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Essays On The Impact Of Oil Price Shocks On The Macroeconomy

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The text of this dissertation includes reprints of the following previously published material:

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The co-authors Dr. Ana María Herrera and Dr. Tatsuma Wada, listed in these publications directed and supervised the research which forms the basis for the dissertation.

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CHAPTER 1 OIL PRICE SHOCKS AND INDUSTRIAL PRODUCTION: IS THE RELATIONSHIP LINEAR?[1]

1. Introduction

Since the oil price shocks of the 1970s, many economists have considered unexpected oil price fluctuations as one of the main sources of fluctuations in macroeconomic aggregates. Linear models of the transmission of oil price shocks, however, cannot explain large fluctuations in U.S. real activity. This fact stimulated interest in models of an asymmetric and possibly nonlinear relationship between the real price of oil and U.S. real activity. For example, Loungani (1986) and Davis (1987a,b) emphasized asymmetries due to costly sectoral reallocation of resources. Mork (1989) observed that feedback from lagged real oil price increases appears negative and statistically significant, while the lagged feedback from oil price decreases is small and statistically insignificant. Given evidence in Hooker (1996) that Mork's model does not fit the data, Lee, Ni and Ratti (1995) and Hamilton (1996, 2003) made the case that empirical work needed to take account of the environment in which the oil price increases take place. Their preferred specification combined asymmetries in the transmission of oil price shocks with additional nonlinearities.[2]

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[2] Specifically, Lee, Ni and Ratti (1995) showed that oil price increases scaled by the standard deviation of recent volatility improved the fit of the predictive relationship between real GDP growth and relative to oil price changes. Similarly, Hamilton (1996, 2003) showed that a nonlinear transformation that records the net oil price increase over the previous 1-year or 3-year maximum improves the fit of a predictive model of real GDP growth.

By the beginning of the 2000s, a consensus had emerged in the literature regarding the nonlinear relationship between U.S. real economic activity and the price of oil, which in turn was thought to account for the seeming structural instability of linear models in the post-1986 era. Yet, recent work by Kilian and Vigfusson (2009) --henceforth KV-- has called into question the view that unexpected oil price increases and decreases have an asymmetric effect on macroeconomic aggregates. They proved that the method commonly employed in the literature to evaluate the asymmetric and potentially nonlinear impact of oil price innovations produces inconsistent estimates and is likely to overestimate the impact of such shocks. They also showed that for a shock of typical magnitude the linear and symmetric model appears to provide a very good approximation to the responses of U.S. real GDP to innovations in the real price of oil.

Our paper builds on these methodological insights, but broadens the scope of the analysis. First, we focus on the relationship between the price of oil and U.S. industrial production on the grounds that asymmetries are likely to be more prevalent in industrial production data than in real GDP data. If oil price innovations involve a costly reallocation of capital and labor, for example, then concentrating on real aggregate GDP might obscure the nature of the reallocative effect (see for instance, Bresnahan and Ramey, 1993; Davis and Haltiwanger, 2001). Second, we conduct a comprehensive analysis of sectoral disaggregates of U.S. industrial production, including sectors that one would expect to be particularly sensitive to the price of oil ex ante. The response of aggregate data represents a weighted average of possibly symmetric and possibly asymmetric responses across sectors. Thus, an obvious concern is that the finding of a symmetric response at the aggregate level could obscure important asymmetries at the sectoral level driven by different degrees of energy intensity in use and production at the sectoral level (see, e.g., Lee and Ni 2002).

We investigate the three leading specifications of asymmetric and possibly nonlinear feedback from the real price of oil to U.S. industrial production: the percent increase specification of Mork (1989) and the 1-year and 3-year net oil price increase specifications of Hamilton (1996, 2003). We start by testing for asymmetries and nonlinearities in the slope of the reduced-form relationship between industrial production growth and the real price of oil. Our results for these traditional slope-based tests are consistent with Hamilton's (2010) and KV's finding that the reduced-form relationship between oil prices and economic activity appears nonlinear in some transformations of the price of oil. Rejections of the linear model are more prevalent for the net oil price increase. We then use the modified slope-based test proposed in KV obtaining similar or even stronger results.

None of the slope-based tests, however, directly addres the question of how asymmetric the response functions of industrial production are to positive and negative innovations in the real price of oil. We address this question using the impulse response function --henceforth IRF-- based test of symmetry proposed in KV. Overall, the IRF based test suggests strong evidence against the null of symmetric responses to innovations in the real price of oil using the 1947-2009 sample. There is considerable disagreement, however, as to which sectors are most affected, depending on the specification chosen. For example, Mork's specification shows statistically significant asymmetric responses in the automobile sector, even after accounting for the data mining involved in considering a large number of sectors, whereas the behavioral specifications of Hamilton (1996, 2003) do not.

There is reason to be cautious in interpreting these full-sample results, however, given evidence of a structural break in 1973 not only in the marginal distribution governing the real price of oil, but in the predictive relationship between the real price of oil and U.S. real economic activity (see Dvir and Rogoff 2010, Kilian and Vigfusson 2010). Using post-1973 data, the evidence against symmetric responses to oil price innovations becomes considerably weaker. For example, for aggregate industrial production, there is no evidence against the hypothesis of symmetric responses to oil price innovations of typical magnitude, consistent with results by KV for U.S. real GDP. Yet, there is strong evidence of asymmetries at the disaggregate level based on the 3-year net increase measure, especially for industries that are energy intensive in production (such as chemicals) or that produce goods that are energy-intensive in use (such as transit equipment). This finding is consistent with our conjecture that asymmetries at the sectoral level may be obscured in the aggregate data. No such evidence is found for the other two oil price specifications, however, and even for the 3-year net increase specification the response of the motor vehicles and parts sector, for example, does not appear asymmetric.

Our findings have important implications for the empirical literature regarding the effect of oil price shocks on industrial production. First, our results suggest that the response of industrial production growth to oil price innovations is asymmetric and nonlinear at least at the disaggregate level. Second, our results highlight the importance of developing multisector models of the transmission of oil price shocks. Third, our results are not consistent with standard theoretical explanations of asymmetries in the literature such as costly reallocation of labor or capital across sectors (see Hamilton, 1988) or asymmetries in the response of petroleum product prices to crude oil prices (Huntington, 1998), as these explanations rely on the asymmetry captured by Mork's (1989) oil price specification. The net oil price increase specifications in particular are not consistent with economic theory, but are based on (yet untested) behavioral arguments.

This paper is organized as follows. Section 2 discusses the data. In section 3 we use slope based tests to test whether nonlinear oil price measures have explanatory power for industrial production in a reduced-form model and to test for nonlinearity in a more general model. In section 4 we employ the impulse response based tests of symmetry of KV to further inquire about the effect of unanticipated oil price shocks on industrial production. Section 5 concludes.

2. Data

We follow Mork (1989) and Lee and Ni (2002) in measuring nominal oil prices by the composite refiners' acquisition cost when possible (i.e., from 1974 onwards), making adjustments to account for the price controls of the 1970s, and extrapolating the data from 1947 until 1974 by using the rate of growth of the producer price index. We then deflate the price of oil by the U.S. CPI. We use three different nonlinear transformations of the logarithm of the real oil price, o_t. First, Mork's (1989) oil price increase, which can be defined as:

$$x_t^1 = max\{0, o_t - o_{t-1}\}. \quad (1)$$

This censoring of the oil price series was proposed by Mork (1989) after the 1985-86 fall in oil prices failed to lead to a boom in real GDP growth. He thus showed that whereas oil price increases preceded an economic recession; in contrast, he could not reject the null hypothesis that declines did not lead to expansions. Subsequently, Hooker (1996) and KV, among others, showed that this result vanishes in longer samples.

The second and third measures are the net oil price increase over the previous 12-month maximum (Hamilton, 1996)

$$x_t^{12} = max\{0, o_t - \max\{ o_{t-1}, \dots, o_{t-12} \}, \quad (2)$$

and the net oil price increase over the previous 36-month maximum (Hamilton, 2003)

$$x_t^{36} = max\{0, o_t - \max\{ o_{t-1}, \ldots, o_{t-36} \}. \quad (3)$$

These nonlinear transformations are intended to filter out increases in the price of oil that represent corrections for recent declines, and have been commonly used in the literature on the macroeconomic effects of oil prices (see for instance Bernanke, Gertler and Watson, 1997; Davis and Haltiwanger, 2001; Lee and Ni, 2002). Note that in the text we report the results for the nonlinear transformations of the log of the real oil price. The results for the nonlinear transformation of the log of the nominal oil price (Hamilton 1996, 2003) are reported in the on-line appendix.[3]

To measure economic activity we use monthly data on the seasonally adjusted industrial production (IP) indices computed by the Board of Governors of the Federal Reserve. We report results for 37 indices of which 5 represent aggregates: total (or aggregate) IP index, manufacturing (SIC), manufacturing (NAICS), durable consumer goods and nondurable consumer goods. The total IP index measures the real output of the manufacturing, mining, and electric and gas utilities industries. The remaining 32 series represent both market and industry groups. Market groups comprise products and materials. Products include aggregates such as consumer goods, equipment and nonindustrial supplies, whereas materials correspond to inputs used in the manufacture of products. Industry groups include three-digit NAICS industries, and other industries that have traditionally been part of manufacturing such as newspaper, periodical, and books. The period spanned by the data varies across series depending on the availability of data on both oil prices and industrial production. Hence, the longest series span the period between January 1947 and September 2009, whereas the shortest series span the period between

[3] See Tables A.8-A.15 and A.22-A.29 in the on-line appendix, available at http://clas.wayne.edu/multimedia/usercontent/File/herrera/HLWappendix.pdf.

January 1986 and September 2009 (see Table A.1 of the on-line appendix for the period covered for each IP index).

3. Slope based tests of nonlinearity

3.1 Is the oil price-industrial production relation nonlinear?

In order to investigate whether the one-step ahead forecast of industrial production of sector *i* is linear in lags of oil prices we estimate the following reduced-form equation by OLS:

$$y_{i,t} = \alpha + \sum_{j=1}^{p} \emptyset_j \, y_{i,t-j} + \sum_{j=1}^{p} \beta_j \, x_{t-j} + \sum_{j=1}^{p} \gamma_j \, x_{t-j}^{\#} + u_{i,t} \qquad (4)$$

where $y_{i,t}$ denotes the log growth in the industrial production index for sector *i* at time *t*, x_t is the log growth in oil prices without any transformation, $x_t^{\#}$ is one of the nonlinear measures of oil price increases described in section 2 ($x_t^{\#} = x_t^1, x_t^{12}, x_t^{36}$), $u_{i,t}$ is the residual for sector *i* at time *t*, and *p* is set equal to 12 months.[4]

We then test the null hypothesis that the coefficients on the nonlinear measure are all equal to zero; that is, $\gamma_1=\gamma_2=\ldots=\gamma_{12}=0$. Table 1 reports the p-values for the Wald test of joint significance for each of the three nonlinear measures of oil prices.

We start with the results for a test of symmetry; that is, the slope based test for the oil price increase, x_t^1, reported in the first panel in Table 1. At the 5% significance level, we reject the null of symmetry for 15 of the 37 industrial production indices. Of particular interest is the finding of asymmetry for chemicals and motor vehicles, industries that are either intensive in the use of energy in production or in the use by consumers. As can be seen in the first panel in Table 1, using the net oil price increase over the previous 12-month maximum, x_t^{12}, also provides

[4] Our choice of twelve monthly lags is consistent with results in Hamilton and Herrera (2004), which suggest that using a smaller number of lags --as indicated by an information criterion such as the AIC or the BIC-- is not enough to capture the dynamic effect of oil prices on economic activity.

evidence in favor of an asymmetry in the slope of the relationship between oil prices and industrial production. We reject the null of symmetry for 19 out of the 37 indices. Similarly, evidence of nonlinearity can be found for 25 indices using the net oil price increase over the previous 36-month maximum, x_t^{36}. This result mirrors similar results in Lee, Ni and Ratti (1995) and Hamilton (1996).

A couple of differences between the test results for the different measures of oil prices are worth noting. First, using Mork's oil price increase results in rejection of symmetry in the slope for 9 indices where one (or more) of the net oil price increase measures suggests symmetry. Second, whereas evidence of nonlinearity is not robust across measures of oil prices for the market group motor vehicles and parts, we do reject the null of linearity for all measures for motor vehicles. This result is consistent with the common view that oil price increases have a significant negative effect on the automobile sector.

Overall, we do not find any evidence of asymmetry in the reduced-form equation (4) for apparel and leather goods, printing and related support industries, petroleum and coal products, pottery, ceramics and plumbing fixtures, clay product and refractory, and industrial machinery. Regardless of the oil price measure, the null of linearity is rejected for the total IP index, manufacturing (NAICS), nondurable consumer goods, foods and tobacco, paper products, and motor vehicles. For the remaining indices we find evidence of asymmetry for at least one of the oil price measures.

3.2 The effect of including contemporaneous regressors

KV propose a more powerful test of the null of symmetric slopes obtained by estimating a more general model of the oil price-macroeconomy relationship, which includes contemporaneous values of x_t and $x_t^{\#}$. Consider the data generating process for each of the IP series as being given by the bivariate dynamic model:

$$x_t = a_{10} + \sum_{j=1}^{12} a_{11,j}\, x_{t-j} + \sum_{j=1}^{12} a_{12,j}\, y_{i,t-j} + \varepsilon_{1t} \quad (5a)$$

$$y_{i,t} = a_{20} + \sum_{j=0}^{12} a_{21,j}\, x_{t-j} + \sum_{j=1}^{12} a_{22,j}\, y_{i,t-j} + \sum_{j=0}^{12} g_{21,j}\, x_{t-j}^{\#} + \varepsilon_{2t} \quad (5b)$$

Note that since the errors are uncorrelated we can estimate only (5b) by *OLS* and then test the null hypothesis that $g_{21,0} = g_{21,1} = \cdots = g_{21,12} = 0$. The second panel in Table 1 reports the p-values for a Wald test of joint significance for each of the three nonlinear measures of oil prices.

Including the contemporaneous regressors provides stronger evidence of asymmetry. Using the oil price increase, x_t^1, we reject the null for 24 out of the 37 indices. Using x_t^{12} and x_t^{36} we reject the null of linearity for 23 and 24 indices, respectively. Regardless of the measure of oil prices, we reject the null of linearity for 15 indices. Only 5 indices (apparel and leather goods, petroleum and coal products, pottery, ceramics and plumbing fixtures, clay products and refractory, and industrial machinery) show no evidence of asymmetry. Interestingly, petroleum and coal products, an industry that is intensive in the use of oil in production, shows no evidence of asymmetry. This is possibly because both increases and decreases in the price of oil (the main production input) have a significant and symmetric effect through the direct requirement of oil in production, whereas the effect of the shock through indirect input-output linkages may be more asymmetric.

In brief, including the contemporaneous value of the oil price change and the nonlinear transformation of oil prices reveals more evidence of nonlinearity in the slope of the oil price-industrial production relation. This result is in line with KV's simulation evidence of an increase in power when contemporaneous terms are included in the economic activity equation.

4. Impulse response function based test

As was first noted by Balke, Brown and Yücel (2002), computing impulse responses in the textbook manner when one of the endogenous variables in the model is censored is problematic. KV show that the standard censored oil price VAR model is inherently misspecified, even if the data generating process is nonlinear and asymmetric, and cannot be consistently estimated. In addition, computing structural IRFs from nonlinear models as in linear models ignores the fact that the effect of a structural oil price innovation depends on the recent history of the censored variable $x_t^{\#}$ and the magnitude of the shock ε_{1t} in (5a).[5]

Moreover, KV show that evidence of asymmetry (or for that matter lack thereof) in the reduced form slopes is not informative about the degree of asymmetry in the response of industrial production to an unanticipated oil price shock. We implement KV's impulse response based test. First, we compute structural IRFs, $I_y(h, \delta, \Omega^t)$, for a given horizon, h --conditional on the history Ω^t-- that take into account the size of the shock, δ. Then, we average over all the histories to obtain the unconditional IRF, $I_y(h, \delta)$. We then compute the Wald test of the null of symmetric response functions:

$$I_y(h, \delta) = -I_y(h, -\delta)\ for\ h = 0, 1, 2, \ldots, H.$$

See section 1 of the on-line appendix for details on the computation of the test. We report the results for one and two standard deviation shocks; we will refer to these shocks as typical and large, respectively.

[5] See, for instance, Gallant, Rossi and Tauchen (1993) and Koop, Pesaran and Potter (1996) in the context of reduced form models and Kilian and Vigfusson (2009) in the context of structural models.

4.1 Is the response of industrial production to oil price shocks linear and symmetric?

Tables 2 and 3 report the results corresponding to the test of symmetry of the IRF for the model (5) where $x_t^{\#} = x_t^1$. Results for a typical shock are reported in Table 2, whereas results for a large shock are reported in Table 3. To conserve space, the tables in this article report the test results for only four horizons (*h=0,1,6,12*). The number of rejections, noted hereafter, is based on all the horizons (*h=0,1,..,12*) and thus might be smaller than the number of rejections found in Tables 2-5; they correspond to the number of rejections for all 13 horizons (i.e., *h=0,1,2,...,12*) in Tables A.2-A.7 found in the on-line appendix (see section 2).[6]

Contrary to the findings of KV for real GNP and unemployment on a shorter sample, we find evidence of asymmetry in the aggregate IP indices (total, manufacturing SIC, manufacturing NAICS) for at least 6 horizons if the size of the shock is one standard deviation. At a more disaggregate level, we find evidence of asymmetry at one or more horizons for 20 indices (see the first panel of Table 2 and Table A.2 in the on-line appendix). Based on the two standard deviation test we find ample evidence of asymmetry (see the first panel of Table 3 and Table A.5 of the on-line appendix). We reject the null of symmetry for 31 out of the 37 indices at the 5% significance level for at least one horizon. In particular, there is statistical evidence of asymmetry for manufacturing (NAICS) at all horizons, and for manufacturing (SIC) at all horizons but *h*=0, 4. Only for non durable consumer goods, food, beverage and tobacco, textiles and products, petroleum and coal products, primary metal, and other transportation equipment are we not able to reject the null of symmetry.

[6] Impulse response functions for VARs using monthly data are typically computed for horizons of at least 12 months. Here, given the computational burden involved in computing the test for 37 indices and 3 oil price measures, we restrict ourselves to 12 months after the shock. See Tables A.2-A.7 of the on-line appendix at http://www.clas.wayne.edu/multimedia/usercontent/File/herrera/HLWappendix.pdf.

Our finding of asymmetry in the response of the IP indices suggests that the oil price-industrial production relationship is nonlinear. However, it has been argued that measures of oil price shocks that take into account the environment in which the increase took place do a better job at capturing the nature of the nonlinearity (see for instance Lee, Ni and Ratti, 1995 and Hamilton, 1996, 2003). Hence, we re-estimate the model (5) where $x_t^{\#}$ is now defined as the net oil price increase over the previous 12-month maximum, x_t^{12}. We then compute the test of symmetry of the IRF to typical and large oil price shocks. The test results for a typical and large shock are reported in the second panel of Tables 2 and 3, respectively. Test results for all horizons *h*=0,1,...,12 are reported in Tables A.3 and A.6 of the on-line appendix.

Our test results suggest there is some evidence of nonlinearity in the response of industrial production when we use the net oil price increase over the previous 12-month maximum. For a typical shock, we reject the null of symmetry for 19 indices at one or more horizons. For large shocks, evidence of asymmetry is considerably stronger: we can reject the null of a symmetry for 34 indices at one or more horizons. Only for three indices --food, beverage and tobacco, periodicals, books and other, and pottery, ceramics and plumbing fixtures-- is there no evidence of nonlinearity in the response to an oil price shock.

As a robustness check, we also compute the impulse response based tests for the net increase over the previous 36-month maximum ($x_t^{\#} = x_t^{36}$). The estimation results for a typical and a large shock are reported in the third panel of Tables 2 and 3, respectively. As can be seen by comparing the results for $x_t^{\#} = x_t^{12}$ and $x_t^{\#} = x_t^{36}$, the results for the 36-month maximum are somewhat weaker. For both a typical and a large oil price shock we can reject the null of symmetry for at least 14 of the indices at one or more horizons (See tables A.4 and A.7 of the on-line appendix). The main difference between the two measures is that we find less statistical evidence of a nonlinear effect using x_t^{36} than with x_t^{12} for sectors with samples that start in 1967 or later.[7]

But, how big is the difference between the response to positive and negative shocks? To illustrate the magnitude of this distance Figure 1 plots the responses $I_y(h,\delta)$ and $-I_y(h,-\delta)$ to a typical shock for the total IP index, manufacturing (SIC and NAICS), motor vehicles and parts, transit equipment, and chemical products. Figures A.1a - A.1e and A.2a - A.2e in the on-line appendix plot the responses for both a typical and a large shock for the total IP index, manufacturing, (SIC and NAICS), all the market groups, motor vehicles and parts, and all industry groups with data starting in 1972 or earlier. Note that to facilitate the comparison, we plot the response to a positive shock, $I_y(h,\delta)$, and the negative of the response to a negative shock, $-I_y(h,-\delta)$. The responses are measured in percentages and the horizontal axis represents months after the shock.

As can be seen in Figure 1, the responses to a typical shock look very similar. Differences are noticeable mostly at short (*h*<5) or long horizons (*h*>10), especially for the total IP index and manufacturing (SIC and NAICS). For instance, depending on the nonlinear transformation of oil prices, at *h*=11 the value of the response to a positive shock, $I_y(h,\delta)$ for the total IP is between 40% and 67% larger than the response to a negative shock, $-I_y(h,-\delta)$. Similarly, the difference for manufacturing SIC (NAICS) $I_y(h,\delta)$ is between 27% (17%) and 50% (26%) larger than $-I_y(h,-\delta)$, depending on the oil price measure. Results not reported herein- but available on the on-line appendix[8]-- illustrate that for a large shock the initial difference between the two impulse responses might not seem large. Yet, for many indices the responses $I_y(h,\delta)$ and

[7] Oil price shocks have a statistically significant effect only for 3 of the 10 sectors where we cannot reject the null of symmetry (textiles and products, electrical equipment and clay product and refractory).
[8] See Figures A.2a-A.2e in the on-line appendix.

$-I_y(h,-\delta)$diverge more as time passes. For instance, for the total IP and manufacturing (SIC and NAICS), the response to a positive shock is more than twice the size of the response to a negative shock at *h*=12.

To summarize, we find evidence against the joint null of linearity and symmetry for most of the aggregates, most of the market groups and some of the industry groups. Furthermore, statistical evidence in favor of a nonlinear relationship between oil prices and industrial production appears to be stronger for the net oil price increase measure over the 12-month maximum (Hamilton 1996) than for the positive oil price change proposed by Mork (1989). These results suggest that inferring the effect of unanticipated oil price shocks on economic activity from the usual linear impulse response analysis might be flawed, especially for the aggregates and some sectors such as motor vehicles and chemicals. Departures from symmetry for a typical one standard deviation shock measured as the ratio of the positive to negative response range from 17% to 67% for the total IP index and the aggregates, depending on the nonlinear transformation. In contrast, a linear approximation might work well for the typical shocks in a number of industries.

4.2 The effect of dropping the pre-1973 data

The test results reported in the previous section suggest that contrary to what was found by KV for aggregate GDP data on a shorter sample, unexpected oil price increases and decreases appear to have an asymmetric effect on industrial production. Two possible explanations for such a difference --that cannot be directly tested-- stem from differences in the computation of GDP and IP indices. First, whereas GDP is a measure of the value added in the economy, the IP index measures gross output. Second, the IP index excludes services, a sector that has gained importance over time in the U.S. economy and that being less energy intensive (in use and consumption) than manufacturing is less likely to exhibit a significant response to oil price shocks. A third (and testable) possible source of divergence is the difference in the sample period due to a structural break in the predictive relationship between the real price of oil and U.S. output in 1973 (see KV). Hence, in this section we report the results for the 1973:1-2009:9 subsample. Tables 4 and 5 report the results for these IRF based test for one and two standard deviations shocks at horizons *h*=0,1,6,12, respectively. Tables for horizons *h*=0,1,2,...,12 are available in section 2 of the on-line appendix (see Tables A.16-A.21).

