse Responses to a Permanent Petroleum Shock

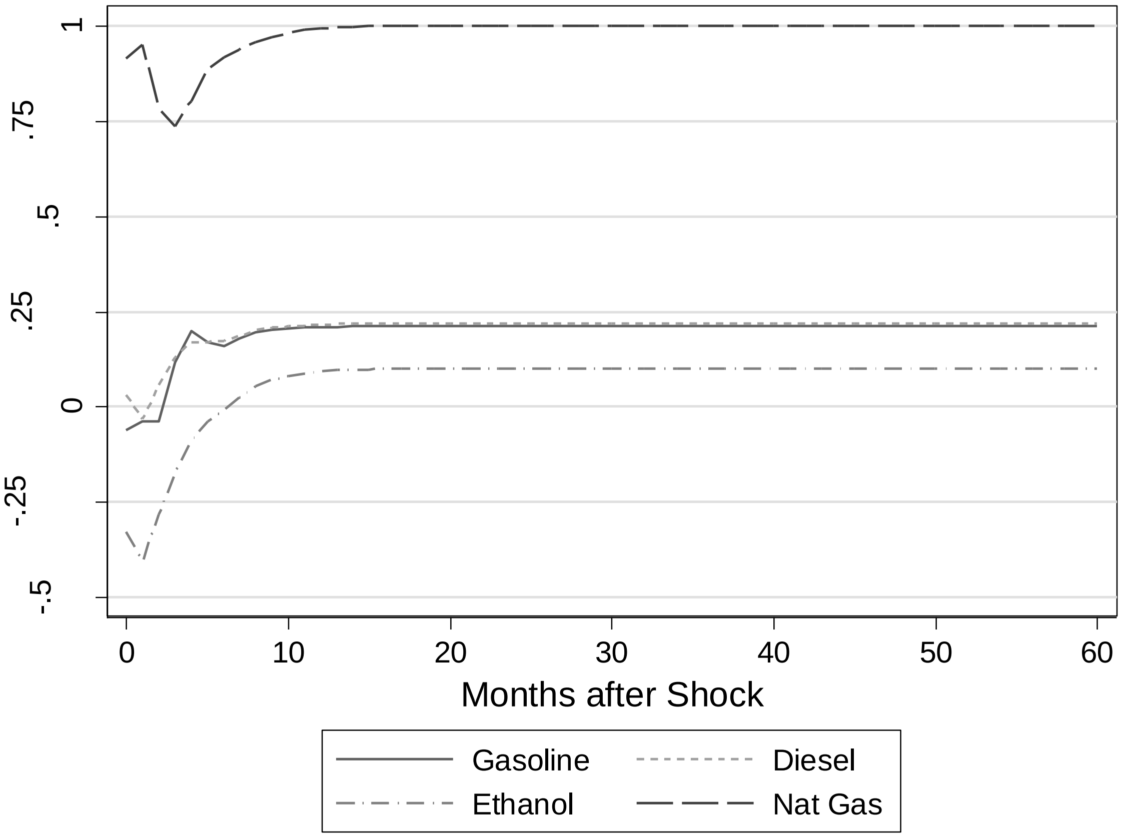

Figure 5. Impulse Responses to a Permanent Natural Gas Shock

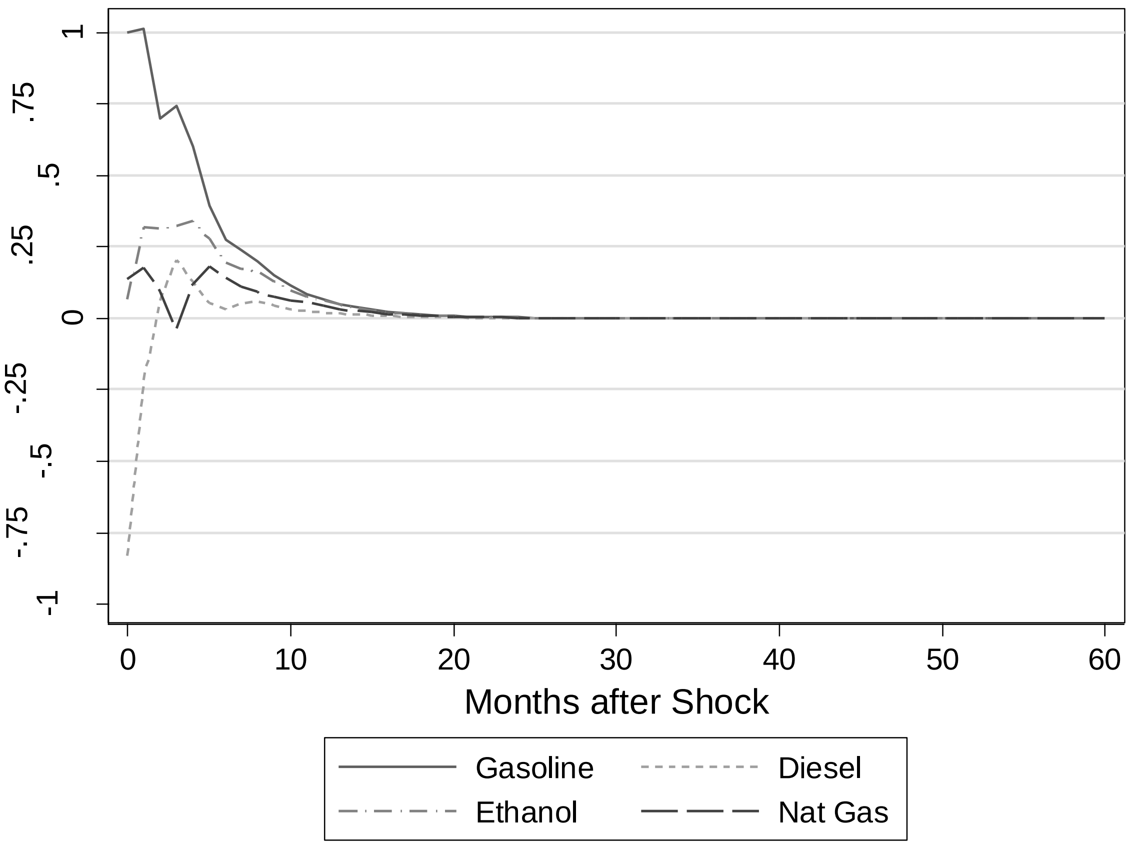

Figure 6. Impulse Responses to a Transitory Petroleum Shock

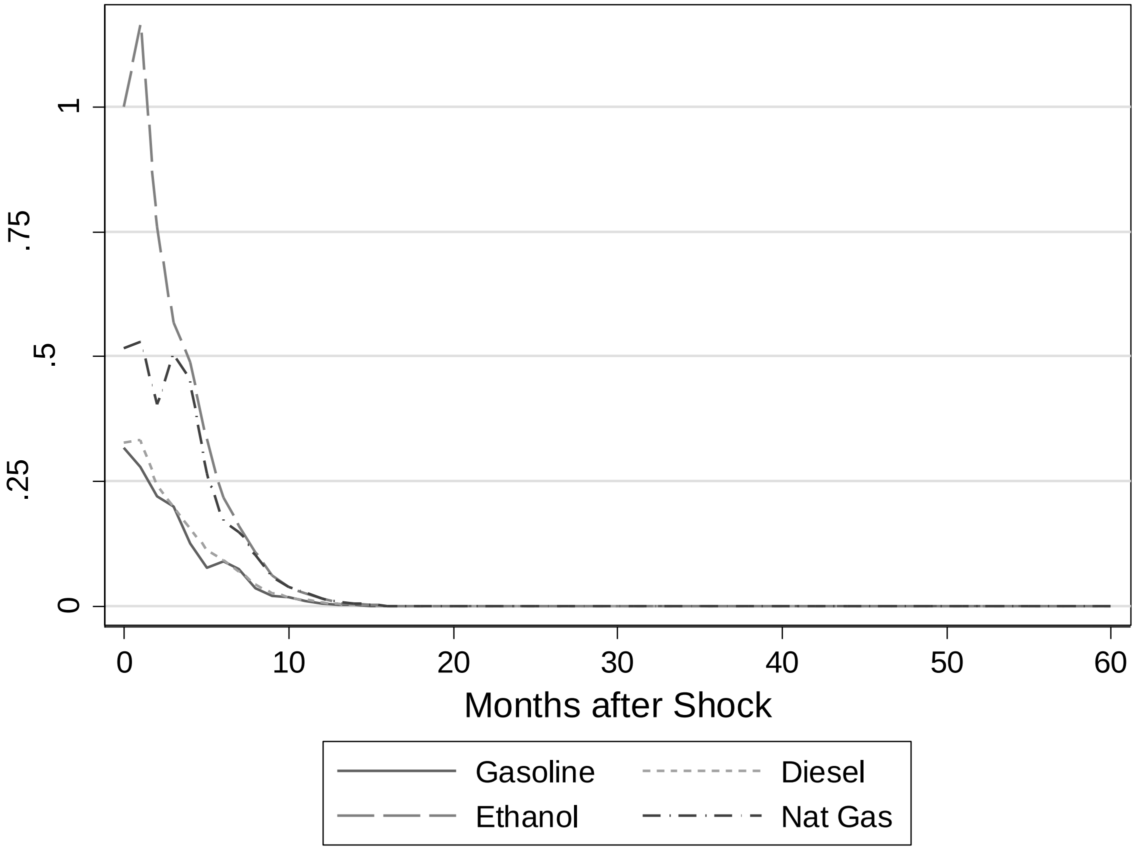

Figure 7. Impulse Responses to a Transitory Ethanol Shock

Table 1. Unit Root Test Results

Variable	*Test*	*Statistic*	*p-value*
Gasoline Price	Dickey-Fuller	-0.996	-2.878
	Phillips-Perron	-0.941	-2.878
	GLS Dickey-Fuller	-2.062	-2.900
Diesel Price	Dickey-Fuller	-0.767	-2.878
	Phillips-Perron	-0.865	-2.878
	GLS Dickey-Fuller	-2.093	-2.900
Ethanol Price	Dickey-Fuller	-2.004	-2.878
	Phillips-Perron	-2.065	-2.878
	GLS Dickey-Fuller	-2.829	-2.900
Natural Gas Price	Dickey-Fuller	-1.767	-2.878