There are two reasons why we could expect these results to be different from the full sample. One is that the responses are likely to be different, given statistical evidence of a structural break in 1973. The other is that reducing the number of observations in the sample increases estimation uncertainty and, all else equal, would be expected to lower the power of tests and to reduce the number of rejections for the 1973-2009 subsample, if asymmetry holds. As we will show below, the loss of power alone cannot explain our findings.

For a typical shock, we find that the test statistic is significant at the 5% level for at least one horizon for 11, 7 and 10 of the 29 IP indices in the subsample using the oil price measure $x_t^{\#} = x_t^1, x_t^{12}, x_t^{36}$, respectively. (See Tables A.16-A.18 in section 2 of the on-line appendix). As it can be seen in Table 4, for the total IP index we are only able to reject the null of symmetry at the 10% level for *h*=1 when we use the oil price increase ($x_t^{\#} = x_t^1$) or the net oil price increase with respect to the previous 12 months ($x_t^{\#} = x_t^{12}$). Evidence of asymmetry for manufacturing (SIC and NAICS) is also less prevalent and less consistent across oil price measures in the 1973:1-2009:9 subsample. Yet, as it is the case for the full sample, the number of rejections is considerably larger when we test for symmetry in the response to a large shock. We reject the null at the 5% level for 22, 27 and 12 of the 29 IP indices in the subsample using the oil price measure $x_t^{\#} = x_t^1, x_t^{12}, x_t^{36}$, respectively (See Tables A.19-A.21 in section 2 of the on-line appendix).

All in all, these results are consistent with KV's original conclusion that a linear model appears to provide a good approximation to the response of aggregate measures of economic activity to a typical real oil price innovation in post-1973 data. For large oil price innovations, however, nonlinear asymmetric models appear to provide a marginally better approximation to the response of both aggregate and sectoral IP indices to oil price shocks.

4.3 Should we interpret the sectoral rejections as evidence of nonlinearity at the aggregate level?

The results from the IRF based tests allow two interpretations. First, one could interpret the rejections as evidence against linearity in the response of a particular IP index to an oil price shock. That is, rejecting the null for a number of sectors would not be taken as evidence that the response of IP as a whole is nonlinear. Instead, one would consider this as evidence that the response of the particular sector is better approximated by a nonlinear model. Such an interpretation is straightforward and does not require additional discussion.

However, a second interpretation would take a large number of rejections as evidence against linearity in the response of aggregate production measured by the total IP index. Moreover, because the total IP index and the aggregates are constructed as a weighted average of the production indices (with weights that change over time), one may expect aggregation across industries to "average out" the nonlinearities if the number of rejections is small. Our estimation results appear to run against this view as in the full sample we reject the null of symmetry for the total IP index and for manufacturing but not for a large number of industries. To understand this result it is important to recall that the effect of a shock that affects a number of industries, such as an oil price increase, depends on two factors: the behavior of the sectoral weights and the degree of comovement across sectors. Work by Foerster, Sarte and Watson (2008) suggests that sectoral weights play little role in explaining the variability of the total IP index. Instead, they find that as in Shea (2002), variability of the total IP index is mainly driven complementarities in production, such as input-output linkages, which work as propagation mechanisms for aggregate and sectoral shocks. While quantifying the importance of these two factors is beyond the scope of our paper, our results in conjunction with Foerster, Sarte and Watson's (2008) findings suggest that the covariability among sectors plays an important role in explaining the response of the aggregates to oil price shocks.

4.4 The effect of data mining

One additional concern with interpreting the disaggregate results as evidence of asymmetry at the aggregate level is that there is an element of data mining involved. That is, such an interpretation would ignore the fact that we have conducted 37 Wald tests for each oil price measure. Conventional critical values do not account for repeated applications of the IRF based test to alternative IP indices.[9] To address this concern we simulate the null distribution of the supremum of the bootstrap test statistic across all disaggregates for each of the oil price measures.[10] Test statistics that are significant at 5% and 10% level are denoted by ** and *, respectively, in Tables 2-5.

[9] See Inoue and Kilian(2004) and Kilian and Vega (2010) for the effect of data mining and solutions to the problem of data mining in the related context of tests of predictability.

[10] The critical values that account for data mining are based on 100 pseudo series generated using the estimated coefficients for the subsample that covers all 37 indices for the full sample and 29 indices for the 1973-2009

As one would expect, accounting for data mining reduces the number of rejections. Using the full sample and a typical shock, we are still able to reject the null of symmetry at the 5% level for at least one horizon for the total IP index and SIC manufacturing across all oil price measures (see Table 2). Evidence of asymmetry is more prevalent for Mork's (1989) oil price increase ($x_t^{\#} = x_t^1$) than for the net oil price increase and it is consistent across at least two oil price measures for foods and tobacco, durable consumer goods, miscellaneous durable goods, and transit equipment.

Using the full sample and a large shock, and accounting for data mining, we are able to reject the null of symmetry at the 5% level for one horizon for the total IP index and SIC manufacturing using the net oil price increase over the previous 36-month maximum (see Table 3). In addition, at the 5% level we are able to reject the null of symmetry for at least one horizon for transit equipment using the net oil price increase over the previous 12-month maximum.

For the 1973-2009 subsample and a typical shock, evidence of asymmetry is found for at least one horizon using one of the oil measures for transit equipment, foods and tobacco, food, beverage and tobacco, petroleum and coal, plastics and rubber, and machinery; we are able to reject the null of symmetry for at least one horizon using one of the oil measures at the 5% level. However, once we account for data mining, we do not find any evidence of asymmetry using the subsample and a large shock. This finding illustrates that much of the evidence of asymmetries appears to be driven by data from the pre-1973 period. This is consistent both with the view that tests on the subsample have lower power against the null of symmetry and the view that there was a structural change in the transmission of oil price shocks in 1973.

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subsample. For each series, we use 100 replications to obtain the conditional IRFs (R=100 in section 1 of the on-line appendix) and 100 bootstraps to get the test statistic.

5. Conclusions

The view that the oil price-output relationship is asymmetric and nonlinear has been questioned by KV. They showed that conventional censored oil price VAR studies of the macroeconomic effect of oil price shocks generally produce inconsistent estimates of the true effects of unanticipated increases in the price of oil due to the censoring applied to the oil price variable. Their paper stresses the importance of correctly specifying the model to be estimated, of using appropriate estimators, and of formally testing the dynamic effects of unexpected oil price changes on U.S. real GDP, when the underlying dynamic relationship is possibly asymmetric and/or nonlinear.

This paper explored these same issues in the context of monthly U.S. industrial production data. We first tested for nonlinearity in the slope of a reduced-form relation between domestic real economic activity and the real price of oil. We found evidence of asymmetric slopes for 15 of the 37 indices using the oil price increase, x_t^1, and for 19 (25) indices using the net oil price increase, $x_t^{12}(x_t^{36})$.

We also explored whether our findings are robust to the inclusion of the contemporaneous value of the oil price series, as suggested by KV. The results for this slope based test are very similar to those obtained using the forecasting equation. We find evidence of asymmetric slopes for 24 out of the 37 indices, using the oil price increase, x_t^1, and for 23 (24) IP indices using the net oil price increase over the previous 12 (36) month maximum.

Evidence of nonlinearity is even stronger when we use the IRF based test proposed by KV, in particular for the net oil price increase measures. We reject the null of symmetry for at least 70% of the IP indices for typical shocks and for most of the indices if the oil price shock is large. Departures from symmetry are economically significant for the typical shock, especially for the total IP index, manufacturing (SIC and NAICS) and sectors such as motor vehicles and chemicals. For larger shocks, departures from symmetry are economically significant for an additional number of industries. These results, however, become much weaker after accounting for the data mining that is inherent in evaluating many industrial production indices.

The baseline results are highly sensitive to whether pre-1973 data are included in the regression or not, possibly due to a structural break in the predictive relationship between the real price of oil and U.S. economic activity in 1973 (see, e.g., Kilian and Vigfusson, 2010). For the post-1973 period we find no evidence against the hypothesis that aggregate industrial production responds symmetrically to oil price innovations of typical magnitude, consistent with findings for real GDP growth in Kilian and Vigfusson (2009, 2010). Yet, there is strong evidence against the hypothesis of symmetric responses at the disaggregate level, even after accounting for data mining, for the 3-year net oil price increase specification. This finding is important because it shows that even on post-1973 data, the impulse response based test has sufficient power to detect departures from the joint null hypothesis of linearity and symmetry.

Like Kilian and Vigfusson (2010), we also find that there is statistically significant evidence of asymmetric aggregate responses to large oil price innovations in the 1973-2009 data. There is no evidence of corresponding significant rejections at the sectoral level in response to such large oil price innovations, however, perhaps because such shocks are rare and imprecisely estimated, undermining the power of the test.

Table 1 : Slope based test of nonlinearity

	Forecasting Equation			Structural Equation		
Sector	$x_t^{\#} = x_t^1$	$x_t^{\#} = x_t^{12}$	$x_t^{\#} = x_t^{36}$	$x_t^{\#} = x_t^1$	$x_t^{\#} = x_t^{12}$	$x_t^{\#} = x_t^{36}$
Total index	0	0.04	0	0	0.01	0
Foods and tobacco	0	0.01	0	0	0.01	0
Clothing	0.01	0.12	0.77	0.01	0.11	0.69
Durable consumer goods	0.08	0.38	0.04	0.02	0.14	0.04
Miscellaneous durable goods	0.29	0.01	0.01	0.03	0	0
Nondurable consumer goods	0.04	0	0	0.03	0	0
Manufacturing (SIC)	0	0.08	0	0	0.03	0
Paper products	0.01	0.02	0.04	0.01	0.01	0.06
Chemical products	0	0.1	0	0	0.03	0
Transit equipment	0.18	0.11	0	0.17	0.1	0
Textiles materials	0.12	0.03	0.07	0.06	0.01	0.06
Paper materials	0.07	0.03	0.02	0.03	0	0.01
Chemical materials	0.07	0.04	0.04	0.07	0.03	0.03
Motor vehicles and parts	0	0.57	0.14	0	0.3	0.15
Food, beverage and tobacco	0.15	0.21	0	0.12	0.19	0
Textiles and products	0.66	0.03	0.1	0.48	0.02	0.11
Apparel and leather goods	0.5	0.15	0.45	0.26	0.15	0.39
Paper	0.08	0.01	0.02	0.04	0	0.01
Printing and related	0.06	0.19	0.42	0.01	0.01	0.2
Chemicals	0	0.12	0.16	0	0.1	0.08
Petroleum and coal	0.89	0.52	0.16	0.84	0.47	0.15
Plastics and rubber	0.15	0.01	0	0.03	0.01	0
Furniture	0.06	0.01	0.03	0	0	0.02
Primary metal	0.34	0.19	0.02	0.32	0.11	0
Fabricated metal	0.53	0	0	0.3	0	0
Machinery	0.11	0	0.02	0.05	0	0.01
Electrical equipment	0.07	0.01	0.01	0.03	0	0.01
Motor vehicles	0	0.04	0	0	0	0
Manufacturing (NAICS)	0.01	0.05	0	0	0.02	0
Newspaper	0.01	0.07	0	0.01	0.02	0
Periodical books and other	0.03	0.16	0	0.04	0.14	0.01
Pottery, ceramics and plumbing	0.1	0.79	0.83	0.11	0.85	0.8
Glass and glass products	0	0	0.18	0	0	0.26
Clay product and refractory	0.36	0.37	0.62	0.33	0.33	0.7
Industrial machinery	0.09	0.18	0.3	0.06	0.08	0.2
Other transportation equipment	0.3	0	0.01	0.24	0	0.01
Navigational, measuring and other	0.01	0.19	0	0	0.16	0

Note: This table reports the p-values for a Robust Wald Test of the joint significance of the lags of $x_t^{\#}$ in the reduced-form equation (4)

Table 2. IRF based test of symmetry to 1 s.d. shock - Full sample

	$x_t^{\#} = x_t^1$				$x_t^{\#} = x_t^{12}$				$x_t^{\#} = x_t^{36}$			
Sector	0	1	6	12	0	1	6	12	0	1	6	12
Total index	0.1	0.06	0.04	0.04**	0.00**	0.00**	0.02**	0.00**	0.55	0.14	0.06*	0.00**
Foods and tobacco	0.29	0.14	0.04	0.16	0.34	0.33	0.00**	0.00**	0.51	0.77	0.11	0.01**
Clothing	0.02	0.04	0.07	0.27	0.16	0.36	0.02**	0.01**	0.66	0.79	0.96	0.75
Durable consumer goods	0.03	0.04	0.08	0.16	0.00**	0.00**	0.00**	0.00**	0.44	0.09	0.06*	0.01**
Miscellaneous durable goods	0.00**	0.01	0.07	0.18	0.00**	0.00**	0.03**	0.01**	0.32	0.08	0.09*	0.03**
Nondurable consumer goods	0.2	0.27	0.11	0.35	0.11	0.07	0.01**	0.00**	0.93	0.35	0.11	0.06**
Manufacturing (SIC)	0.05	0.01	0.03	0.07**	0.00**	0.00**	0.01**	0.01**	0.47	0.09	0.05*	0.00**
Paper products	0.21	0.3	0.05	0.10*	0.39	0.63	0.09*	0.17**	0.95	0.87	0.7	0.09**
Chemical products	0.85	0.22	0.16	0.09*	0.02	0.03	0.11*	0.10**	0.6	0.26	0.09*	0.20*
Transit equipment	0.42	0.04	0.03	0.08**	0.28	0.00**	0.01**	0.00**	0.6	0.73	0.03**	0.00**
Textiles materials	0.08	0.01	0.02**	0.13	0.04	0.11	0.47	0.44	0.05	0.11	0.42	0.53
Paper materials	0.08	0.03	0.21	0.23	0.01	0.04	0.13	0.48	0.15	0.34	0.5	0.66
Chemical materials	0.71	0.00**	0.02**	0.07**	0.6	0.03	0.27	0.32	0.92	0.15	0.35	0.49
Motor vehicles and parts	0.68	0.01	0.00**	0.00**	0.27	0.04	0.23	0.37	0.64	0.05	0.29	0.66
Food, beverage and tobacco	0.47	0.16	0.14	0.57	0.7	0.82	0.58	0.89	0.37	0.07	0.12	0.41
Textiles and products	0.11	0.09	0.42	0.68	0.18	0.28	0.52	0.78	0.88	0.11	0.49	0.88
Apparel and leather goods	0.03	0.08	0.32	0.62	0.55	0.8	0.43	0.69	0.91	0.44	0.53	0.44
Paper	0.11	0.02	0.16	0.48	0.1	0.24	0.5	0.83	0.17	0.26	0.4	0.78
Printing and related	0.01	0.03	0.11	0.29	0.02	0.06	0.32	0.76	0.11	0.22	0.64	0.83
Chemicals	0.69	0.00**	0.00**	0.02**	0.54	0.2	0.57	0.75	0.32	0.03	0.08*	0.31*
Petroleum and coal	0.26	0.17	0.75	0.96	0.18	0.14	0.75	0.88	0.03	0.07	0.06*	0.35
Plastics and rubber	0.03	0.07	0.39	0.09*	0.2	0.37	0.74	0.67	0.7	0.26	0.26	0.30*
Furniture	0.01	0.04	0.17	0.45	0.02	0.06	0.35	0.65	0.07	0.18	0.35	0.54
Primary metal	0.32	0.19	0.61	0.83	0.11	0.04	0.34	0.73	0.07	0.18	0.35	0.54
Fabricated metal	0.09	0.04	0.29	0.68	0.06	0.04	0.43	0.68	0.1	0.05	0.33	0.57
Machinery	0.09	0.03	0.17	0.56	0.16	0.06	0.39	0.64	0.11	0.06	0.22	0.47
Electrical equipment	0.07	0.17	0.43	0.12*	0.08	0.15	0.62	0.57	0.25	0.35	0.78	0.81
Motor vehicles	0.46	0.01	0.08	0.27	0.04	0.04	0.39	0.73	0.99	0.04	0.33	0.75
Manufacturing (NAICS)	0.06	0	0.02*	0.12*	0.07	0.08	0.51	0.87	0.6	0.07	0.33	0.62
Newspaper	0.96	0.27	0.17	0.55	0.14	0.21	0.5	0.89	0.12	0.13	0.34	0.8
Periodical books and other	0.36	0.17	0.25	0.68	0.41	0.69	0.8	0.98	0.62	0.16	0.45	0.81
Pottery, ceramics and plumbing	0.3	0.06	0.12	0.39	0.37	0.59	0.7	0.95	0.65	0.72	0.83	0.99
Glass and glass products	0.16	0.28	0.25	0.62	0.24	0.38	0.79	0.85	0.46	0.75	0.93	0.98
Clay product and refractory	0.76	0.32	0.42	0.85	0.17	0.27	0.62	0.91	0.61	0.36	0.8	0.96
Industrial machinery	0.26	0.16	0.42	0.78	0.04	0.12	0.58	0.67	0.12	0.3	0.51	0.7
Other transportation equipment	0.26	0.28	0.54	0.85	0.96	0.77	0.5	0.84	0.41	0.58	0.68	0.94
Navigational, measuring and other	0.11	0.27	0.2	0.48	0.91	0.35	0.76	0.82	0.72	0.25	0.35	0.63

Table 3. IRF based test of symmetry for 2 s.d. shock - Full sample

	$x_t^\# = x_t^1$				$x_t^\# = x_t^{12}$				$x_t^\# = x_t^{36}$			
Sector	0	1	6	12	0	1	6	12	0	1	6	12
Total index	0.15	0.1	0.06	0.01	0	0	0	0	0.2	0.01	0.04	0.00**
Foods and tobacco	0.34	0.21	0.06	0.1	0.38	0.44	0	0	0.17	0.03	0	0.00*
Clothing	0.02	0.05	0.04	0.13	0.16	0.38	0.01	0	0.35	0.64	0.72	0.38
Durable consumer goods	0.04	0.04	0.06	0.06	0	0	0	0	0.12	0.01	0.06	0.00*
Miscellaneous durable goods	0.01	0.02	0.11	0.2	0	0	0.01	0	0.03	0	0.07	0
Nondurable consumer goods	0.24	0.35	0.15	0.34	0.11	0.1	0	0	0.86	0.03	0	0.00*
Manufacturing (SIC)	0.07	0.02	0.04	0.04	0	0	0	0	0.11	0	0.04	0.00**
Paper products	0.27	0.38	0.03	0.01	0.39	0.56	0.01	0	0.79	0.41	0.13	0.01
Chemical products	0.86	0.26	0.2	0.04	0.02	0.04	0.24	0	0.08	0.06	0.08	0.04
Transit equipment	0.47	0.08	0.01	0	0.39	0.01	0	0.00**	0.07	0.01	0.03	0
Textiles materials	0.1	0.01	0.01	0.05	0.01	0.05	0.07	0	0.04	0.13	0.21	0.03
Paper materials	0.09	0.02	0.12	0.03	0	0.01	0.01	0	0.15	0.28	0.38	0.14
Chemical materials	0.72	0	0	0	0.59	0	0.01	0.00*	0.91	0.1	0.05	0
Motor vehicles and parts	0.71	0	0	0	0.24	0	0	0	0.66	0.01	0.03	0.12
Food, beverage and tobacco	0.49	0.17	0.07	0.29	0.65	0.77	0.09	0.11	0.38	0.06	0.06	0.21
Textiles and products	0.12	0.09	0.27	0.35	0.11	0.12	0.11	0.02	0.89	0.07	0.33	0.47
Apparel and leather goods	0.02	0.06	0.08	0.1	0.46	0.71	0.11	0.07	0.96	0.46	0.39	0.45
Paper	0.11	0.01	0.08	0.11	0.02	0.06	0.03	0.01	0.16	0.33	0.41	0.53
Printing and related	0	0.01	0.01	0.02	0	0	0	0	0.07	0.11	0.2	0.46
Chemicals	0.72	0	0	0	0.47	0.04	0.15	0	0.35	0.01	0.04	0.12
Petroleum and coal	0.3	0.19	0.77	0.96	0.12	0.04	0.45	0.23	0.02	0.08	0.11	0.2
Plastics and rubber	0.03	0.07	0.26	0	0.07	0.13	0.08	0	0.71	0.27	0.02	0.1
Furniture	0.01	0.02	0.04	0.08	0	0	0	0	0.06	0.16	0.13	0.17
Primary metal	0.36	0.2	0.51	0.69	0.06	0.01	0.01	0.01	0.03	0.1	0.15	0.27
Fabricated metal	0.11	0.04	0.18	0.4	0.01	0	0.01	0	0.1	0.01	0.13	0.21
Machinery	0.09	0.02	0.05	0.25	0.08	0	0	0	0.07	0.01	0.06	0.11
Electrical equipment	0.08	0.18	0.32	0.01	0.02	0.01	0.09	0	0.23	0.29	0.44	0.45
Motor vehicles	0.46	0.01	0.01	0.01	0	0.01	0	0	0.99	0.02	0.06	0.17
Manufacturing (NAICS)	0.05	0	0	0.01	0	0	0.01	0	0.59	0.01	0.03	0.13
Newspaper	0.96	0.24	0	0	0.06	0.02	0.03	0.13	0.11	0.01	0.04	0.24
Periodical books and other	0.32	0.09	0	0.03	0.3	0.51	0.11	0.14	0.61	0.07	0.21	0.6
Pottery, ceramics and plumbing	0.28	0.03	0	0	0.24	0.26	0.12	0.5	0.6	0.76	0.83	0.99
Glass and glass products	0.12	0.19	0	0	0.11	0.08	0	0.01	0.41	0.63	0.43	0.72
Clay product and refractory	0.75	0.24	0.07	0.27	0.09	0.04	0.11	0.14	0.59	0.19	0.69	0.85
Industrial machinery	0.25	0.1	0.03	0.04	0.01	0.01	0.03	0.01	0.1	0.14	0.39	0.36
Other transportation equipment	0.22	0.17	0.16	0.25	0.96	0.7	0.02	0	0.38	0.62	0.38	0.81
Navigational, measuring and other	0.1	0.25	0.04	0.04	0.94	0.16	0.15	0.01	0.71	0.19	0.11	0.26