	Phillips-Perron	-1.790	-2.878
	GLS Dickey-Fuller	-2.332	-2.900

Notes: All variables are in logarithms. Dickey-Fuller tests are augmented with 3 lagged differences included in the estimation equations (suggested by lag length selection tests) and the number of Newey-West lags in the Phillips-Perron tests is the suggested default of $\text{int}\{4(N/100)^{2/9}\}$ where N is the number of observations. The number of lags for the Dickey-Fuller GLS test (with trend) is chosen by the Schwarz criterion.

Table 2. Cointegration Test Results

Cointegrating Relationship	*Maximum No. of Cointegrating Relationships*	*Trace Statistic*	*5% Critical Value*
All prices	0	82.402	47.21
	1	42.006	29.68
	2*	7.554	15.41
	3	0.974	3.76
Gasoline, Diesel and Ethanol	0	61.773	29.68
	1	28.290	15.41
	2*	0.802	3.76
Gasoline, Diesel and Nat Gas	0	43.161	29.68
	1*	7.444	15.41
	2	0.856	3.76
Gasoline, Ethanol and Nat Gas	0	47.088	29.68
	1*	7.978	15.41
	2	1.363	3.76
Diesel, Ethanol and Nat Gas	0	46.435	29.68
	1*	7.909	15.41
	2	1.001	3.76
Gasoline and Diesel	0	29.641	15.41
	1*	0.701	3.76
Gasoline and Ethanol	0	35.269	15.41
	1*	1.049	3.76
Gasoline and Nat Gas	0*	7.903	15.41
	1	1.218	3.76
Diesel and Ethanol	0	34.846	15.41
	1*	0.836	3.76
Diesel and Nat Gas	0*	7.731	15.41
	1	0.843	3.76
Ethanol and Nat Gas	0*	15.024	15.41
	1	4.409	3.76

Notes: All variables are in logarithms. Trace statistics based on VEC estimation with three lagged differences included in each model (as suggested by lag selection criteria). * indicates the number of cointegrating vectors supported by the statistics.