Table 4. IRF based test of symmetry to 1 s.d. shock - 1973-2009 subsample

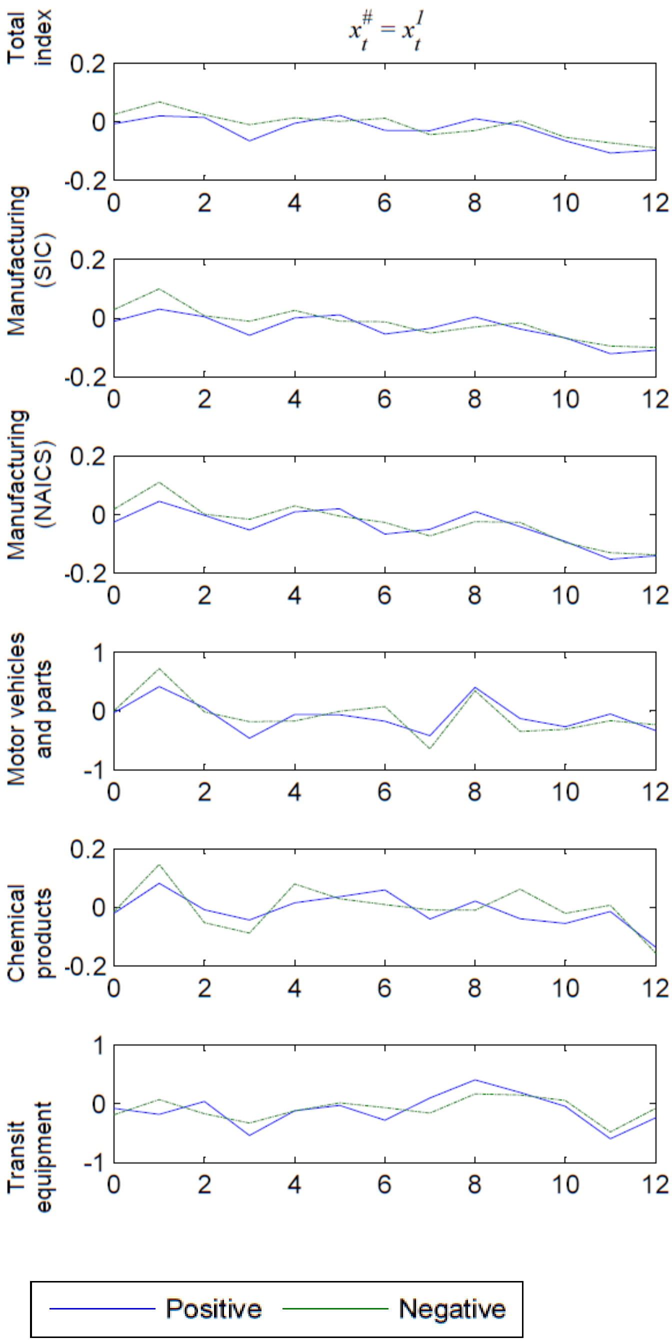
	$x_t^{\#} = x_t^1$				$x_t^{\#} = x_t^{12}$				$x_t^{\#} = x_t^{36}$			
Sector	0	1	6	12	0	1	6	12	0	1	6	12
Total index	0.14	0.06	0.07	0.18	0.12	0.09	0.5	0.74	0.88	0.18	0.65	0.8
Foods and tobacco	0.29	0.13	0.31	0.57	0.42	0.62	0.77	0.96	0.28	0.11	0.06**	0.33
Clothing	0.09	0.2	0.47	0.71	0.86	0.5	0.47	0.71	0.8	0.25	0.34	0.67
Durable consumer goods	0.11	0.08	0.13	0.27	0.22	0.3	0.84	0.94	0.99	0.08	0.22	0.66
Miscellaneous durable goods	0.02	0.07	0.51	0.81	0.07	0.12	0.44	0.78	0.15	0.13	0.26	0.63
Nondurable consumer goods	0.13	0.29	0.53	0.75	0.31	0.59	0.65	0.92	0.41	0.26	0.76	0.97
Manufacturing (SIC)	0.09	0.03	0.11	0.42	0.14	0.06	0.39	0.74	0.53	0.06	0.21	0.26
Paper products	0.15	0.33	0.06	0.29	0.42	0.49	0.42	0.66	0.69	0.37	0.21	0.47
Chemical products	0.68	0.17	0.14	0.28	0.22	0.44	0.76	0.97	0.19	0.28	0.29	0.62
Transit equipment	0.5	0.12	0.14	0.38	0.23	0.13	0.43	0.48	0.02*	0.00**	0.01**	0.00**
Textiles materials	0.14	0.06	0.19	0.46	0.07	0.16	0.34	0.7	0.2	0.29	0.2	0.48
Paper materials	0.07	0.02	0.22	0.29	0.04	0.11	0.44	0.86	0.31	0.31	0.3	0.72
Chemical materials	0.65	0.01	0.08	0.22	0.46	0.12	0.4	0.69	0.79	0.2	0.08	0.26
Motor vehicles and parts	0.71	0.02	0.07	0.2	0.27	0.12	0.52	0.73	0.34	0.02*	0.11	0.39
Food, beverage and tobacco	0.25	0.13	0.24	0.54	0.32	0.48	0.63	0.9	0.35	0.12	0.03**	0.24
Textiles and products	0.18	0.07	0.42	0.76	0.93	0.78	0.6	0.74	0.81	0.19	0.46	0.82
Apparel and leather goods	0.1	0.25	0.59	0.82	0.03	0.1	0.44	0.87	0.89	0.5	0.68	0.84
Paper	0.05	0.02	0.18	0.37	0.04	0.11	0.44	0.81	0.27	0.24	0.19	0.59
Printing and related	0.07	0.08	0.37	0.8	0.17	0.1	0.46	0.74	0.1	0.21	0.44	0.66
Chemicals	0.79	0	0.03	0.11	0.06	0.09	0.36	0.75	0.35	0.07	0.08	0.22*
Petroleum and coal	0.27	0.12	0.61	0.95	0.27	0.38	0.73	0.92	0.05	0.06	0.01**	0.10**
Plastics and rubber	0.07	0.18	0.64	0.63	0.03	0.11	0.44	0.75	0.96	0.31	0.2	0.07**
Furniture	0.03	0.09	0.38	0.55	0.03	0.11	0.44	0.75	0.11	0.16	0.26	0.54
Primary metal	0.52	0.2	0.54	0.81	0.05	0.05	0.4	0.63	0.06	0.15	0.21	0.13*
Fabricated metal	0.16	0.19	0.67	0.92	0.19	0.03	0.29	0.71	0.18	0.11	0.15	0.33
Machinery	0.1	0.06	0.25	0.61	0.07	0.15	0.7	0.87	0.08	0.14	0.09	0.11**
Electrical equipment	0.13	0.28	0.75	0.32	0.07	0.15	0.7	0.87	0.2	0.39	0.68	0.37
Motor vehicles	0.88	0.03	0.15	0.32	0.17	0.09	0.54	0.81	0.94	0.08	0.13	0.46
Manufacturing (NAICS)	0.1	0.03	0.12	0.43	0.16	0.06	0.39	0.74	0.57	0.06	0.2	0.26

Table 5. IRF based test of symmetry for 2 s.d. shock - 1973-2009 subsample

	$x_t^{\#} = x_t^1$				$x_t^{\#} = x_t^{12}$				$x_t^{\#} = x_t^{36}$			
Sector	0	1	6	12	0	1	6	12	0	1	6	12
Total index	0.01	0.01	0.02	0	0.24	0.06	0.23	0.03	0.67	0.03	0.05	0.09
Foods and tobacco	0.26	0.51	0.57	0.66	0.64	0.89	0.29	0.54	0.3	0.17	0.12	0.36
Clothing	0.06	0.14	0.08	0.08	0.84	0.37	0.11	0.03	0.88	0.27	0.37	0.63
Durable consumer goods	0.09	0.03	0	0	0.07	0	0.03	0.07	0.67	0.09	0.25	0.35
Miscellaneous durable goods	0.01	0.04	0.27	0.46	0.01	0	0.01	0	0.17	0.06	0.2	0.38
Nondurable consumer goods	0.11	0.24	0.35	0.53	0.22	0.44	0.02	0.02	0.53	0.2	0.28	0.69
Manufacturing (SIC)	0.06	0	0	0.02	0.04	0	0.01	0	0.56	0.02	0.03	0.1
Paper products	0.16	0.34	0	0.01	0.31	0.34	0.01	0.01	0.77	0.43	0.06	0.13
Chemical products	0.7	0.12	0.01	0	0.11	0.23	0.43	0.38	0.29	0.29	0.38	0.65
Transit equipment	0.54	0.1	0.01	0.01	0.18	0.03	0.02	0	0.06	0.03	0.12	0.09
Textiles materials	0.14	0.04	0.03	0.05	0.01	0.04	0.01	0	0.23	0.43	0.39	0.65
Paper materials	0.07	0.01	0.16	0.08	0.01	0.02	0.03	0.01	0.31	0.49	0.37	0.6
Chemical materials	0.66	0	0.01	0	0.38	0.01	0.05	0.01	0.79	0.06	0.05	0.06
Motor vehicles and parts	0.72	0	0	0	0.23	0.03	0.01	0.07	0.49	0.04	0.06	0.31
Food, beverage and tobacco	0.28	0.1	0.07	0.11	0.22	0.32	0.03	0.09	0.37	0.17	0.06	0.26
Textiles and products	0.18	0.04	0.19	0.41	0.06	0.12	0.01	0	0.89	0.2	0.42	0.63
Apparel and leather goods	0.06	0.18	0.17	0.23	0.94	0.7	0.21	0.06	0.98	0.58	0.64	0.78
Paper	0.04	0.01	0.07	0.06	0	0	0.01	0.01	0.28	0.44	0.28	0.5
Printing and related	0.04	0.03	0.11	0.26	0.01	0	0	0.01	0.11	0.18	0.2	0.5
Chemicals	0.8	0	0	0	0.11	0.01	0.05	0.07	0.42	0.02	0.07	0.13
Petroleum and coal	0.29	0.11	0.59	0.92	0.02	0.03	0.02	0.03	0.04	0.11	0.11	0.25
Plastics and rubber	0.07	0.19	0.49	0.07	0.2	0.23	0.04	0	0.95	0.33	0.06	0.03
Furniture	0.02	0.06	0.09	0.11	0	0.01	0	0	0.09	0.21	0.21	0.36
Primary metal	0.54	0.19	0.52	0.64	0.09	0.04	0.11	0.05	0.06	0.13	0.1	0.15
Fabricated metal	0.16	0.14	0.54	0.8	0.01	0	0	0	0.2	0.04	0.23	0.45
Machinery	0.08	0.04	0.09	0.17	0.07	0	0	0	0.09	0.05	0.18	0.21
Electrical equipment	0.13	0.25	0.56	0.04	0.02	0.02	0.12	0	0.21	0.31	0.28	0.41
Motor vehicles	0.89	0.01	0.01	0	0.11	0	0.01	0.06	0.96	0.07	0.04	0.17
Manufacturing (NAICS)	0.07	0	0	0.02	0.06	0	0.01	0	0.6	0.03	0.04	0.11

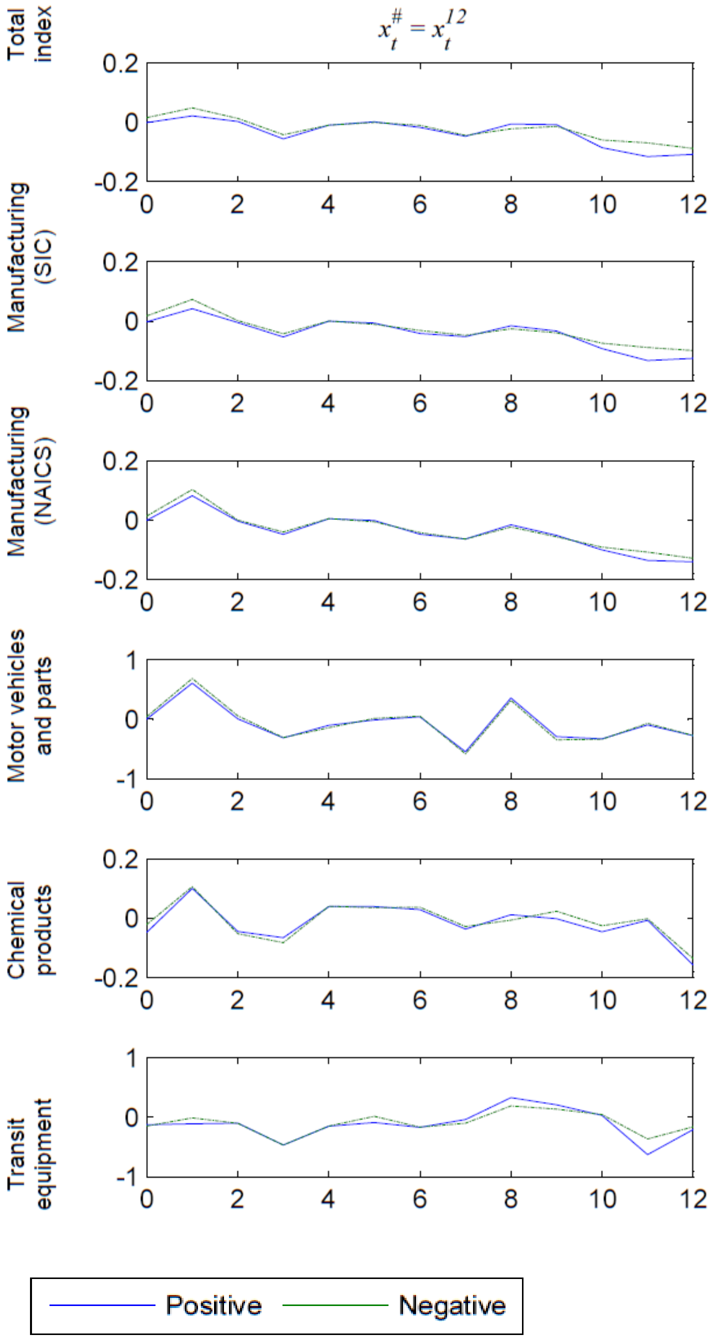
Notes for Tables 2-5: Tests are based on 1000 simulations of model (5) . p-values are based on the χ^2_{H+1}. Bold and italics denote significance at the 5% and 10% level, respectively. ** and * denote significance after accounting for data mining at the 5% and 10% level, respectively.

Figure 1a: Impulse Response to two standard deviation positive and negative shocks to the real oil price (percentage)



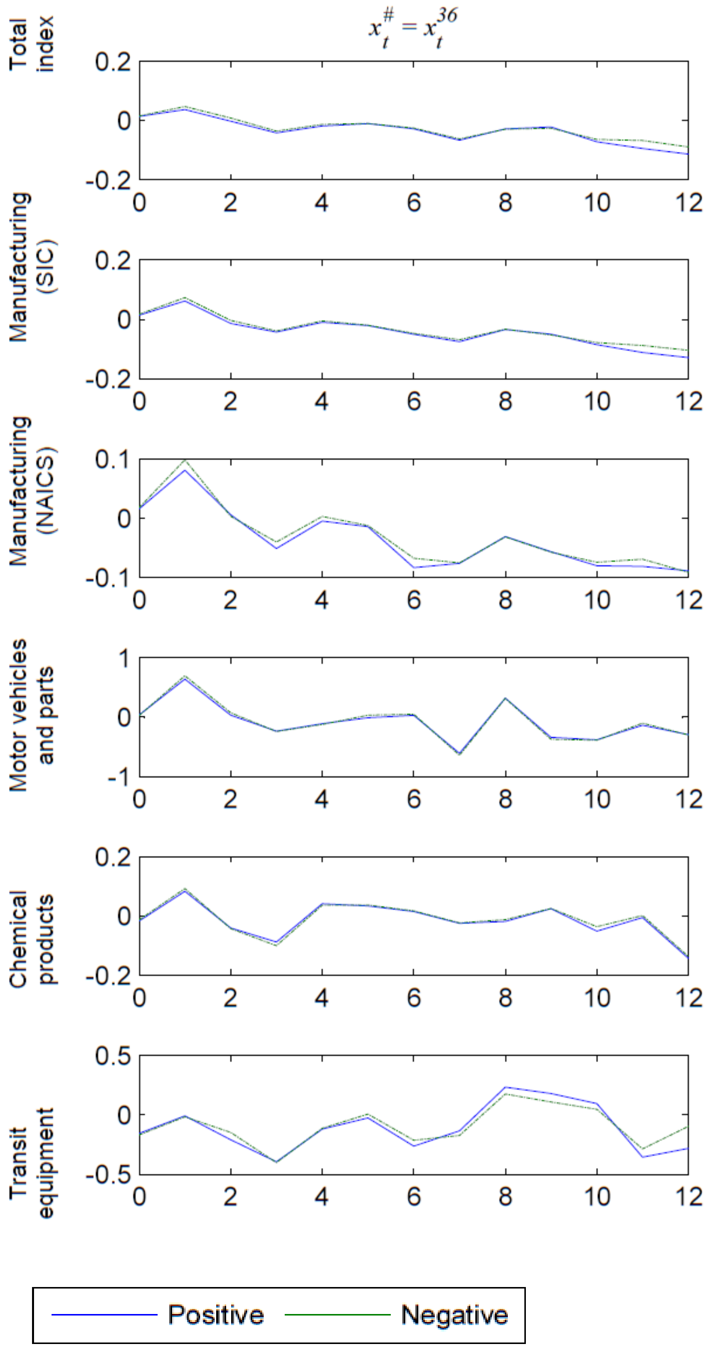
Note: Estimates are based on VAR in (5) where the number of replications to obtain the IRFs equal 1000.

Figure 1b: Impulse Response to two standard deviation positive and negative shocks to the real oil price (percentage)



Note: Estimates are based on VAR in (5) where the number of replications to obtain the IRFs equal 1000.

Figure 1c: Impulse Response to two standard deviation positive and negative shocks to the real oil price (percentage)



Note: Estimates are based on VAR in (5) where the number of replications to obtain the IRFs equal 1000.

CHAPTER 2 NONLINEARITIES IN THE OIL PRICE-INDUSTRIAL PRODUCTION RELATIONSHIP: EVIDENCE FROM 18 OECD COUNTRIES[1]

1. Introduction

Since the oil price shocks of the 1970s, economists have considered oil price movements as a main source of fluctuations in macroeconomic aggregates. A negative correlation between energy prices and aggregate measures of output has been reported for the United States,[2] Canada, Japan, the United Kingdom, Germany, France, Belgium, Austria, Ireland, Luxemburg, Netherlands, Denmark, Greece, and Sweden. Until recently, there appeared to be a widespread agreement that unexpected increases in the price of oil lead to recessions in industrialized oil-importing economies while oil price decreases did not lead to booms. In other words, the effect of unexpected oil price shocks on economic activity has been thought to be asymmetric.[3]

Amongst different reasons why an oil shock affects macroeconomic variables, some of them might require a non-linear specification of the oil price--macroeconomy relationship (Cunado and Gracia 2005). The oil price shock can work by redistributing income between net oil importing and net oil exporting countries. Alternately, it might lead to fall in productivity due to reduced energy use and hence fall in labor supply due to lower wages directly affecting potential output (Cunado and Gracia 2005). Furthermore, it may have a nonlinear effect on economic activity if it affects through sectoral reallocations of resources (see for instance,

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[1] Co-authored with Ana María Herrera and Tatsuma Wada. The authors thank Elena Pesavento, Lutz Kilian, and seminar participants at Emory University and Midwestern Economic Association 2011 Conference.

[2] Evidence of a negative effect of oil price shocks on U.S. economic activity has been found by Rasche and Tatom (1977, 1981), Hamilton (1988, 1996, 2003), Burbidge and Harrison (1984), Gisser and Goodwin (1986), Rotemberg and Woodford (1996), Daniel (1997), and Carruth, Hooker, and Oswald (1998), among others.

[3] Mork, Mysen and Olsen (1994) find a significant relationship between oil price increases and slower economic growth for net importing countries such as the U.S., Canada, Japan, the U.K., Germany and France, and a positive relation for Norway. These results are confirmed by Cuñado and Pérez de Gracia (2003) for some nonlinear transformations of oil prices using a sample of European countries covering the 1960-1999 period. Similar but somewhat weaker results are found by Jiménez-Rodríguez and Sánchez (2005) for a number of OECD countries.

Hamilton, 1988; Bresnahan and Ramey, 1993; Davis and Haltiwanger, 2001) or depressing irreversible investment through their effects on uncertainty. The former literature argues that after an oil price shock, the reallocation of capital and labor is slow and costly due to search and matching issues. Costly sectoral reallocation would thus amplify the negative impact of a real oil price increase on economic activity, while mitigating the positive effect of a real oil price decrease. Further, the dispersion hypothesis of Lilien (1982) states that sectors that use oil as an input witness a decline further contributing to the sectoral imbalances created by coordination failures between firms (Huntington 2000).

The next explanation involves the impact of heightened uncertainty about future oil prices on consumption and investment decisions. That is, in the wake of an oil price increase, uncertainty regarding the future price of crude oil would cause individuals to abstain from purchasing energy-intensive consumer durables such as automobiles. Similarly, uncertainty regarding the future price of oil would cause investors to postpone their purchases of capital goods (see for instance Bernanke, 1983, Dixit and Pindyck, 1993, and Pindyck, 1991). Hence, heightened uncertainty would also amplify the recessionary effect of an oil price increase and mitigate the expansionary impact of an oil price decrease. Finally, a theoretical justification for the presence of asymmetries relies on the asymmetric response of the monetary authorities to oil price increases and decreases. In particular, in the case of the U.S., it has been argued that the Federal Reserve responds more aggressively to rises in crude oil prices than it does to falls (e.g., Bernanke, Gertler and Watson, 1997). Yet, empirical evidence regarding the role of monetary policy in amplifying the recessionary effect of oil price shocks is rather weak (see, e.g., Hamilton and Herrera, 2004; Herrera and Pesavento, 2009; and Kilian and Lewis, 2010). Fourth, there is empirical evidence that shows that petroleum product prices, in particular, gasoline, increase more quickly in response to oil price increase than they fall when oil price decrease. (Bacon 1991, Balke, Brown, and Yücel 1998)

However, recent work by Kilian and Vigfusson (2010a) has called into question the view that oil price shocks have an asymmetric effect on U.S. real GDP. In particular, they show that the methodology used in most of the empirical literature to assess the possible asymmetry in the effect of oil price shock on economic activity leads to inconsistent estimates and overestimates the magnitude of the effect. They also show that for a shock of the typical magnitude a symmetric model appears to provide a very good approximation to the response of U.S. real GDP growth to a shock in the real price of oil. They argue that the estimation methods used in VAR studies of the macroeconomic effect of oil price innovations generally produce inconsistent estimates of the true effects of unanticipated increases in the price of oil due to the censoring applied to the oil price variable. More importantly, such tests do not address the question of interest for most researchers and policy analysts. That is, whether the response of economic activity to oil price innovations, say a year after a shock, is or is not symmetric.

In light of these methodological insights, this paper re-evaluates the evidence in favor of an asymmetric response in economic activity using a sample of 18 industrialized economies. It is essential to look at different countries since an oil shock may have a differential impact on each of the countries due to different sectoral composition, their relative position as oil importer or exporter or their differential tax structure (Cunado and Gracia 2005). In addition, there seems to have been a lack of non-US studies especially the ones that deal with the endogeniety issue of oil prices (Jones, Leiby and Paik (2003)). Additionally, increase in oil price volatility may directly affect terms of trade volatility (Backus and Crucini, 2000) which may affect each country differently especially since these countries vary in terms of their dependence on oil as an input and dependence of foreign oil. Oil price increases worsen terms of trade for oil importing countries (Dohner 1981). It may be important to note that the role of oil prices on business cycles may be a function of, say, per-capita energy consumption (Engemann, Kliesen, Owyang 2010). It might be especially important to look at the impact of oil prices on economic activity in European countries since Europe is an important second largest consumer, the largest importer of oil and since the 1970s countries like U.K. and Norway have become large oil producers as well. It is also a region that has reduced its dependence on oil (Lardic and Mignon 2006). Similarly, Canada is included in our sample since it is one of the few net exporters of natural resources amongst the OECD countries with natural resource exports being around 24% for the early 2000s. Even though oil and gas industry is less than 5% of GDP energy intesive industries are a big part of Canada's GDP. In addition, Japan is considered since it is the world's second largest economy, third largest oil consumer, and second largest oil importer (Zhang 2008). More than ever, it is important to compare responses of net oil exporters to net oil importers. Net oil exporters face an interesting trade-off in response to an oil shock; while there is a terms-of-trade improvement, energy intensive industries can be adversely affected along with a negative effect on the demand for labor and capital.

We investigate the three leading specifications of asymmetric and possibly nonlinear feedback from the real price of oil to U.S. industrial production: the percent increase specification of Mork (1989) and the 1-year and 3-year net oil price increase specifications of Hamilton (1996, 2003). We carry out the impulse response based test proposed by Kilian and Vigfusson (2010a). In the full sample and for a typical one standard deviation innovation, we found evidence of asymmetry in the response for about half of the countries when we use the real oil price increase. Evidence of asymmetry is slightly stronger when we use the net oil price increase relative to the previous one-year maximum; but it is considerably weaker when we use the net oil price increase relative to the previous three-year maximum. Evidence of asymmetry is more prevalent for a large (i.e., two standard deviation) innovation. Nevertheless, the evidence of asymmetry is considerably weakened when we restrict the sample to the post-1973 period. Amongst net oil exporters evidence of an overall positive response to an oil price increase is only found for Denmark. We also conduct tests to uncover evidence in favor of a time varying relationship between log growth of industrial production and the real price of oil for a large number of countries.

The remainder of this chapter is organized as follows. Section 2 discusses the data; Section 3 discusses slope based tests, Section 4 presents the impulse response based tests; Section 5 concludes.

2. Data

To investigate the relationship between oil price shocks and economic activity we use monthly data on oil prices and industrial production indices for 18 OECD countries and 3 country groups. Because macroeconomic models of the transmission of oil price shocks are typically specified in terms of the price of imported crude oil (Kilian and Vigfusson, 2010), we use the Refiners Acquisition Cost --hereafter RAC-- for crude oil imported into the U.S. and reported by the Energy Information Agency.[4]

However, Hamilton (2010) finds that Producer Price Index for crude petroleum better relates to prices consumers pay for gasoline for the 1970s than the West Texas Intermediate or the refiner

[4] One may argue that we should use the U.K. Brent price as it better represents the price faced by European importers. However, whereas the RAC price is available at a monthly frequency since January 1974, the U.K. Brent spot price is only available starting on January 1997. Furthermore, the correlation between the spot U.K. Brent spot price and the RAC price for imported crude oil is 0.995.

acquisition cost. In order to compute a measure of the price faced by consumers and investors in each country we multiply the RAC price by the exchange rate and deflate it by each country's Consumer Price Index (CPI). Both the exchange rate and the CPI for each country is provided by International Financial Statistics of the International Monetary Fund. The base year for the CPI data is 2005. For country groups such as OECD-Europe, OECD-Total, and G7, the real price of oil is calculated using the U.S. CPI.

For countries that switched to the Euro after 1998, a conversion factor provided by the IFS of the International Monetary Fund is used to adjust the exchange rate. This is done in order to maintain historical continuity. Data for euro-area countries have been converted to national currency by applying the official irrevocably fixed Euro/national currency conversion rates to years after the introduction of the Euro. Data for Germany are linked at 1991 to data that pertain to the former West Germany.

We use three different nonlinear transformations of the logarithm of the real oil price, o_t. The first of these measures is Mork's (1989) oil price increase, which can be defined as:

$$x_t^1 = max\{0, o_t - o_{t-1}\}. \tag{1}$$

This censoring of the oil price series was proposed by Mork (1989) after the 1985-86 fall in oil prices failed to lead to a boom in real GDP growth. He thus showed that whereas oil price increases preceded an economic recession; in contrast, he could not reject the null hypothesis that declines did not lead to expansions. Subsequently, Hooker (1996) and Kilian and Vigfusson (2011), among others, showed that this result vanishes in longer samples.

The second measure used in our paper is the net oil price increase over the previous 12-month maximum (Hamilton, 1996)

$$x_t^{12} = max\{0, o_t - \max\{ o_{t-1}, \dots, o_{t-12} \}, \tag{2}$$

and the last one is the net oil price increase over the previous 36-month maximum (Hamilton, 2003)

$$x_t^{36} = max\{0, o_t - \max\{ o_{t-1}, \dots, o_{t-36} \}. \quad (3)$$

The last two nonlinear transformations are intended to filter out increases in the price of oil that represent corrections for recent declines, and have been commonly used in the literature on the macroeconomic effects of oil prices (see for instance Bernanke, Gertler and Watson, 1997; Davis and Haltiwanger, 2001; Lee and Ni, 2002). Note, however, that in the text we report the results for the nonlinear transformations of the log of the real oil price.

3. Slope Based Test

Since the large hikes in the price of oil during the 1970s, both academics and policy makers have considered crude oil prices as one of the main sources of fluctuations in economic activity. Nevertheless, linear models of the transmission of oil price shocks had not been very successful in explaining large fluctuations in U.S. real activity. This appears to be also the case for other industrialized countries such as the G-7 economies. This fact has stimulated interest in models of an asymmetric and possibly nonlinear relationship between the real price of oil and real economic activity. In fact, since the seminal work of Mork (1989), there appeared to be a consensus suggesting that oil price increases lead to economic recessions whereas oil price decreases did not lead to booms. Thus, most of the literature on the response of economic activity to oil price innovations considered the response to be asymmetric.

Three main theoretical explanations for an asymmetric response have been put forward in the literature: costly reallocation of capital and labor, increased uncertainty, and asymmetries in the systematic response of monetary policy. These three transmission channels are thought to amplify the recessionary effect of an oil price increase and to mitigate the expansionary impact of an oil price decrease. In fact, evidence of asymmetry in the oil price-economic activity relationship has been commonly used in the literature to explain why the effect of oil price increases on GDP (gross domestic product) growth is not bounded by the share of energy in the value added (see Hamilton, 2008).

Then, the relevant query is: how do we assess whether the effect of real oil price increases and decrease on economic activity is asymmetric? Since the seminal work of Mork (1989), it has been common in the literature to answer this question by implementing a test of asymmetry in the slopes. The test is usually carried out in the following manner. First, the researcher estimates a reduced-form equation:

$$y_{i,t} = \alpha + \sum_{j=1}^{p} \emptyset_j \, y_{i,t-j} + \sum_{j=1}^{p} \gamma_j \, x_{t-j}^{\#} + u_{i,t} \quad (4)$$

where $y_t =$ denotes economic activity growth (e.g., GDP growth or the growth in the Industrial Production index), $x_t^{\#}$ is a non-linear measures of real oil prices (e.g., $x_t^1, x_t^{12}, x_t^{36}$) as described in the previous section), u_t is the residual, and p the number of lags is set to 12 months or another lag length chosen by an information criterion. A Wald-test is then used to evaluate the null hypothesis that the coefficients on the lags of the oil variable, $x_t^{\#}$, are jointly equal to zero; that is, $\gamma_1=\gamma_2=\ldots\gamma_p=0$. If the null is rejected, then it is common to conclude that lags of real oil prices are informative for future economic activity. Moreover, rejection of the null is seen by many researchers as evidence that real oil price increases do lead economic recessions.

Suppose we followed this path and evaluated the effect of real oil prices on industrial production by using the above described slope based test. For instance, let us consider the effect of real oil price increases, x_t^1, on industrial production growth, y_t. Then, using x_t^1, we would conclude that lags of the real oil price increase are informative about the growth of industrial production in the Netherlands, the U.S., the G-7, OECD-Europe, Greece and Spain. Note that for those countries we reject the null hypothesis that the coefficients on the lags of the real oil price measure are jointly significant as the p-values for the F-test are equal or less than 0.05 (see the first column of Table 2). Using the net oil price increase with respect to the previous 12-month maximum, x_t^{12}, would lead to a higher number of rejections. The p-values reported in the second column of Table 3 are less or equal to 0.05 for Canada, Germany, Japan, Netherlands, U.K., U.S., Spain, the G-7, and OECD-Europe. The test results using the net oil price increase relative to the previous 36-month maximum are very similar (see third column of Table 2), thus leading researchers to conclude that increases (or net increases) in the real oil price lead to recessions.

Kilian and Vigfusson (2010a) propose a more powerful test of the null of symmetric slopes. They suggest estimating a more general model of the oil price-macroeconomy relationship where:

$$y_{i,t} = a_{20} + \sum_{j=0}^{12} a_{21,j}\, x_{t-j} + \sum_{j=1}^{12} a_{22,j}\, y_{i,t-j} + \sum_{j=0}^{12} g_{21,j}\, x_{t-j}^{\#} + \varepsilon_{i,t} \qquad (5)$$

Note that, in contrast with the regression model in (1), here contemporaneous values of the real oil price change, x_t, and of the non-linear measure of real oil prices, $x_t^{\#}$, enter the economic activity equation (2a). More importantly, lags of the real oil price change are also included as explanatory variables in the equation for economic activity. In addition, equation (2b) puts in evidence the effect of past growth in economic activity and past real oil price changes on the current economic activity growth.

Now, to test for asymmetry in the slopes, one would only have to estimate the economic activity equation. Then, one would test the null hypothesis that the coefficients on the lags of the non-linear measure of real oil prices are all equal to zero. That is, $g_{21,0} = \cdots = g_{21,p} = 0$.

How does our view of the effect of real oil price increases on economic activity change if we implement this slope based test? The p-values reported in the second panel of Table 2 suggest that our conclusions would change only slightly. There is an increase in the p-value for OECD-Europe and Spain, which would lead one to conclude that the oil price-economic activity relationship is linear. In contrast, real oil price increases now appear to have predictive power for industrial production growth in Canada, Japan, Norway, U.K., and OECD-Total. Similar results are obtained when we use the net oil price increase with respect to the 12 or 36-month maximum (see columns 5 and 6 of Table 2). All in all, this more general test provides more evidence of asymmetry in the slope. In fact, using the net oil price increase relative to the past 36-month maximum would suggest that net oil price increases have predictive power for industrial production growth in Austria, Belgium, Canada, Italy, Japan, Sweden, U.K., U.S., Greece, Spain, the G-7, OECD-Europe and OECD-Total.

But, what can we really learn from this slope test? While the test results might be informative regarding the presence of asymmetry in the slope of the industrial production equation, Kilian and Vigfusson (2010a) demonstrate that evidence of asymmetry in the slopes is not informative about the degree of asymmetry in the response of economic activity to an unexpected real oil price shock. The reason is that the impulse response functions needed to assess the degree of asymmetry in the response of economic activity, say 6 months or a year after an unexpected increase in the real crude oil price, are not only a function of the slope coefficients but also of other variables. As Kilian and Vigfusson (2010b) note "standard slope-based tests for asymmetry based on single-equation models are neither necessary nor sufficient for judging the degree of asymmetry in the structural response functions, which is the question of ultimate interest to users of these models." For that reason, in what follows, we follow a different avenue to explore the response of industrial production to real oil price innovations.

4. Impulse response function based test

This paper looks at the relationship between oil prices and industrial production for several countries. We extend the work done by Kilian and Vigfusson (2011) by testing for nonlinearity in the oil price-industrial production relationship. In other words we test whether oil price increases have the same impact as oil price decreases. We start conducting impulse response based tests for a general vector autoregressive (hereafter VAR) model. We start by using Mork's (1989) measure of oil prices that ignores oil price decreases. In addition, we use Hamilton's (1996, 2003) net oil price increase measures of oil prices that filter out not only decreases in the price but also increases that corrected for previous declines.

Consider estimating by *OLS* the following simultaneous equation model

$$x_t = a_{10} + \sum_{j=1}^{12} a_{11,j}\, x_{t-j} + \sum_{j=1}^{12} a_{12,j}\, y_{i,t-j} + \varepsilon_{1t} \qquad (6a)$$

$$y_{i,t} = a_{20} + \sum_{j=0}^{12} a_{21,j}\, x_{t-j} + \sum_{j=1}^{12} a_{22,j}\, y_{i,t-j} + \sum_{j=0}^{12} g_{21,j}\, x^{\#}_{t-j} + \varepsilon_{2t} \qquad (6b)$$

and then tracing the response of industrial production for a particular country, $y_{i,t}$ to an unexpected one unit increase in the price of oil at time *t*=1, $\frac{\partial y_{i,t}}{\partial \varepsilon_{11}}$ at horizons *t*=1,2,...*h*. Because this response function is a nonlinear function of the parameters $g_{21,0} = g_{21,1} = \cdots = g_{21,12} = 0$. as well as of the other parameters in (6), rejecting the null of symmetry in the slopes is not enough to conclude that the response of industrial production to oil price increases and decreases at horizon h is asymmetric. Moreover, computing this impulse response requires the researcher to take into account both the recent history of the censored variable $x_t^{\#}$ and the magnitude of the shock ε_{1t}.[5]

To avoid this problem we compute the impulse response based test proposed by Kilian and Vigfusson (2011). That is, we first compute impulse response functions for a given horizon, *h*, that take into account the size of the shock, δ, as well as the recent history of all the variables, $I_y(h, \delta)$. Then, we compute the Wald test of the null of symmetric response functions (i.e., the response of industrial production to a positive shock of size δ equals the negative of the response to a negative shock of the same size, -δ):

$$I_y(h, \delta) = -I_y(h, -\delta) \; for \; h = 0, 1, 2, \ldots, H.$$

4.1 Real Prices

We report the p-values for the impulse response based test using real prices in Tables 3 to 14. We first evaluate the response of industrial production to a one standard deviation shock to real oil price increases, $x_t^{\#} = x_t^1$. For a typical one standard deviation shock, we find statistical evidence against the null of a symmetric response for 10 of the 18 countries. Note that the p-values reported in Table 9 are equal or lower than 0.05 for at least one horizon for Canada, Finland, Germany, Italy, Japan, Netherlands, Norway, UK, US, and Greece. In addition, evidence of asymmetry is also found for the aggregates (i.e., G-7, OECD-Europe, and OECD Total). The finding of asymmetry for Norway contradicts results from Mork, Olsen, and Mysen (1994) who do not find any evidence of asymmetry.

Instead, when we consider the net oil price increase relative to the previous 12-month maximum, $x_t^{\#} = x_t^{12}$we find evidence of asymmetry for Canada, Finland, Italy, Japan,

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[5] This problem has been long recognized in the econometrics literature. See for instance Gallant, Rossi and Tauchen, 1993, and Koop, Pesaran and Potter, 1996.

Luxemburg, Sweden, UK, US, Greece, and Spain and the country aggregates (see Table 10). However, in contrast with the results obtained for the real oil price increase, no evidence of asymmetry is found for Germany, Netherlands, and Norway. Similar, but somewhat weaker results are obtained for the net oil price increase relative to the previous 36-month maximum, $x_t^{\#} = x_t^{36}$ (see Table 11). In particular, p-values of 0.05 or lower are only observed for Canada, Japan, U.K., Greece, Spain, the G-7, and OECD-Total. These results seem to fall in line with Jiménez-Rodríguez and Sánchez (2009), who using a sample starting in 1972, find evidence of asymmetry in the response of GDP growth for net oil exporters such as Norway and the U.K. and net oil importers such as the U.S.

Evidence of asymmetry is more prevalent for a large two standard deviation shock (see Tables 11-13). Note, that we reject the null of a symmetric response at a larger number of horizons for Canada, Finland, Germany, Netherlands, U.K., and OECD-Total using the real oil price increases, $x_t^{\#} = x_t^{1}$. Evidence of asymmetry is found for more horizons for a larger number of countries using the net oil price increase relative to the previous 12-month maximum,$x_t^{\#} = x_t^{12}$. In addition, p-values of 0.05 or lower are now found for Austria and Belgium. Yet, regardless of the oil price measure, no evidence of asymmetry is found for France, Portugal, and Denmark.

Summarizing, our test results would suggest that, for only slightly more than 50% of the countries, there is asymmetry in the response to positive and negative innovations of the typical one standard deviation magnitude. Therefore, real oil price innovations might be mainly transmitted to the economy via the decrease in the purchasing power of households that now face a higher price of imported oil. Evidence of asymmetry one year after a typical innovation is found for Canada, Japan, Luxemburg, Greece, Norway, and the U.S.; yet, the results are not consistent across oil price measures.

An important point to note here is that we consistently find evidence in favor or both asymmetry and nonlinearity for Japan which confirms results from Zhang (2008) but are contradictory to the result found by Jimenez--Rodriguez and Sanchez (2004). However, as far as UK is concerned, our results are in line with Jimenez--Rodriguez and Sanchez (2004) who find evidence of asymmetry for UK one year after the shock. These results support the possibility of a Dutch disease phenomenon described earlier.

Interestingly, while the tests results are consistent for most of the G-7 nations in that they either reject or fail to reject the null of symmetry, there is no clear pattern pointing towards a particular functional form for the largest developed countries. On one hand, we reject the null of symmetry for Canada, the U.S., the U.K., and Japan. On the other hand, for France, Germany, and Italy it appears that a linear model would suffice to capture the transmission of unanticipated real oil price innovations to industrial production, especially for capturing the response of industrial production to a small shock in oil prices. Similarly, there is no clear pattern separating net oil exporters from net oil importers. For instance, take the cases three net oil exporters: Canada, Denmark and Norway. Regardless of the oil price measure, there is evidence of asymmetry at a 10% level in the response to a typical innovation for Canada. However, we always fail to reject the null of symmetry for Denmark and we reject the null of symmetry only for the real oil price increase in the case of Norway for both typical and large shocks.

Nevertheless, our results suggest that caution should be exercised when computing the effect of a large real oil price shock (e.g. a two standard deviation shock) as, after a year, the response of about 70% of the countries shows evidence of asymmetry. Thus, both the size of the shock and the past history of the variables need to be taken into account when computing the magnitude of the effect. For a large innovation, costly sectoral reallocation and heightened uncertainty appear to play a role in the transmission of real oil price shocks.

4.1.1 The effect of dropping pre-1974 data

In the previous section we explored the question of asymmetry using the longest data set available for each country. Therefore, for all the countries but Denmark and the country group, OECD-Total, the data spans a period that starts in the 1960s. However, it has been argued (see Kilian and Vigfusson, 2010, 2011 and Herrera, Lagalo and Wada, 2011) that the transmission mechanism of real oil price innovations could have changed in the 1970s, at least for the U.S. In fact, the Texas Railroad Commission largely set world oil prices between the 1930s and 1960s, but was displaced by the Organization of Petroleum Exporting Countries (OPEC) in 1973. Since then, nominal oil prices have become more flexible and responsive to world market conditions. Therefore, in this section, we discuss the results obtained when we restrict the sample to the post-1973 period. The p-values for the impulse response based tests on this smaller sample are reported in Tables 3-8.

As it can be seen on Tables 3-5, for the typical one standard deviation shock, we find evidence of asymmetry for at least one horizon in only seven countries (Canada, Finland, Germany, Japan, U.S., Norway, and Greece), the G-7, and OECD-Total using the real oil price increase, $x_t^{\#} = x_t^{1}$. In particular, for countries such as Italy, Netherlands, and U.K., all the p-values exceed 0.05 in the smaller sample, whereas we were able to reject the null for at least one horizon in the full sample. Evidence of asymmetry is even weaker when we use the net oil price increase with the number of rejections being smaller $x_t^{\#} = x_t^{36}$ than for $x_t^{\#} = x_t^{12}$. Moreover, regardless of the oil price measure, one year after the shock, the response of industrial production to typical real oil price innovations appears to be linear for all countries.

As it is the case in the full sample, Tables 6-8 reveal more evidence of asymmetry in the response of industrial production to a large shock (i.e. two standard deviations) than to a typical shock (i.e., one standard deviation). Using the real oil price increase we can reject the null of symmetry for at least one horizon for Canada, Finland, Germany, Italy, Japan, Netherlands, Norway, U.K., U.S., Greece, the G-7, and OECD-Total (see Table 12). The number of countries for which we get rejections increases slightly if we use the net oil price increase over the 12-month maximum; we find asymmetry to large innovations, for at least one horizon, for 11 countries. Yet, the evidence in favor of asymmetry is considerably weakened when we use the net oil price increase over the 36-month maximum; for at least one horizon, we reject the null of symmetry at a 5% significance level only for Luxemburg, Sweden, U.S., U.K., Greece, Spain, and OECD-Total. Yet, we fail to reject the null for most countries at the one year horizon. These results are consistent with Kilian and Vigfusson (2011) and Herrera, Lagalo and Wada (2011) who find that the evidence of asymmetry in the oil price-economic activity relationship for the U.S. is weakened when the pre-1974 data is dropped.

4.1.2 Data Mining

One concern with interpreting evidence of asymmetry for a particular country as evidence of asymmetry for the industrialized countries in general is that there is an element of data mining involved. That is so because we have conducted 21 Wald tests for each oil price measure. As mentioned in Herrera, Lagalo and Wada (2010), conventional critical values do not account for repeated applications of the IRF based test to alternate IP indices, in this case the alternate IP indices being IP indices for different countries. [6]

To address this concern we simulate the null distribution of the supremum of the bootstrap test statistic across all countries for each of the oil price measures. The critical values that account for data mining are based on 100 pseudo series generated using the estimated coefficients for the subsample that covers 19 country indices for the full sample and 21 indices for the 1974-2010 subsample. For each series, we use 100 replications to obtain the conditional IRFs and 100 bootstraps to get the test statistic.Test statistics that are significant at 5% and 10% level are denoted by ** and *, respectively, in Tables 3-14.

As expected, accounting for data mining reduces the number of rejections. Using the the net oil price increase measure with respect to 36 month maximum and a typical shock, evidence of asymmetry is found only for Greece at the 10% level. Using one month max measure and the net oil price increase measure with respect to 12 month maximum we now find evidence of nonlinearity for no countries. The results using a large shock are much different; evidence of asymmetry is no longer found for any country using any of the three oil price measures.

When we consider the full sample and use a typical shock, we find evidence of nonlinearity for Canada, Japan, UK, and Greece using the net oil price increase with respect to 12 month maximum at the 5% level. Using the net oil price increase with respect to 36 month maximum, we find evidence of nonlinearity for Canada, G7, and Greece. for at least two horizons. In the previous subsection, we find evidence of nonlinearity for all three oil price measures for several countries. However, once we account for data mining we only find evidence

[6] See Inoue and Kilian(2004) and Kilian and Vega (2010) for the effect of data mining and solutions to the problem of data mining in the related context of tests of predictability.

of a nonlinear relationship between oil prices and industrial production for the U.S. for 1 horizon using the net oil price increase with respect to 12 month maximum.

4.2 Impulse Response Plots

But, how big is the difference between the response to positive and negative shocks? To illustrate the magnitude of this distance Figures 1a-1c and Figures 2a-2c plot the responses $I_y(h,\delta)$ and $-I_y(h,-\delta)$ to a typical shock (one standard deviation) and large shock (2 standard deviation) respectively for the post 1973 subsample. Figures 3a-3c and 4a-4c plot the responses for a typical and large shock for the full sample. Note that to facilitate the comparison, we plot the response to a positive shock, $I_y(h,\delta)$, and the negative of the response to a negative shock, $-I_y(h,-\delta)$. The responses are measured in percentages and the horizontal axis represents months after the shock.

4.2.1 Full Sample

As can be seen in Figures 3a-3c the responses to a small shock look very similar. Differences are noticeable for France, Germany, Italy, Japan, Netherlands, Luxemburg, Sweden, UK, and US after one year of the shock for the real oil price increase. For instance, at *h*=12 the value of the response to a positive shock, $I_y(h,\delta)$for the total IP is between 2% and 12 times larger than the response to a negative shock, $-I_y(h,-\delta)$. When using the net oil price increase with respect to 12-month maximum the ratio between positive to negative response is bigger than 1 for 10 countries, 1 year after the shock. For instance, for *h*=12, the ratio of positive to negative response ranges between 1.05 to 3.16 depending on the country. Lower evidence of asymmetry is found after one year for the net oil price increase with respect to 36 month maximum measure with only 6 countries where the ratio between positive to negative response is greater than 1.

For a large shock at *h*=12, the countries for which we find evidence of asymmetry using the IRF based tests, the ratio of the positive to negative response, $\frac{I_y(h,\delta)}{I_y(h,-\delta)}$, ranges from 1.08 for Finland to 5.90 for the U.S. For the response to a net oil price increase measures, the ratio of the positive to negative response, $\frac{I_y(h,\delta)}{I_y(h,-\delta)}$, ranges from 1.02 to 3.53.

A few points are worth mentioning here. First, for the real oil price increase and a small shock, noticeable differences are observed between positive and negative response for net oil exporters at short horizons. The ratio of positive to negative response ranges from 5.20 to 19.85 for the net oil exporters Denmark, UK, Norway, and Canada. Second, for a large shock using the real oil price increase, the response to a negative shock is 78 times than that to a positive shock for Norway at *h*=12. Third, for a large shock using the net oil price increase with respect to the 12 month maximum, the response to a positive shock is about 3-4 times than that to a negative shock for Denmark and the UK for mid-horizons *h*=6 and *h*=7. Similar differences are observed for the net oil exporters at *h*=2,6,7 using the net oil price increase with respect to 36 month maximum. Fourth, both positive and negative shocks are found to be recessionary one year after the shock for Austria using a large shock for all three measures of oil price. Fifth, all results for the UK which is a net oil exporter point out that a year after the shock, an increase in oil prices leads to a fall in industrial production whether we consider a typical or a large shock and irrespective of the oil price measure used. These results propose the possibility of a Dutch disease phenomenon suggested in the literature.

4.2.2 Post 1973 Sample

Having shown that there is very little statistical evidence of asymmetry, the question that comes to mind is: when there is asymmetry, how big is the difference between the response to a positive and a negative innovation? Consider the cases of Canada, Japan and the U.S. where we find evidence of asymmetry using the real oil price increase. In these countries, an unexpected increase in real crude oil prices of one standard deviation would lead to roughly a 0.1% drop in industrial production a year after the shock. For Canada, this recessionary effect would be 34% larger than the expansionary effect of a negative shock of the same magnitude. The effect of a positive shock would be 8% and 17% larger than the effect of a negative shock for Japan and the U.S., respectively. Instead, our estimates suggest that for Norway a decrease in the price of oil has a recessionary effect on industrial production that is almost three times as large as the expansionary effect of an unexpected increase in the price of crude oil.

Departures from symmetry appear to be economically smaller, and sometimes negligible, for the net oil price increase. For instance, when we use the net oil price increase over the previous 12-month maximum, for the typical one standard deviation shock the ratio of the positive to the negative response for Canada, Japan and the U.S. are 1.15, 0.99 and 1.03, respectively. The ratio for Norway is considerably smaller if we use the net oil price increase instead of the price increase. A decrease in oil prices would only result in roughly a 14% larger decrease in industrial production than the expansionary effect of an oil price increase of the same size.

Not surprisingly, departures from symmetry are of greater magnitude for a large shock. For the oil price increase the ratio of the positive to negative responses are 2.10, 1.23, and 1.87 for Canada, Japan and the U.S., respectively. For instance, our estimates for Canada suggest that, after a year, a large increase in the price of crude oil would result in a 0.21% fall in industrial production whereas the same size decrease in the price of oil would lead to a 0.1% expansion.

A few interesting points are worth noting: For net oil exporters such as Denmark and Canada the response to a typical size positive shock is as high as 74 times and 14 times respectively (at horizon 8 and 7) than that of a negative shock of the same magnitude for the real oil price increase. Similarly, when we use the net oil price increase over the previous 36-month maximum, for Denmark the response to a positive shock is 28 times the response to a negative shock immediately after the shock. For a large shock, similar differences are observed for the net oil exporters, Canada, Denmark, Norway, and the UK, with the response to a positive shock being between 3 times to 40 times larger than the response to a negative shock when using the real oil price increase. Differences are also observed for Denmark when using the net oil price increase measures, although the ratios of positive to negative responses are smaller. We find evidence in favor of a possibility of a Dutch disease phenomenon for the UK after a positive oil price shock due to a real exchange rate appreciation of the pound since amongst all countries the largest accumulated decline occurs for UK when using the net oil price increase measures and for Norway when using the one month max measure for both a typical shock and a large shock (The latter result is in contrast to the results obtained by Jimenez-Rodriguez and Sanchez (2005) and Mork, Olsen, and Mysen (1994) who find the overall response of Norway to an oil shock to be positive). The accumulated response of Canada's IP to oil price increases is also negative but much smaller in magnitude. This result is different from Dissou (2010) who find that oil shocks can have a positive impact on Canada using simulation results. However, Rasche and Tatom (1981) had observed that neither UK nor Canada experienced an increase in aggregate demand after the 1979-80 oil price increase. The only net oil exporter that has an overall positive response to an oil price increase is Denmark.

These results suggest that it might be useful to compare the magnitude of net oil exports per capita across countries as suggested by Engemann, Kliesen, and Owyang (2010) whose results show that there is a tendency for countries with low oil exports per capita to have a larger probability of a recession due to an oil price increase. Alternately, one might want to consider the magnitude of net oil exports over GDP for different countries as suggested by Bruckner, Ciccone, Tesei (2011) who find that countries with a bigger net oil exports over GDP ratio see improvements in democratic institutions as a result of an oil price shock. It might also be useful to study the export intensity of energy intensive sectors in net oil exporting countries in order to determine the negative impact of an oil price increase on the economy. Issues such as the degree of diversification and inter-industry relationships along with government's policy response might be vital in determining the existence of a Dutch disease phenomenon especially since it may not be possible to distinguish between the Dutch disease phenomenon and a general economic slow down caused by high oil prices (Dissou 2010).

Another interesting point to be noted is that during several instances, both a positive shock and a negative shock in the oil price are found to be recessionary. These results are in line with the theory that oil-induced reallocations proposed by Loungani(1986) and Hamilton (1988) can be recessionary irrespective of whether they are caused by an oil price increase or decrease (Mory 1993). For instance, for a typical shock evidence of a recessionary impact through both a positive and a negative shock in oil price is found for 12 countries (Austria, Belgium, Canada, France, Germany, Italy, Luxemburg, Netherlands, Portugal, UK, US, Greece, Spain, and Denmark) and 1 country group (G7) for at least one horizon when using the real oil price increase. In addition, both positive and negative shocks in oil price are found to be recessionary for at least one horizon for Denmark irrespective of the oil price measure used. However, no such evidence is found for Japan and Sweden irrespective of the oil price measure used. This evidence of a recessionary effect in response to both a positive and a negative shock is found to be even stronger when the shock is large. For example, all countries and country aggregates show evidence of a decline in industrial production for at least one horizon because of both a positive and a negative shock in oil price when using the oil price increase measure. However, no such evidence is found for Norway and Japan when using either of the net oil price increase measures. The largest accumulated decline to a decrease in oil prices is observed for Finland for both a typical (.6% to .7 %) and a large shock (1.68% to 1.8%) and for all oil price measures.

We also find that the response of certain countries like Luxemburg, Netherlands, and Norway's industrial production to a typical shock is, in general, bigger in magnitude compared to responses of other countries. For example, in response to a typical size oil price increase, using the one month max measure, one month after the shock we find that Luxemburg's IP goes down by .40% while for most other countries the response varies between .09% to .2%. Similarly, in response to a large shock, Luxemburg's IP goes down by 1.18% one month after the shock while the response of most other countries remains under .65% in magnitude. This result is similar to that of Cunado and Gracia (2003) who find that Luxemburg is more vulnerable than the rest of the countries to oil price changes. Similarly, Engemann, Kliesen and Owyang (2010) find Norway to be the most responsive to oil shocks.

In light of the above results, let us consider a question closely related to the query at the opening of the previous section. Consider an industrialized country that faces a decrease in the real price of oil today. Should this country expect an increase in economic growth of the same magnitude of the recession that it would experience in the face of a positive real oil price shock of equal size? The answer depends on the country and the size of the shock at hand.

First, a structural change in the transmission mechanism of oil prices appears to have taken place in the early 1970s. As a result, in the post-1973 data, the response of industrial production to real oil price innovations is well approximated by a linear function for most OECD countries under consideration. For these countries, the expansionary effect of a real oil price decrease should be of similar magnitude as the recessionary effect of a real oil price increase.

Second, for the few countries where there is some evidence of asymmetry (Canada, Finland, Japan, Norway, Sweden, the U.S., and Greece), departures from symmetry range between 1.02 and 14 times for the typical one standard deviation innovation. For the large (two standard deviation) and infrequent innovations, the recessionary effect of a positive real oil price shock can be twice as large as the expansionary effect of a negative shock.

Finally, the fact that we find the largest (though still small) number of rejections for the real oil price increase suggest that costly reallocation of capital and labor and heightened uncertainty may play a role in the transmission of oil innovations for countries such as Canada, Japan, Norway, the U.S., and Greece. Now, whether the disparity across countries responds to differences in the costs of shifting capital and labor across sectors, differences in the effect of uncertainty on investment and consumption of durable goods, and/or differences in monetary policy across countries is an important topic of research that will have to be addressed in the future.

5. Conclusions

This paper revisits a question that has been extensively studied in the literature on the oil price-macroeconomy literature: is the oil price-macroeconomy relationship linear? Using a data set on industrial production for 18 OECD countries and 3 country groups we find ample evidence of asymmetry in the slopes. Consistent with the extant literature, we find more evidence of asymmetry for the net oil price increase than for Mork's (1989) real oil price increase.

Yet, the premise that slope based test are enough to quantify the degree of asymmetry in the response of economic activity to real oil price innovations has been recently questioned by Kilian and Vigfusson (2011). They argue that the estimation methods used in VAR studies of the macroeconomic effect of oil price innovations generally produce inconsistent estimates of the true effects of unanticipated increases in the price of oil due to the censoring applied to the oil price variable. More importantly, such tests do not address the question of interest for most researchers and policy analysts. That is, whether the response of economic activity to oil price innovations, say a year after a shock, is or not symmetric.

Hence, in this paper we carry out the impulse response based test proposed by Kilian and Vigfusson (2011). In the full sample and for a typical one standard deviation innovation, we find evidence of asymmetry in the response for about half of the countries when we use the real oil price increase. Evidence of asymmetry is slightly stronger when we use the net oil price increase relative to the previous one-year maximum; but it is considerably weaker when we use the net oil price increase relative to the previous three-year maximum. Evidence of asymmetry is more prevalent for a large (i.e., two standard deviation) innovation. In that case, we reject the null of a symmetric response for about 80% of the countries in the sample for at least one horizon.

Nevertheless, the evidence of asymmetry is considerably weakened when we restrict the sample to the post-1973 period. In other words, for most countries, nonlinearity in the response of industrial production to a typical real oil price shock is likely due to the inclusion of the period when the Texas Railroad Commission set world oil prices. In fact, we fail to reject the null at a one year horizon for all the countries in the sample and all the oil measures. For a large innovation, we still find some statistical evidence of asymmetry in the response to real oil price shocks, especially when we use the net oil price increase with respect to the previous 12-month maximum.

Our results suggest that a linear model is a good approximation for the response of industrial production to a typical real oil price innovation for the 18 OECD countries in the sample at most --but not all horizons. Some exceptions are Canada, Finland, Japan, Norway, Sweden, the U.S., and Greece where we reject the null of symmetry for at least one horizon. Departures from symmetry for a typical one standard deviation shock are of some economic significance for Canada, Japan, Norway and the U.S.

The fact that evidence of asymmetry is more prevalent for large innovations suggests that care must be taken in computing impulse response functions that correctly account for the nonlinearity of the oil price-industrial production relationship when considering these large (two standard deviation) but infrequent shocks. However, conventional critical values reported in our tables do not account for repeated applications of the IRF based test to various countries or alternative horizons and, thus, are likely to overstate the evidence in favor of asymmetry (see, e.g., Herrera, Lagalo and Wada, 2011).

In brief, there appears to be very limited evidence in favor of asymmetry in the response of industrial production to real oil price increases and decreases for the 18 OECD countries under analysis. Furthermore, different non-linear specifications lead to different results across countries, thus making it difficult to match the empirical results with a particular theoretical explanation for asymmetry in the transmission of oil price shocks. Future work will be needed to understand whether the disparity across countries responds to differences in the importance of the various transmission channels related to the composition of the economy and, especially, to the role that oil plays in each country (e.g., whether the country is a net oil importer or a net oil exporter).

Table 1. Country List and Sample Period

Country	Sample period
Austria	1961:2010:7
Belgium	1961:2010:7
Canada	1961:2010:7
Finland	1961:2010:7
France	1961:2010:7
Germany	1961:2010:7
Italy	1961:2010:7
Japan	1961:2010:7
Luxemburg	1961:2010:7
Netherlands	1961:2010:7
Norway	1961:2010:7
Portugal	1961:2010:7
Sweden	1961:2010:7
UK	1961:2010:7
US	1961:2010:7
G7	1961:2010:7
OECD-Europe	1961:2010:7
Greece	1962:2010:7
Spain	1965:2010:7
Denmark	1974:2010:7
OECD-Total	1975:2010:7

Table 2. Slope based test of nonlinearity

	Forecasting Equation			Structural Equation		
Sector	$x_t^{\#} = x_t^1$	$x_t^{\#} = x_t^{12}$	$x_t^{\#} = x_t^{36}$	$x_t^{\#} = x_t^1$	$x_t^{\#} = x_t^{12}$	$x_t^{\#} = x_t^{36}$
Austria	0.27	0.31	0.11	0.33	0.21	0.04
Belgium	0.25	0.13	0.02	0.09	0.08	0.02
Canada	0.16	0	0	0.01	0	0
Finland	0.07	0.26	0.17	0.51	0.88	0.71
France	0.39	0.32	0.18	0.67	0.65	0.44
Germany	0.07	0.01	0.01	0.53	0.1	0.11
Italy	0.51	0.08	0.02	0.48	0.13	0.05
Japan	0.08	0.02	0	0	0.01	0
Luxemburg	0.81	0.17	0.73	0.93	0.1	0.66
Netherlands	0	0.03	0.13	0.01	0.09	0.29
Norway	0.37	0.71	0.5	0	0.77	0.62
Portugal	0.42	0.13	0.21	0.79	0.22	0.44
Sweden	0.47	0.11	0.03	0.14	0.03	0.02
UK	0.06	0.01	0	0.01	0	0
US	0.01	0	0	0	0	0
G7	0.04	0	0	0	0	0
OECD-Europe	0.05	0	0	0.11	0	0
Greece	0.02	0.28	0.03	0	0.01	0
Spain	0.02	0	0	0.42	0	0
Denmark	0.29	0.44	0.42	0.06	0.24	0.14
OECD-Total	0.94	0.22	0.01	0.01	0.04	0.01

Table 3. IRF based test of symmetry to 1 s.d. shock to the real oil price ($x_t^{\#} = x_t^1$) - post 1973 subsample

Horizon													
Country	0	1	2	3	4	5	6	7	8	9	10	11	12
Austria@	0.33	0.44	0.26	0.39	0.53	0.38	0.5	0.54	0.44	0.29	0.34	0.38	0.45
Belgium@	0.34	0.43	0.52	0.58	0.72	0.73	0.77	0.73	0.81	0.73	0.72	0.77	0.74
Canada#	0.11	0.06	0.05	0.09	0.15	0.2	0.27	0.3	0.15	0.21	0.26	0.25	0.27
Finland@	0.91	0.18	0.03	0.06	0.09	0.14	0.2	0.28	0.31	0.4	0.37	0.38	0.41
France@	0.2	0.38	0.51	0.41	0.27	0.36	0.32	0.3	0.18	0.23	0.29	0.3	0.37
Germany@	0.81	0.4	0.01	0.03	0.06	0.09	0.14	0.19	0.22	0.29	0.37	0.45	0.53
Italy@	0.06	0.14	0.11	0.12	0.2	0.28	0.37	0.44	0.17	0.21	0.28	0.33	0.3
Japan@	0.39	0.08	0.06	0.08	0.07	0.03	0.05	0.07	0.11	0.13	0.15	0.19	0.25
Luxemburg#	0.94	0.1	0.16	0.26	0.23	0.31	0.4	0.5	0.61	0.69	0.77	0.83	0.88
Netherlands@	0.65	0.11	0.14	0.12	0.17	0.25	0.32	0.4	0.48	0.55	0.57	0.25	0.26
Norway#	0.19	0.2	0.02	0.03	0.06	0.09	0.04	0.05	0.07	0.1	0.13	0.14	0.19
Portugal#	0.52	0.77	0.19	0.32	0.44	0.57	0.56	0.56	0.63	0.71	0.79	0.82	0.82
Sweden@	0.36	0.59	0.19	0.32	0.37	0.49	0.6	0.61	0.69	0.73	0.74	0.6	0.62
UK#	0.45	0.65	0.12	0.12	0.2	0.2	0.12	0.17	0.22	0.3	0.37	0.45	0.49
US#	0.38	0.03	0.08	0.05	0.09	0.13	0.11	0.13	0.11	0.16	0.21	0.14	0.19
G7#	0.09	0.02	0.01	0.01	0.02	0.03	0.04	0.07	0.1	0.11	0.15	0.17	0.17
OECD-Europe@	0.37	0.53	0.23	0.34	0.47	0.59	0.67	0.61	0.56	0.65	0.73	0.71	0.61
Greece@	0.1	0.01	0.02	0.03	0.06	0.09	0.13	0.15	0.21	0.28	0.35	0.28	0.34
Spain#	0.22	0.32	0.43	0.59	0.72	0.82	0.88	0.87	0.31	0.32	0.39	0.44	0.36
Denmark@	0.93	0.56	0.33	0.49	0.6	0.65	0.5	0.6	0.7	0.76	0.43	0.44	0.51
OECD-Total#	0.06	0.03	0.03	0.05	0.09	0.03	0.04	0.07	0.11	0.13	0.16	0.19	0.25

Notes: Tests are based on 1000 simulations of model (6). p-values are based on the χ_{H+1}². Bold and italics denote significance at the 5% and 10% level, respectively. # and @ denote whether the impulse response to a positive shock was bigger or smaller than that to a negative shock, respectively.** and * denote significance after accounting for data mining at the 5% and 10% level, respectively.

Table 4. IRF based test of symmetry to 1 s.d. shock to the real oil price ($x_t^{\#} = x_t^{12}$) - post 1973 subsample

Horizon													
Country	0	1	2	3	4	5	6	7	8	9	10	11	12
Austria@	0.25	0.2	0.13	0.19	0.28	0.36	0.46	0.57	0.59	0.54	0.6	0.65	0.72
Belgium@	0.13	0.24	0.38	0.41	0.49	0.62	0.71	0.62	0.71	0.79	0.81	0.85	0.88
Canada#	0.01	0.02	0.05	0.09	0.09	0.15	0.22	0.3	0.13	0.18	0.23	0.29	0.34
Finland@	0.02	0.04	0.09	0.15	0.08	0.12	0.15	0.2	0.27	0.16	0.11*	0.12*	0.16
France@	0.06	0.11	0.22	0.29	0.34	0.21	0.3	0.37	0.46	0.55	0.61	0.62	0.7
Germany@	0.39	0.55	0.65	0.8	0.89	0.86	0.91	0.82	0.88	0.92	0.94	0.94	0.96
Italy@	0.07	0.12	0.24	0.35	0.46	0.45	0.5	0.56	0.66	0.74	0.77	0.83	0.84
Japan@	0.25	0.11	0.09	0.16	0.21	0.17	0.24	0.32	0.35	0.31	0.39	0.44	0.48
Luxemburg#	0.55	0.67	0.77	0.42	0.52	0.64	0.73	0.63	0.72	0.63	0.71	0.78	0.84
Netherlands@	0.49	0.5	0.51	0.47	0.58	0.63	0.74	0.82	0.88	0.92	0.93	0.96	0.96
Norway#	0.99	0.99	1	0.9	0.72	0.8	0.77	0.73	0.77	0.83	0.89	0.88	0.91
Portugal#	0.72	0.62	0.71	0.84	0.84	0.91	0.95	0.94	0.97	0.98	0.99	1	1
Sweden@	0.04	0.12	0.16	0.18	0.29	0.39	0.49	0.44	0.48	0.57	0.64	0.64	0.68
UK#	0.56	0.43	0.29	0.43	0.57	0.69	0.79	0.82	0.86	0.91	0.92	0.94	0.96
US#	0.11	0.08	0.16	0.22	0.33	0.43	0.55	0.52	0.49	0.58	0.67	0.65	0.72
G7#	0.08	0.14	0.27	0.41	0.46	0.39	0.51	0.58	0.66	0.75	0.81	0.85	0.87
OECD-Europe@	0.45	0.3	0.48	0.63	0.74	0.79	0.86	0.84	0.9	0.94	0.96	0.97	0.98
Greece#	0.01	0.02	0.03	0.06	0.11	0.16	0.23	0.27	0.36	0.43	0.49	0.58	0.65
Spain#	0.66	0.14	0.25	0.39	0.45	0.56	0.5	0.6	0.68	0.76	0.8	0.85	0.85
Denmark@	0.74	0.94	0.85	0.87	0.45	0.56	0.44	0.43	0.52	0.6	0.61	0.52	0.6
OECD-Total#	0.04	0.09	0.18	0.28	0.36	0.37	0.49	0.59	0.61	0.7	0.77	0.84	0.88

Notes: Tests are based on 1000 simulations of model (6). p-values are based on the χ_{H+1}². Bold and italics denote significance at the 5% and 10% level, respectively. # and @ denote whether the impulse response to a positive shock was bigger or smaller than that to a negative shock, respectively.** and * denote significance after accounting for data mining at the 5% and 10% level, respectively.

Table 5. IRF based test of symmetry to 1 s.d. shock to the real oil price ($x_t^{\#} = x_t^{36}$) - post 1973 subsample

	Horizon												
Country	0	1	2	3	4	5	6	7	8	9	10	11	12
Austria@	0.48	0.68	0.32	0.43	0.58	0.56	0.55	0.59	0.68	0.72	0.8	0.85	0.9
Belgium@	0.21	0.34	0.48	0.56	0.34	0.42	0.4	0.45	0.55	0.61	0.7	0.77	0.83
Canada#	0.11	0.27	0.45	0.61	0.69	0.73	0.82	0.88	0.77	0.7	0.77	0.84	0.87
Finland@	0.43	0.72	0.78	0.83	0.74	0.82	0.89	0.93	0.95	0.9	0.93	0.96	0.96
France@	0.34	0.63	0.58	0.62	0.74	0.71	0.65	0.75	0.82	0.88	0.92	0.95	0.97
Germany@	0.6	0.76	0.83	0.91	0.96	0.96	0.96	0.97	0.98	0.99	0.99	0.99	0.99
Italy@	0.46	0.65	0.76	0.86	0.9	0.94	0.86	0.8	0.87	0.91	0.95	0.96	0.98
Japan@	0.5	0.58	0.71	0.84	0.8	0.77	0.82	0.51	0.57	0.59	0.67	0.71	0.78
Luxemburg#	0.11	0.29	0.41	0.42	0.41	0.44	0.56	0.66	0.75	0.82	0.88	0.92	0.95
Netherlands@	0.3	0.45	0.43	0.51	0.65	0.76	0.84	0.83	0.87	0.92	0.91	0.93	0.96
Norway#	0.99	0.79	0.91	0.94	0.98	0.99	0.82	0.75	0.82	0.87	0.89	0.89	0.92
Portugal#	0.75	0.94	0.76	0.88	0.92	0.95	0.97	0.64	0.73	0.8	0.83	0.88	0.91
Sweden@	0.5	0.6	0.17	0.27	0.3	0.31	0.37	0.24	0.11*	0.15	0.15*	0.20*	0.18*
UK#	0.24	0.13	0.22	0.35	0.49	0.62	0.73	0.73	0.76	0.81	0.83	0.88	0.91
US#	0.96	0.09	0.13	0.15	0.22	0.31	0.3	0.29	0.32	0.39	0.46	0.54	0.55
G7#	0.17	0.38	0.52	0.68	0.81	0.84	0.62	0.71	0.75	0.63	0.62	0.7	0.7
OECD-Europe#	0.12	0.12	0.19	0.29	0.42	0.54	0.66	0.48	0.58	0.68	0.61	0.69	0.75
Greece#	0.02*	0.05	0.11	0.19	0.29	0.4	0.51	0.62	0.72	0.79	0.85	0.88	0.92
Spain#	0.47	0.03	0.08	0.14	0.23	0.24	0.33	0.42	0.51	0.6	0.65	0.66	0.73
Denmark@	0.47	0.75	0.84	0.87	0.8	0.81	0.73	0.66	0.74	0.81	0.84	0.89	0.92
OECD-Total#	0.05	0.13	0.17	0.29	0.38	0.5	0.37	0.47	0.48	0.51	0.56	0.65	0.72

Notes: Tests are based on 1000 simulations of model (6). p-values are based on the χ_{H+1}². Bold and italics denote significance at the 5% and 10% level, respectively. # and @ denote whether the impulse response to a positive shock was bigger or smaller than that to a negative shock, respectively.** and * denote significance after accounting for data mining at the 5% and 10% level, respectively.

Table 6. IRF based test of symmetry to 2 s.d. shock to the real oil price ($x_t^{\#} = x_t^1$) - post 1973 subsample

Horizon													
Country	0	1	2	3	4	5	6	7	8	9	10	11	12
Austria@	0.3	0.42	0.2	0.3	0.43	0.25	0.34	0.36	0.17	0.07	0.08	0.08	0.11
Belgium@	0.31	0.35	0.44	0.48	0.62	0.6	0.61	0.46	0.56	0.43	0.42	0.48	0.43
Canada@	0.07	0.02	0.01	0.02	0.03	0.04	0.07	0.05	0.01	0.01	0.01	0.01	0.01
Finland@	0.91	0.11	0	0	0.01	0.01	0.02	0.03	0.05	0.07	0.05	0.04	0.04
France@	0.21	0.37	0.48	0.35	0.2	0.27	0.19	0.19	0.08	0.11	0.13	0.11	0.15
Germany@	0.81	0.38	0	0	0.01	0.01	0.02	0.03	0.03	0.05	0.07	0.09	0.12
Italy@	0.04	0.11	0.05	0.04	0.07	0.11	0.15	0.17	0.01	0.01	0.02	0.03	0.03
Japan@	0.39	0.03	0	0.01	0	0	0	0	0	0	0	0	0
Luxemburg#	0.94	0.06	0.08	0.14	0.08	0.11	0.16	0.22	0.3	0.38	0.46	0.54	0.62
Netherlands@	0.66	0.1	0.12	0.07	0.11	0.16	0.22	0.29	0.33	0.39	0.37	0.05	0.06
Norway#	0.17	0.18	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.02	0.01	0.02
Portugal#	0.49	0.74	0.14	0.24	0.35	0.46	0.47	0.42	0.47	0.56	0.65	0.68	0.69
Sweden@	0.34	0.56	0.13	0.22	0.29	0.38	0.5	0.44	0.5	0.55	0.52	0.27	0.26
UK#	0.42	0.62	0.07	0.06	0.11	0.09	0.02	0.04	0.04	0.07	0.09	0.13	0.14
US#	0.4	0.02	0.04	0.01	0.02	0.02	0.01	0.01	0	0.01	0.01	0.01	0.01
G7#	0.08	0	0	0	0	0	0	0	0	0	0	0	0
OECD-Europe@	0.37	0.5	0.19	0.28	0.41	0.52	0.62	0.56	0.48	0.57	0.66	0.62	0.55
Greece@	0.08	0	0	0	0	0	0	0	0.01	0.01	0.02	0	0
Spain#	0.19	0.27	0.35	0.51	0.65	0.77	0.84	0.79	0.17	0.16	0.22	0.25	0.15
Denmark@	0.93	0.59	0.3	0.45	0.56	0.6	0.42	0.5	0.61	0.64	0.19	0.21	0.24
OECD-Total#	0.04	0	0	0	0	0	0	0	0	0	0	0	0

Notes: Tests are based on 1000 simulations of model (6). p-values are based on the χ_{H+1}². Bold and italics denote significance at the 5% and 10% level, respectively. # and @ denote whether the impulse response to a positive shock was bigger or smaller than that to a negative shock, respectively.** and * denote significance after accounting for data mining at the 5% and 10% level, respectively.

Table 7. IRF based test of symmetry to 2 s.d. shock to the real oil price ($x_t^{\#} = x_t^{12}$) - post 1973 subsample

Horizon													
Country	0	1	2	3	4	5	6	7	8	9	10	11	12
Austria@	0.15	0.11	0	0.01	0.01	0.02	0.02	0.04	0.03	0	0	0	0.01
Belgium@	0.11	0.18	0.28	0.27	0.35	0.47	0.52	0.12	0.13	0.18	0.08	0.11	0.14
Canada#	0	0	0.01	0.01	0.02	0.02	0.04	0.06	0.03	0.04	0.07	0.06	0.02
Finland@	0.01	0	0.01	0.02	0.02	0.02	0.01	0.01	0.02	0	0	0	0
France@	0.03	0.04	0.08	0.06	0.04	0.01	0.01	0.01	0.02	0.03	0.02	0.02	0.04
Germany@	0.37	0.44	0.43	0.6	0.69	0.65	0.75	0.4	0.49	0.54	0.63	0.55	0.61
Italy@	0.02	0.01	0.03	0.06	0.11	0.06	0.06	0.04	0.07	0.1	0.13	0.11	0.13
Japan@	0.25	0.06	0.01	0.02	0.03	0.01	0.02	0.04	0.04	0.02	0.03	0.05	0.04
Luxemburg#	0.5	0.59	0.65	0.11	0.18	0.26	0.33	0.07	0.06	0.03	0.04	0.06	0.07
Netherlands@	0.44	0.39	0.3	0.09	0.1	0.13	0.19	0.23	0.3	0.38	0.38	0.42	0.34
Norway#	0.99	0.98	0.99	0.92	0.65	0.76	0.62	0.59	0.64	0.72	0.78	0.64	0.67
Portugal#	0.66	0.43	0.45	0.61	0.46	0.58	0.69	0.52	0.58	0.67	0.71	0.77	0.82
Sweden@	0.03	0.09	0.06	0.02	0.02	0.04	0.06	0.07	0.06	0.07	0.06	0.01	0.01
UK#	0.51	0.32	0.11	0.13	0.21	0.3	0.41	0.39	0.41	0.47	0.3	0.21	0.16
US#	0.04	0	0	0	0	0	0	0	0	0	0	0	0
G7#	0	0	0	0	0	0	0	0	0	0	0	0	0
OECD-Europe#	0.32	0.06	0.11	0.15	0.16	0.19	0.27	0.04	0.06	0.08	0.07	0.11	0.11
Greece@	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0.02
Spain#	0.64	0.04	0.08	0.15	0.18	0.27	0.08	0.1	0.14	0.16	0.17	0.21	0.16
Denmark@	0.74	0.94	0.84	0.88	0.3	0.34	0.27	0.24	0.32	0.31	0.15	0.18	0.18
OECD-Total#	0	0	0	0	0	0	0	0	0	0	0	0	0

Notes: Tests are based on 1000 simulations of model (6). p-values are based on the χ_{H+1}². Bold and italics denote significance at the 5% and 10% level, respectively. # and @ denote whether the impulse response to a positive shock was bigger or smaller than that to a negative shock, respectively.** and * denote significance after accounting for data mining at the 5% and 10% level, respectively.

Table 8. IRF based test of symmetry to 2 s.d. shock to the real oil price ($x_t^{\#} = x_t^{36}$) - post 1973 subsample

Horizon													
Country	0	1	2	3	4	5	6	7	8	9	10	11	12
Austria@	0.95	0.93	0.18	0.22	0.29	0.28	0.33	0.3	0.35	0.39	0.48	0.54	0.62
Belgium@	0.24	0.39	0.48	0.62	0.37	0.48	0.38	0.22	0.22	0.2	0.22	0.2	0.22
Canada#	0.06	0.09	0.18	0.29	0.36	0.43	0.54	0.56	0.59	0.59	0.6	0.59	0.51
Finland@	0.4	0.64	0.58	0.73	0.46	0.59	0.7	0.73	0.74	0.31	0.27	0.34	0.42
France@	0.25	0.51	0.33	0.29	0.42	0.35	0.17	0.19	0.26	0.31	0.32	0.39	0.44
Germany@	0.55	0.54	0.57	0.64	0.77	0.67	0.73	0.54	0.58	0.66	0.61	0.68	0.63
Italy@	0.25	0.36	0.48	0.62	0.7	0.79	0.48	0.25	0.34	0.41	0.49	0.33	0.4
Japan@	0.38	0.29	0.25	0.29	0.35	0.31	0.27	0.1	0.15	0.07	0.07	0.06	0.09
Luxemburg#	0.06	0.14	0.15	0.07	0.12	0.14	0.18	0.18	0.18	0.23	0.29	0.32	0.32
Netherlands@	0.23	0.38	0.12	0.06	0.09	0.13	0.17	0.14	0.2	0.26	0.29	0.37	0.38
Norway#	0.99	0.71	0.86	0.9	0.96	0.97	0.46	0.4	0.49	0.56	0.62	0.56	0.64
Portugal#	0.73	0.91	0.73	0.86	0.86	0.89	0.94	0.15	0.2	0.24	0.3	0.37	0.45
Sweden@	0.51	0.7	0.24	0.28	0.39	0.39	0.26	0.32	0.13	0.13	0.06	0.04	0.03
UK#	0.18	0.03	0.03	0.07	0.12	0.16	0.22	0.15	0.13	0.18	0.13	0.06	0.02
US#	0.98	0.04	0.09	0.04	0.07	0.11	0.09	0.13	0.17	0.22	0.29	0.25	0.29
G7#	0.09	0.16	0.14	0.21	0.32	0.36	0.36	0.46	0.55	0.58	0.45	0.34	0.38
OECD-Europe#	0.11	0.27	0.21	0.32	0.42	0.53	0.61	0.28	0.2	0.27	0.26	0.22	0.24
Greece@	0	0	0.01	0.02	0.05	0.08	0.12	0.15	0.2	0.27	0.32	0.25	0.3
Spain#	0.53	0.01	0.02	0.04	0.06	0.04	0.07	0.07	0.08	0.11	0.13	0.16	0.17
Denmark@	0.44	0.71	0.82	0.82	0.69	0.56	0.51	0.39	0.42	0.44	0.33	0.37	0.31
OECD-Total#	0.03	0.07	0.07	0.12	0.19	0.28	0.19	0.2	0.27	0.28	0.31	0.33	0.39

Notes: Tests are based on 1000 simulations of model (6). p-values are based on the χ_{H+1}². Bold and italics denote significance at the 5% and 10% level, respectively. # and @ denote whether the impulse response to a positive shock was bigger or smaller than that to a negative shock, respectively.** and * denote significance after accounting for data mining at the 5% and 10% level, respectively.

Table 9. IRF based test of symmetry to 1 s.d. shock to the real oil price ($x_t^{\#} = x_t^1$)- full sample

Horizon													
Country	0	1	2	3	4	5	6	7	8	9	10	11	12
Austria[@]	0.16	0.21	0.15	0.2	0.24	0.21	0.23	0.29	0.33	0.14	0.17	0.23	0.22
Belgium[#]	0.47	0.45	0.26	0.08	0.14	0.2	0.2	0.27	0.35	0.29	0.36	0.34	0.41
Canada[@]	0.17	0.03	0.03	0.06	0.1	0.12	0.16	0.11	0.11	0.13	0.18	0.2	0.07
Finland[#]	0.91	0.09	0.01	0.02	0.02	0.04	0.07	0.11	0.14	0.19	0.16	0.14	0.12
France[#]	0.35	0.36	0.34	0.41	0.34	0.45	0.52	0.6	0.62	0.71	0.63	0.67	0.63
Germany[@]	0.88	0.19	0	0.01	0.01	0.02	0.04	0.06	0.07	0.1	0.14	0.14	0.15
Italy[#]	0.05	0.08	0.11	0.07	0.13	0.18	0.18	0.25	0.19	0.24	0.3	0.13	0.15
Japan[#]	0.45	0.03	0	0	0	0	0	0	0	0	0	0	0
Luxemburg[#]	0.5	0.03	0.06	0.08	0.12	0.13	0.2	0.13	0.15	0.15	0.17	0.22	0.21
Netherlands[#]	0.99	0.11	0.15	0.01	0.02	0.04	0.06	0.1	0.13	0.16	0.13	0.14	0.16
Norway[@]	0.1	0.2	0	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.04
Portugal[#]	0.32	0.41	0.29	0.44	0.49	0.55	0.67	0.65	0.72	0.8	0.8	0.81	0.85
Sweden[#]	0.3	0.31	0.06	0.12	0.19	0.26	0.34	0.44	0.48	0.56	0.65	0.53	0.27
UK[@]	0.01	0.02	0.03	0.04	0.01	0.03	0.02	0.03	0.04	0.03	0.04	0.06	0.08
US[#]	0.27	0.02	0.04	0.03	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.01
G7[@]	0.03	0	0	0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01
OECD-Europe[#]	0.11	0.03	0.01	0.03	0.05	0.04	0.06	0.09	0.12	0.12	0.13	0.09	0.09
Greece[#]	0.33	0.01	0.02	0.01	0.02	0	0.01	0.01	0.01	0.02	0.02	0.03	0.04
Spain[@]	0.89	0.31	0.16	0.25	0.36	0.48	0.55	0.57	0.6	0.68	0.59	0.67	0.66
Denmark[@]	0.93	0.56	0.33	0.49	0.6	0.65	0.5	0.6	0.7	0.76	0.43	0.44	0.51
OECD-Total[#]	0.06	0.03	0.03	0.05	0.09	0.03	0.04	0.07	0.11	0.13	0.16	0.19	0.25

Notes: Tests are based on 1000 simulations of model (6). p-values are based on the $\chi\_\{H+1\}^2$. Bold and italics denote significance at the 5% and 10% level, respectively. # and @ denote whether the impulse response to a positive shock was bigger or smaller than that to a negative shock, respectively.** and * denote significance after accounting for data mining at the 5% and 10% level, respectively.

Table 10. IRF based test of symmetry to 1 s.d. shock to the real oil price ($x_t^{\#} = x_t^{12}$)- full sample

Horizon													
Country	0	1	2	3	4	5	6	7	8	9	10	11	12
Austria[#]	0.44	0.71	0.09	0.15	0.16	0.2	0.29	0.38	0.35	0.31	0.28	0.33	0.4
Belgium[@]	0.06	0.17	0.16	0.24	0.25	0.23	0.12	0.08	0.11	0.13	0.14	0.19	0.24
Canada[@]	0.02	0.04	0.09	0.09	0.06	0.09	0.11	0.03	0.00**	0.00**	0.00**	0.00**	0.00**
Finland[@]	0.15	0.12	0.03	0.06	0.04	0.06	0.1	0.12	0.17	0.16	0.21	0.08*	0.09*
France[@]	0.21	0.23	0.39	0.32	0.3	0.22	0.3	0.4	0.5	0.57	0.49	0.55	0.6
Germany[#]	0.07	0.09	0.09	0.17	0.26	0.36	0.45	0.26	0.3	0.24	0.3	0.26	0.32
Italy[@]	0.11	0.05	0.09	0.16	0.25	0.2	0.19	0.23	0.17	0.22	0.29	0.31	0.39
Japan[#]	0.11	0.06	0.02	0.04	0.01**	0.01*	0.01**	0.02**	0.02**	0.02**	0.03**	0.03*	0.05**
Luxemburg[@]	0.57	0.22	0.39	0.23	0.33	0.43	0.54	0.51	0.49	0.25	0.19	0.24	0.27
Netherlands[@]	0.91	0.44	0.3	0.19	0.27	0.32	0.33	0.37	0.44	0.54	0.58	0.6	0.65
Norway[#]	0.85	0.56	0.53	0.52	0.13	0.12	0.14	0.17	0.23	0.29	0.37	0.33	0.38
Portugal[@]	0.17	0.08	0.1	0.14	0.16	0.19	0.28	0.31	0.39	0.48	0.57	0.42	0.46
Sweden[@]	0.02	0.06	0.05	0.09	0.15	0.2	0.24	0.3	0.32	0.41	0.47	0.49	0.51
UK[@]	0.00**	0.00**	0.00**	0.01**	0.01**	0.02*	0.03*	0.05	0.07	0.07	0.11	0.13	0.17
US[#]	0.02	0.02	0.02	0.04	0.07	0.09	0.13	0.19	0.15	0.21	0.25	0.14	0.17
G7[@]	0.01	0.01	0.03	0.06	0.07	0.11	0.16	0.22	0.13	0.18	0.22	0.23	0.22
OECD-Europe[@]	0.07	0.04	0.07	0.14	0.21	0.29	0.39	0.37	0.46	0.33	0.41	0.49	0.52
Greece[#]	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.01**
Spain[@]	0.03	0.02	0.04	0.06	0.11	0.14	0.2	0.24	0.28	0.33	0.41	0.49	0.55

Notes: Tests are based on 1000 simulations of model (6). p-values are based on the χ_{H+1}². Bold and italics denote significance at the 5% and 10% level, respectively. # and @ denote whether the impulse response to a positive shock was bigger or smaller than that to a negative shock, respectively.** and * denote significance after accounting for data mining at the 5% and 10% level, respectively.

Table 11. IRF based test of symmetry to 1 s.d. shock to the real oil price ($x_t^{\#} = x_t^{36}$)- full sample

Horizon													
Country	0	1	2	3	4	5	6	7	8	9	10	11	12
Austria@	0.47	0.62	0.47	0.63	0.32	0.43	0.55	0.58	0.66	0.64	0.72	0.72	0.79
Belgium@	0.12	0.3	0.38	0.35	0.19	0.2	0.24	0.32	0.41	0.42	0.46	0.51	0.47
Canada#	0.02	0.06	0.08	0.07	0.07	0.04 **	0.05 **	0.01 **	0.01 **	0.01 **	0.01 **	0.02 **	0.01 **
Finland@	0.8	0.82	0.26	0.33	0.47	0.59	0.63	0.72	0.79	0.74	0.77	0.82	0.87
France@	0.72	0.47	0.37	0.45	0.54	0.65	0.75	0.82	0.84	0.82	0.47	0.52	0.51
Germany#	0.18	0.31	0.42	0.58	0.7	0.8	0.8	0.82	0.88	0.93	0.93	0.85	0.9
Italy@	0.31	0.11	0.22	0.35	0.46	0.54	0.37	0.46	0.55	0.64	0.72	0.7	0.76
Japan#	0.25	0.11	0.04	0.08	0.12	0.18	0.24	0.25	0.3	0.24	0.28	0.35	0.43
Luxemburg @	0.96	0.43	0.55	0.39	0.37	0.42	0.5	0.58	0.52	0.43	0.32	0.33	0.35
Netherlands @	0.62	0.46	0.52	0.26	0.38	0.49	0.61	0.69	0.76	0.83	0.84	0.81	0.82
Norway#	0.83	0.94	0.87	0.91	0.73	0.79	0.66	0.6	0.69	0.77	0.83	0.85	0.87
Portugal@	0.65	0.68	0.86	0.92	0.78	0.57	0.56	0.61	0.65	0.74	0.79	0.78	0.84
Sweden@	0.36	0.65	0.14	0.15	0.24	0.34	0.38	0.46	0.47	0.55	0.6	0.66	0.73
UK#	0.00 **	0.01 *	0.02 *	0.03	0.04	0.07	0.11	0.15	0.19	0.18	0.2	0.24	0.3
US@	0.62	0.33	0.15	0.26	0.38	0.47	0.54	0.65	0.68	0.55	0.6	0.25	0.15 *
G7@	0.36	0.03	0.03 *	0.06	0.08	0.1	0.06 **	0.08	0.11 *	0.12	0.17	0.19	0.10 **
OECD-Europe@	0.45	0.11	0.11	0.15	0.24	0.26	0.34	0.43	0.41	0.35	0.38	0.34	0.38
Greece#	0.00 *	0.00 **	0.00 **	0.01 **	0.02 **	0.03 **	0.04 **	0.04 **	0.06 *	0.07 *	0.09 *	0.13 *	0.14 *
Spain@	0.01	0.02	0.03	0.07	0.12	0.15	0.22	0.25	0.31	0.38	0.4	0.46	0.53

Notes: Tests are based on 1000 simulations of model (6). p-values are based on the $\chi\_\{H+1\}^2$. Bold and italics denote significance at the 5% and 10% level, respectively. # and @ denote whether the impulse response to a positive shock was bigger or smaller than that to a negative shock, respectively.** and * denote significance after accounting for data mining at the 5% and 10% level, respectively.

Table 12. IRF based test of symmetry to 2 s.d. shock to the real oil price ($x_t^{\#} = x_t^1$)- full sample

	Horizon												
Country	0	1	2	3	4	5	6	7	8	9	10	11	12
Austria@	0.19	0.26	0.17	0.2	0.26	0.18	0.2	0.24	0.26	0.06	0.08	0.11	0.08
Belgium@	0.49	0.48	0.28	0.07	0.12	0.17	0.13	0.16	0.23	0.17	0.22	0.17	0.23
Canada@	0.18	0.03	0.02	0.02	0.05	0.07	0.08	0.06	0.03	0.05	0.07	0.07	0.01
Finland#	0.92	0.06	0	0	0	0	0	0	0	0.01	0	0	0
France#	0.38	0.37	0.32	0.37	0.28	0.38	0.41	0.49	0.53	0.62	0.49	0.51	0.46
Germany@	0.89	0.21	0	0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01
Italy#	0.07	0.12	0.17	0.11	0.19	0.27	0.22	0.3	0.18	0.21	0.27	0.08	0.08
Japan@	0.51	0.02	0	0	0	0	0	0	0	0	0	0	0
Luxemburg #	0.52	0.02	0.04	0.06	0.08	0.08	0.12	0.07	0.08	0.08	0.06	0.08	0.07
Netherlands #	0.99	0.11	0.15	0	0.01	0.01	0.02	0.03	0.04	0.06	0.02	0.02	0.02
Norway@	0.11	0.22	0	0	0	0	0	0	0	0	0	0	0
Portugal#	0.34	0.43	0.27	0.4	0.41	0.43	0.54	0.43	0.46	0.55	0.59	0.62	0.66
Sweden#	0.33	0.34	0.07	0.13	0.2	0.26	0.35	0.45	0.5	0.57	0.65	0.47	0.21
UK@	0.01	0.03	0.03	0.04	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.04	0.05
US#	0.34	0.02	0.06	0.04	0.06	0.06	0.02	0.02	0	0	0	0	0
G7#	0.06	0	0	0	0	0	0	0	0	0	0	0	0
OECD-Europe#	0.15	0.06	0.02	0.03	0.04	0.04	0.06	0.1	0.13	0.13	0.12	0.06	0.03
Greece@	0.35	0	0.01	0	0.01	0	0	0	0	0	0	0	0
Spain@	0.89	0.28	0.09	0.15	0.22	0.32	0.33	0.35	0.34	0.42	0.21	0.28	0.25

Notes: Tests are based on 1000 simulations of model (6). p-values are based on the $\chi\_\{H+1\}^2$. Bold and italics denote significance at the 5% and 10% level, respectively. # and @ denote whether the impulse response to a positive shock was bigger or smaller than that to a negative shock, respectively.** and * denote significance after accounting for data mining at the 5% and 10% level, respectively.

Table 13. IRF based test of symmetry to 2 s.d. shock to the real oil price ($x_t^{\#} = x_t^{12}$)- full sample

	Horizon												
Country	0	1	2	3	4	5	6	7	8	9	10	11	12
Austria#	0.47	0.75	0.08	0.15	0.17	0.18	0.26	0.35	0.22	0.03	0.04	0.06	0.07
Belgium@	0.1	0.25	0.28	0.37	0.31	0.28	0.11	0.04	0.01	0.01	0	0	0
Canada#	0.04	0.04	0.09	0.06	0.07	0.09	0.12	0.03	0	0	0	0.01	0
Finland@	0.21	0.11	0.01	0.01	0.01	0.02	0.03	0.01	0.02	0	0	0	0
France@	0.26	0.25	0.42	0.28	0.22	0.22	0.3	0.39	0.49	0.5	0.25	0.32	0.15
Germany#	0.12	0.12	0.06	0.11	0.15	0.21	0.26	0.06	0.08	0.09	0.12	0.03	0.05
Italy@	0.12	0.02	0.04	0.08	0.14	0.08	0.02	0.03	0.04	0.02	0.03	0.01	0.01
Japan#	0.12	0.05	0	0	0	0	0	0	0	0	0	0	0
Luxemburg#	0.59	0.29	0.46	0.24	0.35	0.47	0.58	0.53	0.46	0.32	0.21	0.28	0.16
Netherlands@	0.91	0.44	0.23	0.04	0.03	0.06	0.07	0.08	0.11	0.15	0.13	0.01	0
Norway#	0.87	0.62	0.52	0.56	0.16	0.16	0.11	0.12	0.15	0.2	0.26	0.14	0.19
Portugal@	0.2	0.09	0.08	0.08	0.07	0.07	0.11	0.08	0.06	0.09	0.11	0.11	0.14
Sweden@	0.04	0.11	0.03	0.05	0.08	0.12	0.11	0.13	0.03	0.04	0.01	0	0.01
UK@	0	0	0	0	0	0	0	0	0	0	0	0	0
US#	0	0	0	0	0	0	0	0	0	0	0	0.00**	0.00*
G7@	0	0	0	0	0	0	0	0	0	0	0	0.00*	0
OECD-Europe@	0.03	0	0	0.01	0.02	0.03	0.04	0.01	0.01	0.01	0	0	0
Greece#	0	0	0	0	0	0	0	0	0	0	0	0	0
Spain@	0.02	0	0	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.02

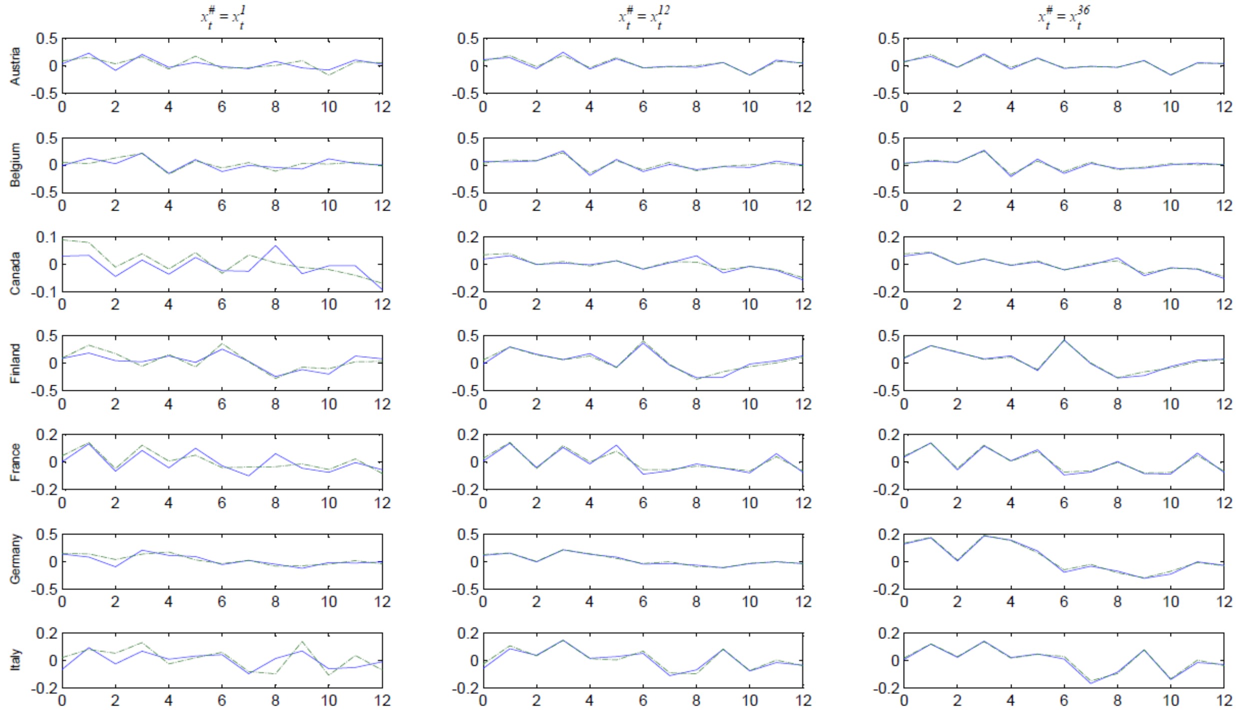
Notes: Tests are based on 1000 simulations of model (6). p-values are based on the χ_{H+1}^2. Bold and italics denote significance at the 5% and 10% level, respectively. # and @ denote whether the impulse response to a positive shock was bigger or smaller than that to a negative shock, respectively.** and * denote significance after accounting for data mining at the 5% and 10% level, respectively.

Table 14. IRF based test of symmetry to 2 s.d. shock to the real oil price ($x_t^{\#} = x_t^{36}$)- full sample

Horizon													
Country	0	1	2	3	4	5	6	7	8	9	10	11	12
Austria#	0.52	0.66	0.38	0.52	0.27	0.32	0.41	0.39	0.43	0.29	0.33	0.27	0.14
Belgium@	0.17	0.38	0.44	0.38	0.18	0.2	0.21	0.22	0.28	0.21	0.11	0.14	0.06
Canada#	0.07	0.15	0.19	0.16	0.24	0.05	0.07	0.01	0.01	0.01	0.02	0.01	0
Finland@	0.78	0.74	0.11	0.04	0.08	0.13	0.17	0.2	0.18	0.07	0.04	0.06	0.07
France@	0.74	0.58	0.48	0.51	0.52	0.59	0.71	0.75	0.71	0.56	0.06	0.08	0.03
Germany#	0.12	0.15	0.15	0.2	0.29	0.39	0.37	0.21	0.25	0.33	0.31	0.02	0.03
Italy@	0.25	0.02	0.04	0.08	0.13	0.16	0.02	0.02	0.03	0.04	0.04	0.01	0.01
Japan#	0.21	0.06	0	0	0	0	0.01	0	0.01	0	0	0.01	0.01
Luxemburg@	0.93	0.46	0.53	0.27	0.35	0.44	0.55	0.63	0.52	0.48	0.4	0.22	0.13
Netherlands@	0.63	0.46	0.4	0.06	0.09	0.14	0.2	0.23	0.31	0.36	0.31	0.12	0.04
Norway#	0.81	0.93	0.81	0.85	0.43	0.46	0.33	0.3	0.38	0.46	0.55	0.48	0.52
Portugal@	0.61	0.46	0.64	0.73	0.53	0.44	0.47	0.22	0.25	0.32	0.32	0.26	0.33
Sweden@	0.36	0.65	0.06	0.03	0.06	0.11	0.13	0.19	0.11	0.09	0.06	0.04	0.04
UK#	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0
US@	0.1	0	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0	0
G7@	0	0	0	0	0	0	0	0	0	0	0	0	0
OECD-Europe@	0.01	0	0	0	0	0	0.01	0.01	0.01	0.01	0	0	0
Greece@	0	0	0	0	0	0.01	0	0	0	0.01	0.01	0.01	0.02
Spain@	0	0	0	0.01	0.02	0.02	0.03	0.04	0.04	0.04	0.04	0.03	0.04

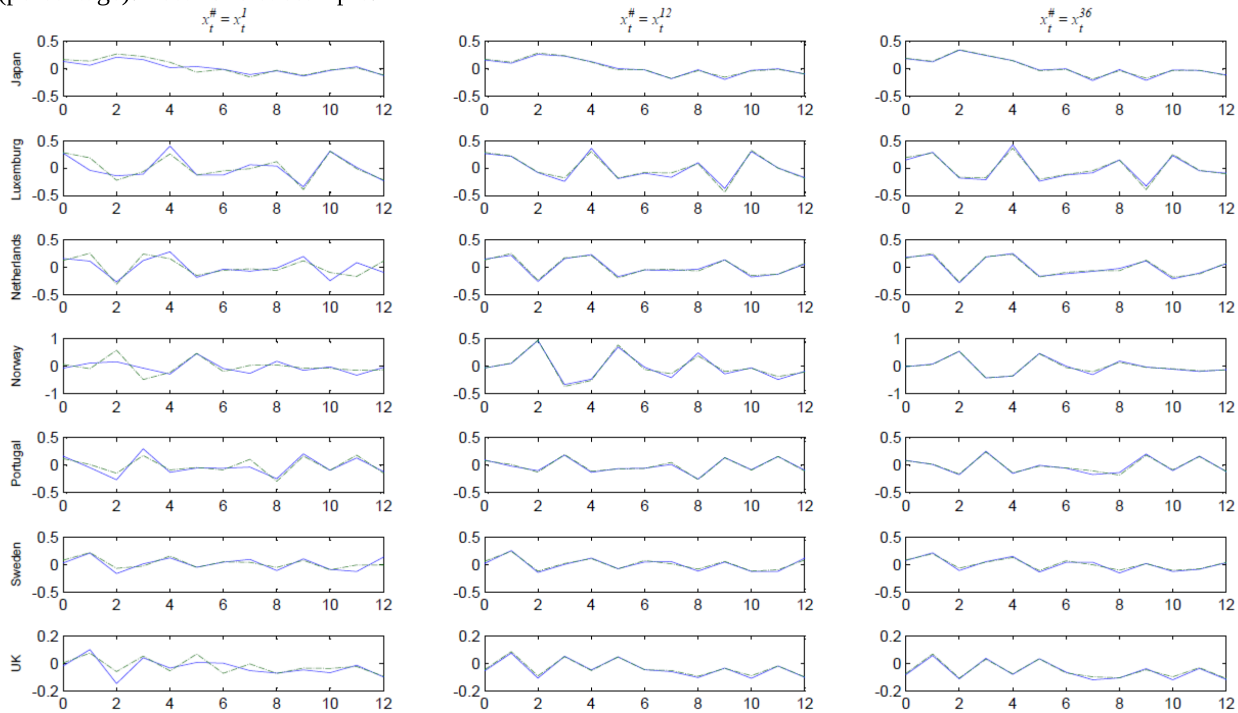
Notes: Tests are based on 1000 simulations of model (6). p-values are based on the χ_{H+1}^2. Bold and italics denote significance at the 5% and 10% level, respectively. # and @ denote whether the impulse response to a positive shock was bigger or smaller than that to a negative shock.** and * denote significance after accounting for data mining at the 5% and 10% level, respectively.

Figure 1a: Impulse Response to a one standard deviation positive and negative shocks to the real price of oil (percentage): Post 1973 subsample.



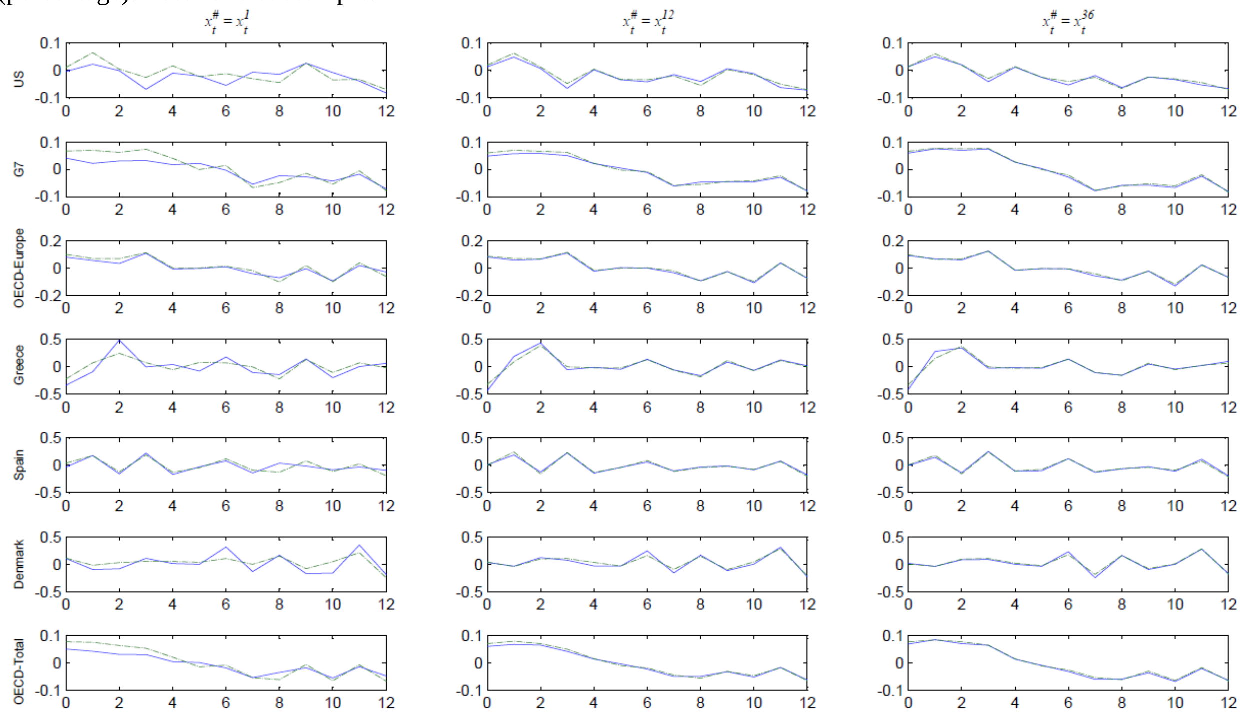
Note: Estimates are based on the VAR in (6) where the number of replications to obtain IRFs equal 1000.

Figure 1b: Impulse Response to a one standard deviation positive and negative shocks to the real price of oil (percentage): Post 1973 subsample.



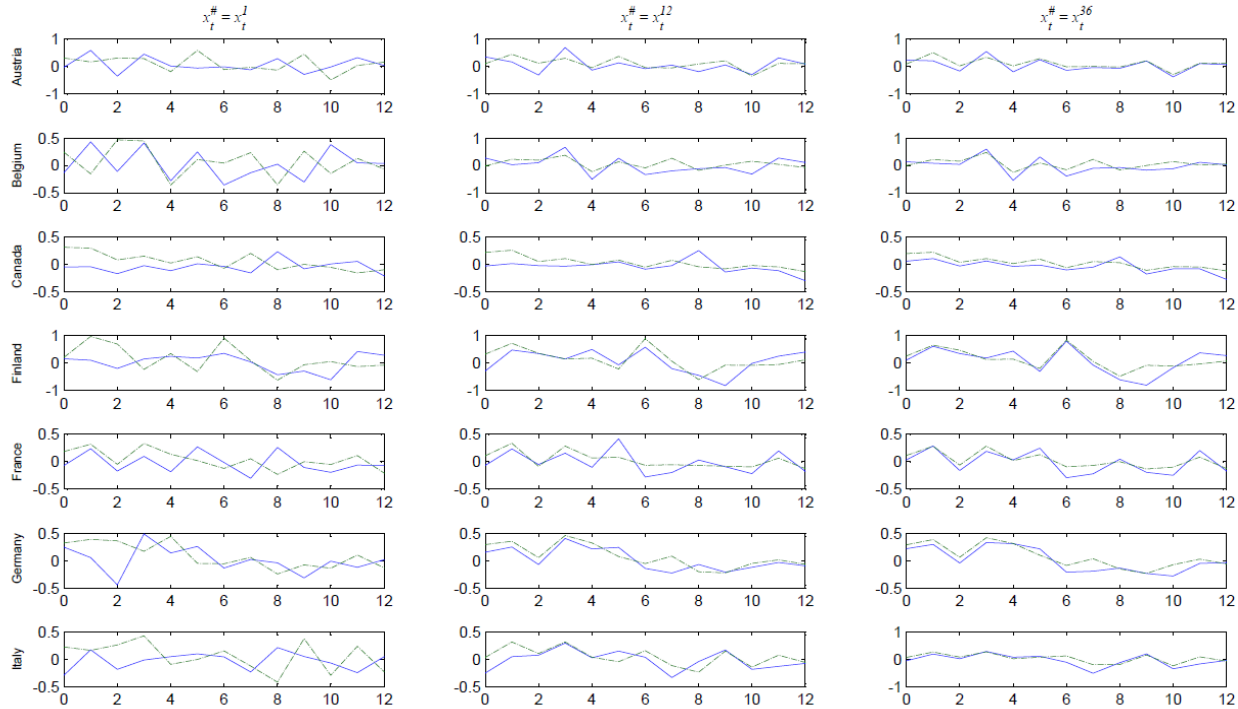
Note: Estimates are based on the VAR in (6) where the number of replications to obtain IRFs equal 1000.

Figure 1c: Impulse Response to a one standard deviation positive and negative shocks to the real price of oil (percentage): Post 1973 subsample.



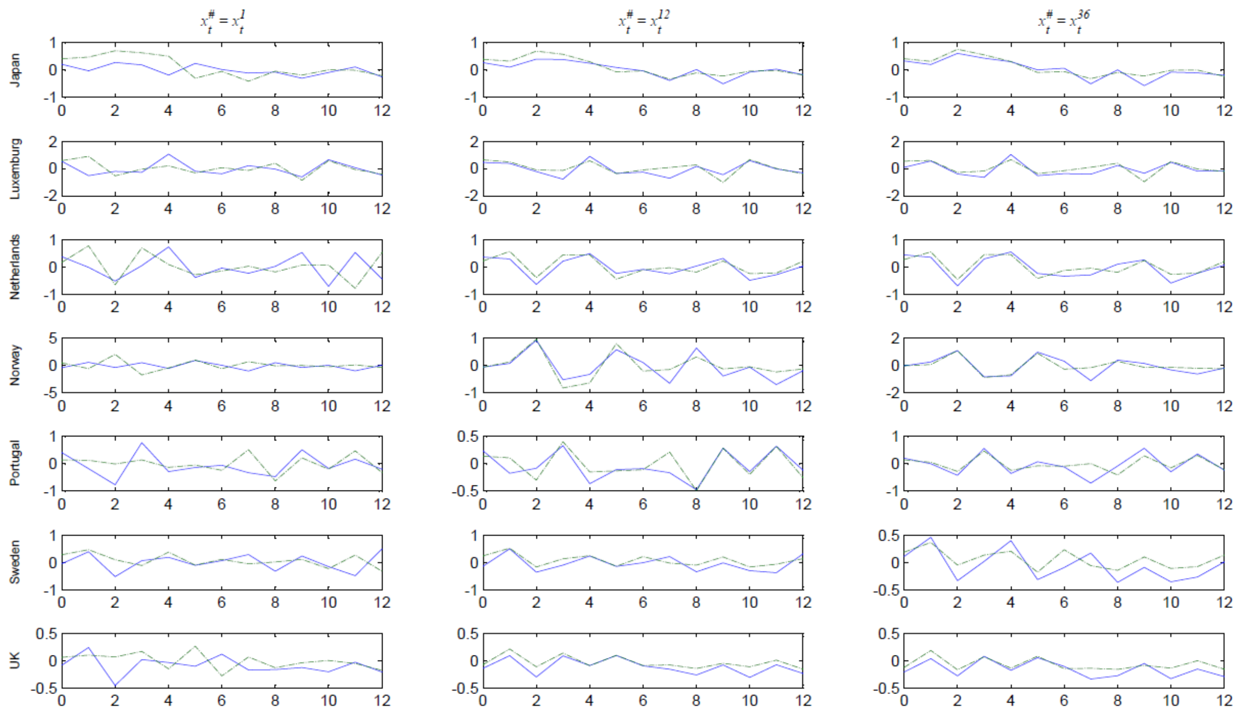
Note: Estimates are based on the VAR in (6) where the number of replications to obtain IRFs equal 1000.

Figure 2a: Impulse Response to a two standard deviation positive and negative shocks to the real price of oil (percentage): Post 1973 subsample.



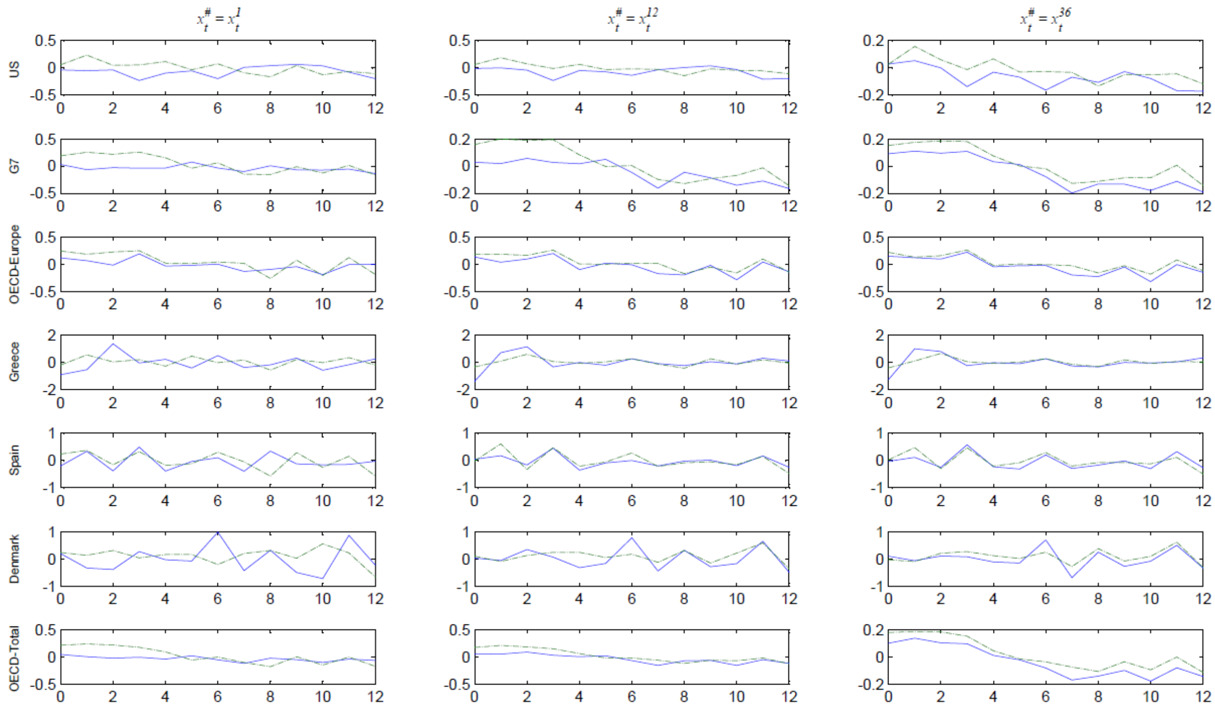
Note: Estimates are based on the VAR in (6) where the number of replications to obtain IRFs equal 1000.

Figure 2b: Impulse Response to a two standard deviation positive and negative shocks to the real price of oil (percentage): Post 1973 subsample.



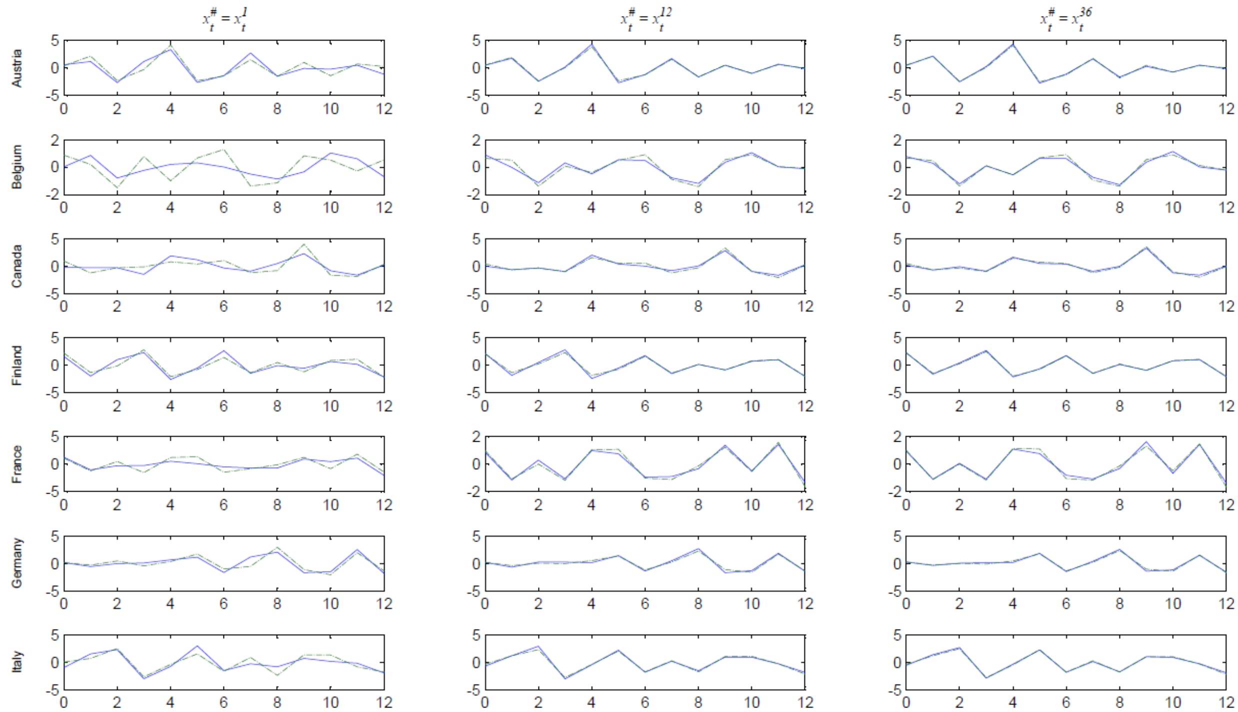
Note: Estimates are based on the VAR in (6) where the number of replications to obtain IRFs equal 1000.

Figure 2c: Impulse Response to a two standard deviation positive and negative shocks to the real price of oil (percentage): Post 1973 subsample.



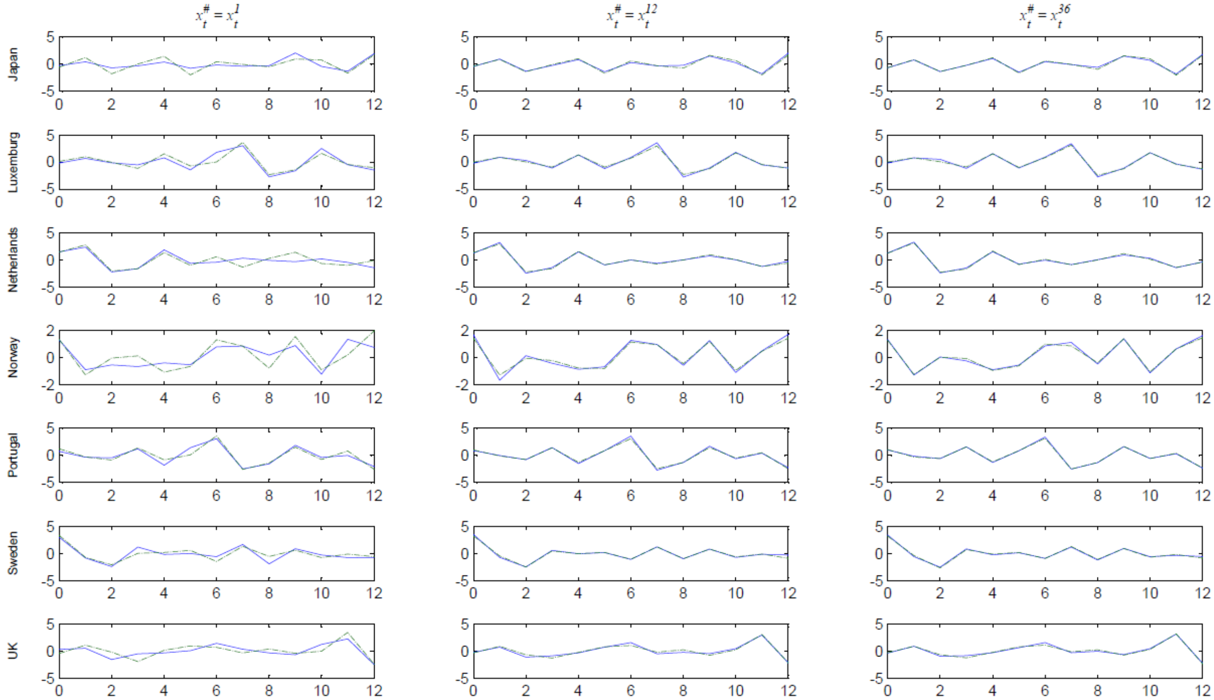
Note: Estimates are based on the VAR in (6) where the number of replications to obtain IRFs equal 1000.

Figure 3a: Impulse Response to a one standard deviation positive and negative shocks to the real price of oil (percentage): Full sample.



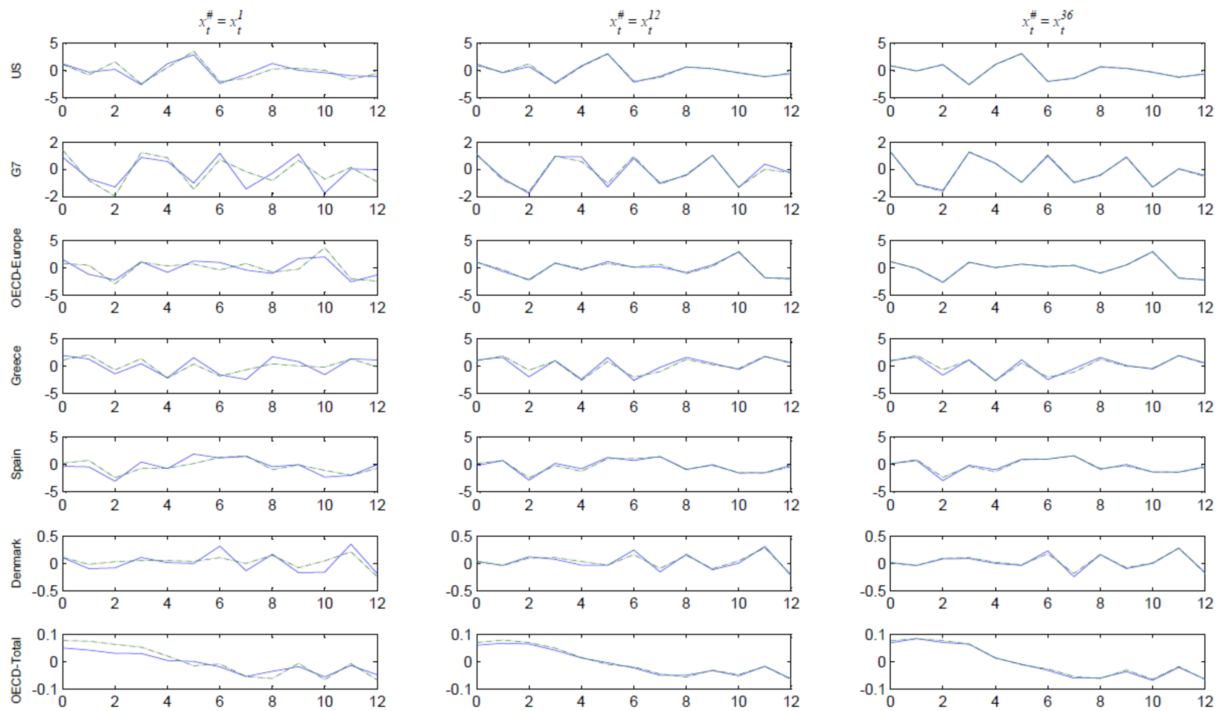
Note: Estimates are based on the VAR in (6) where the number of replications to obtain IRFs equal 1000.

Figure 3b: Impulse Response to a one standard deviation positive and negative shocks to the real price of oil (percentage): Full sample.



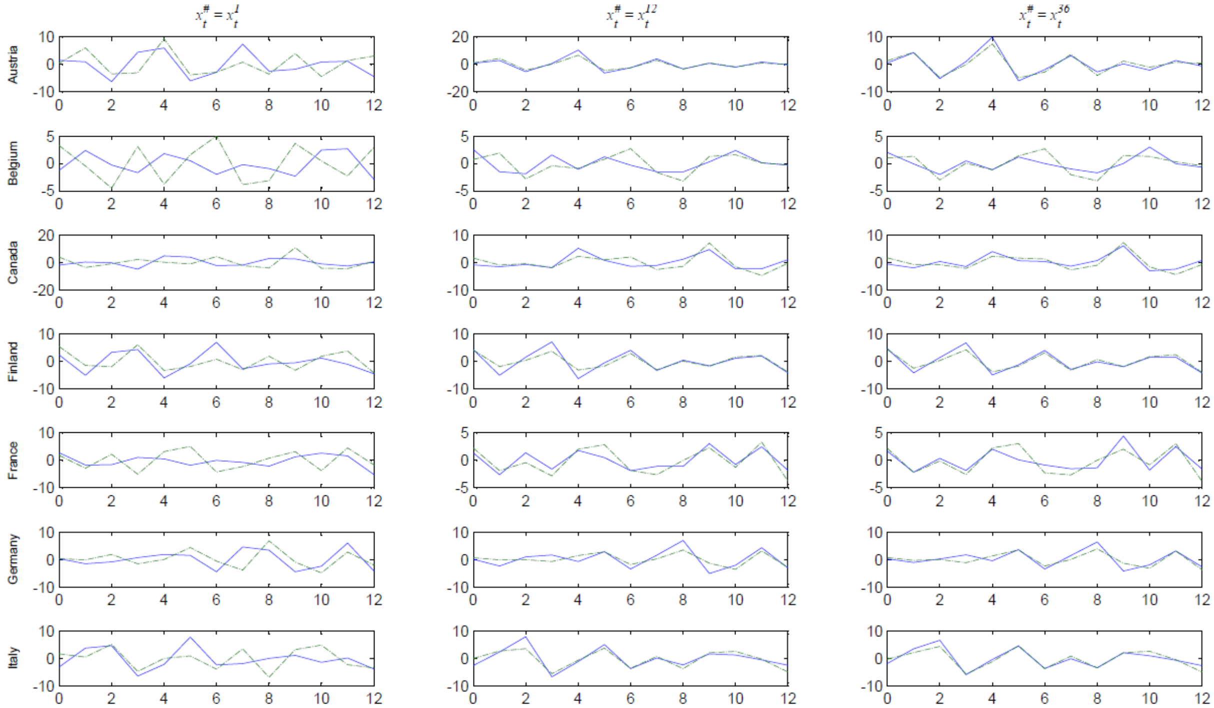
Note: Estimates are based on the VAR in (6) where the number of replications to obtain IRFs equal 1000.

Figure 3c: Impulse Response to a one standard deviation positive and negative shocks to the real price of oil (percentage): Full sample.



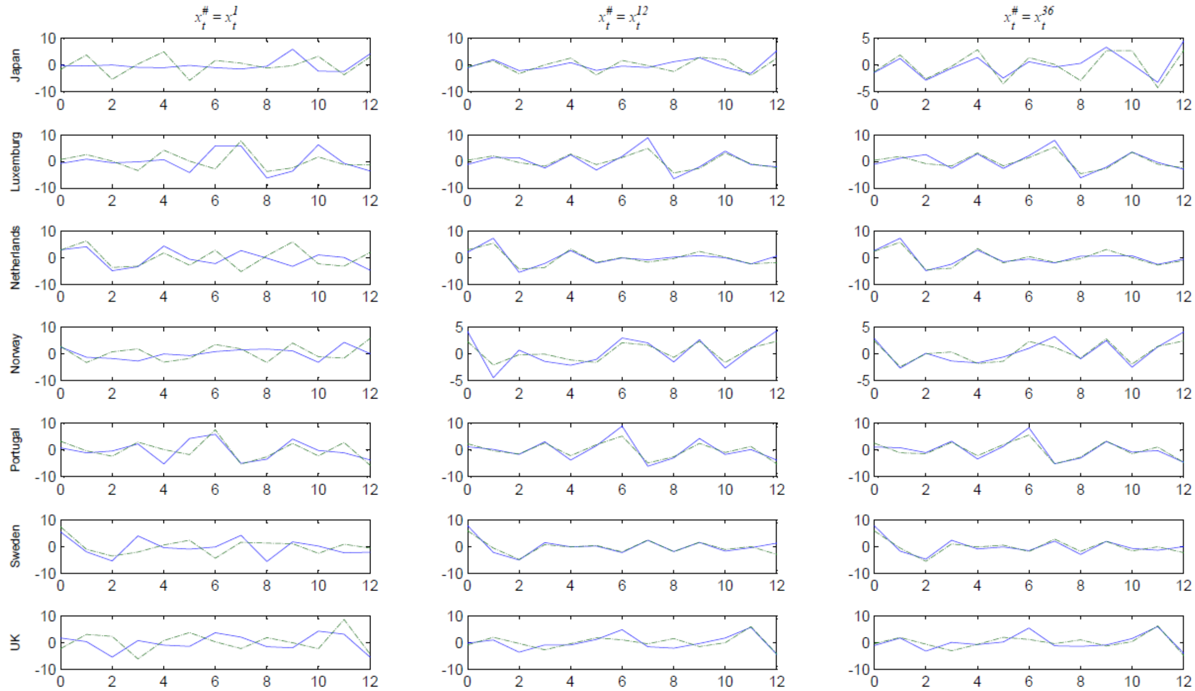
Note: Estimates are based on the VAR in (6) where the number of replications to obtain IRFs equal 1000.

Figure 4a: Impulse Response to a two standard deviation positive and negative shocks to the real price of oil (percentage): Full sample.



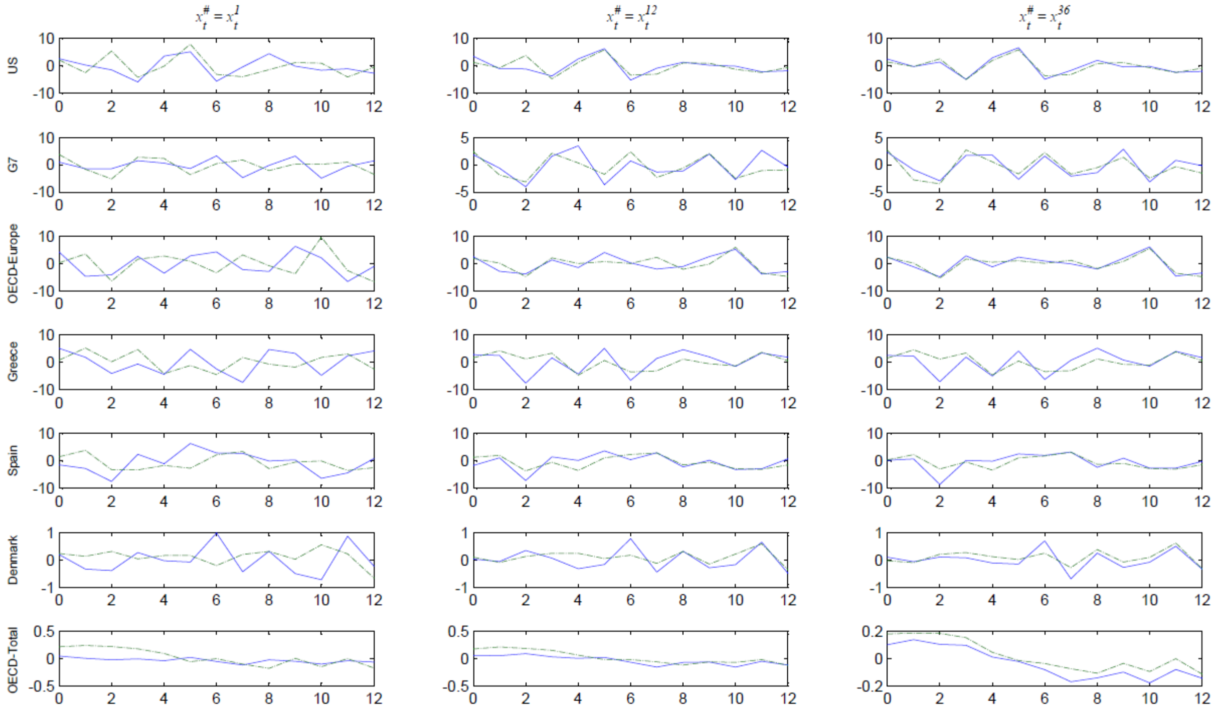
Note: Estimates are based on the VAR in (6) where the number of replications to obtain IRFs equal 1000.

Figure 4b: Impulse Response to a two standard deviation positive and negative shocks to the real price of oil (percentage): Full sample.



Note: Estimates are based on the VAR in (6) where the number of replications to obtain IRFs equal 1000.

Figure 4c: Impulse Response to a two standard deviation positive and negative shocks to the real price of oil (percentage): Full sample.



Note: Estimates are based on the VAR in (6) where the number of replications to obtain IRFs equal 1000.

CHAPTER 3 SEPARATING DEMAND AND SUPPLY SHOCKS IN THE OIL MARKET — AN ANALYSIS USING DISAGGREGATED DATA[1]

1. Introduction

The weaker response of the economy to oil price increases in the 2000s led to the question of whether oil should be treated as exogenous or endogenous. A large number of authors in recent years have looked at what Nordhaus(2007) describes as "the surprising oil non-crisis" that followed the oil price increase of 2003-2008.[2]

This branch of the oil price shock literature further addresses the issue of studying the nature of the underlying oil shock. Lippi and Nobili (2010) show that the relationship between oil price shocks and US business cycles depends on whether the shocks are oil supply shocks, global supply shocks, US supply shocks, or global demand shocks. Similar results have been confirmed by Balke, Brown and Yücel (2010) who through their use of Bayesian methods with DSGE models identify sources of oil price shocks (Also see, Barsky and Kilian (2004), and Kilian (2008a)).

Regardless, until recently, the common approach in the literature that analyzes the oil price-macroeconomy relationship has been to treat the change in the price of oil as exogenous. However, Kilian (2009) treats oil prices as endogenous and decomposes the price of oil into three components: oil supply shocks, shocks to the aggregate world demand for industrial commodities, and demand shocks that are specific to the crude oil market. According to the

[1] I thank Ana María Herrera for her immense guidance and help. I am grateful to Lutz Kilian for his comments and data. I also thank seminar participants at Georgia State University, Emory University, University of Michigan, and University of North Carolina- Charlotte for helpful comments and suggestions.

[2] Herrera and Pesavento (2009), Blanchard and Gali (2008), Edelstein and Kilian (2007) among others explain the difference seen in the 2000s by citing increased global financial integration, greater flexibility, smaller shocks, better monetary response, reduced energy intensity and increased experience as some of the reasons.

author, the last component reflects precautionary demand. The paper examines the importance of each of these components in determining the real price of oil and concludes that policies that deal with higher oil prices should look at its underlying determinants.

Unlike the traditional idea that crude oil supply disruptions drive the real price of oil, Kilian (2009) concludes that crude oil production changes only cause a small and temporary increase in the real price of oil. On the other hand, he finds that both an increase in oil-specific demand and an increase in aggregate demand for world industrial commodities cause a substantial increase in the real price of oil. In addition, historical oil price decompositions also show that from 1973-2007, the real price of oil was mainly influenced by a combination of changes in aggregate demand for industrial commodities and oil-specific demand shock. These findings have an important implication on how changes in the real price of oil affect the U.S. economy. Since each of these shocks affect the real price of oil differently, they also have different impacts on the US economy. In addition, some of these shocks may have direct effects on the US economy and indirect effects through the real price of oil.

This paper extends the work done by Kilian (2009) by examining the impact of demand and supply shocks in the crude oil market on 29 industrial production indices in the US. It has been argued that it is useful to consider disaggregated data while studying the relationship between oil prices and the macroeconomy as focusing on real aggregate GDP might hide the reallocative affects of capital and labor as a result of an oil price increase. In addition, the effect of different oil shocks on GDP maybe a weighted total of the effects on individual industries and simply analyzing the effects of oil shocks on an aggregate measure will ignore individual industry responses (Herrera, Lagalo, and Wada, 2011). Further, we examine both energy intensive and non-energy-intensive industries since analysis in existing literature tends to focus only on energy intensive industries.

This paper deals with several issues. First, we treat oil prices as endogenous. As shown by Balke, Brown and Yücel (2010), Barsky and Kilian (2004), Kilian and Vega (2009) and Kilian (2009) amongst others, oil prices should be treated as endogenous. Second, we determine the role of oil demand conditions and global macroeconomic conditions in defining the relationship between oil prices and industrial production. In particular, we examine the roles that oil supply shocks driven by political events, other oil supply shocks, demand shocks to industrial commodities, and oil-specific demand shocks play in explaining industrial production. Third, we attempt to find if demand shocks in the crude oil market matter more than supply shocks. Fourth, the paper analyzes if energy intensive sectors have a stronger response to oil shocks than non-energy-intensive oil shocks.

This paper looks at two different cases. In the first case, the global crude oil production measures the supply side effects. In contrast, the demand side effects are measured by the real price of oil and the Kilian index of global real economic activity (Kilian 2009) which is based on a global index of dry cargo single voyage freight rates. In the second case, a measure of oil supply shocks driven by political events is explicitly included to further separate oil supply shocks from political events from other supply shocks. We find that impact of oil supply shocks, although significant for a few sectors, is not as important as that of aggregate demand shock and oil-specific demand shock. We also find that the effect of an aggregate demand shock, while positive and significant at first, eventually becomes negative. The oil-specific demand shock seems to be more important than other shocks since it leads to significant responses for more horizons and more sectors than the other shocks. We also find that there seem to be no clear connection between energy intensity and the response of a sector to the structural oil shocks. Furthermore, inclusion of a political supply shock does not change our overall conclusion.

Our results are in line with Kilian and Hicks (2010), Dvir and Rogoff (2010), and Kilian (2009), who show that demand side oil shocks contribute more to changes in U.S. macroeconomic aggregates than supply side oil shocks. However, our results also show that oil supply shocks may play a bigger role in determining industrial production in certain non-energy-intensive sectors such as machinery, fabricated metal, and transit equipment. Similarly, aggregate demand shocks seem to play a more important role for sectors like nondurable consumer goods, paper products, chemical products, printing and related, and chemicals. It is also observed that the response of not all sectors is negative to some shocks. Several sectors have a positive and significant response to an aggregate demand shock. In addition, motor vehicles and consumer durables have a positive response to an oil supply shock. Our results also show that demand shocks do not have an impact on food and tobacco, food, beverage and tobacco, and paper. In short, we find that the impact of an oil price shock can be positive, negative, or insignificant depending on the sector and on the nature of the shock. In addition, our findings show that further research efforts need to focus on developing theoretical models that address the underlying nature of an oil shock.

The paper is organized as follows: Section 2 describes the data while Section 3 describes the methodology for both cases considered. The results are described in Section 4 and Section 5 concludes.

2. Data

We consider two different cases. In the first case we use the global crude oil production to measure the supply side effects, while the demand side effects are measured by the real price of oil and the Kilian index of global real economic activity (Kilian 2009). In the second case, the supply side effects are measured by: 1) a measure of oil price shocks due to political events proposed by Kilian (2008 a, b) and 2) the global crude oil production. The Kilian index on global real economic activity is based on a global index of dry cargo single voyage freight rates. It is the measure of the component of worldwide economic activity that drives demand for industrial commodities in world markets. The measure of oil price shocks due to political events is important to include since production of crude oil may be disrupted by wars and revolutions in the Middle East. This measure distinguishes between crude oil production changes caused directly by political events in OPEC countries and endogenous changes in production caused by changes in the real price of oil.

Because macroeconomic models of the transmission of oil price shocks are typically specified in terms of the price of imported crude oil (Kilian and Vigfusson, 2010), we use the Refiners Acquisition Cost for crude oil imported into the U.S. The series is deflated using the U.S. CPI. Both the data on Refiners Acquisition Cost and global crude oil production are reported by the Energy Information Agency. The data for the Kilian index for economic activity is obtained from Kilian (2009) and that for the oil price shocks due to political events is obtained from Kilian (2008a). While the sample period considered for the first case is 1973.2 to 2007.12 , the one for the second case extends only until 2004.9 due to limited availability of the measure of oil price shocks due to political events.

The four series are plotted in Figure 1. The measure of oil price shock due to political events witnesses considerable fluctuation in late 1973 and early 1974 but remains flat until late 1978 (see upper left panel of Figure 1). Further wild oscillations are seen in the early 1980s, early 1990s, and throughout the 2000s. The biggest fall is observed in November 1980 while the biggest increases are seen in 1974 and 1979. The growth rate of crude oil production is plotted in the upper right panel of Figure 1 and averages at 0.94. We first observe a large negative growth rate of crude oil production in November 1973, followed by October 1975 and January 1977; however, in the latter two cases it quickly recovers. The series is relatively less volatile in the 1980s and the variability of the series further diminishes in the 1990s and the 2000s.

Global real economic activity and the rate of growth of the real price of oil are plotted in the bottom left and right panels, respectively, of Figure 1. Global real economic activity goes through huge increases in late 1973/early 1974 and big declines in the mid 1980s. There is a further reduction in global real economic activity in the late 1990s. The rate of growth in the real price of oil is high throughout 1979-1984 and then starts declining, becoming negative by the mid 1980s. Barring some positive growth in the real price of oil in latter half of 1990, the rate of growth of the real price of oil remains negative throughout the 1990s, with a large decrease in 1998-1999.

To measure U.S. economic activity we use data on seasonally adjusted industrial production (IP) index for 29 sectors computed by the Board of Governors of the Federal Reserve. These indices include 5 aggregates and market and industry groups. Market groups comprise of products and materials. Products include aggregates such as consumer goods, equipment and nonindustrial supplies, whereas materials correspond to inputs used in the manufacturing of products. Industry groups include three digit NAICS industries. The period spanned by the data is 1974.12 to 2007.12 and 1974.12 to 2004.9 for Case 1 and Case 2, respectively, depending on the availability of data on the oil market measures.

Table 1 provides summary statistics for the industries in our sample. The industries with the highest monthly average growth rates in our sample are durable consumer goods, manufacturing (SIC), chemical products, plastics and rubber products, motor vehicle, and manufacturing (NAICS) with monthly average growth rates ranging between 0.25% to 0.36% . The lowest average monthly growth rates are observed for clothing, apparel and leather goods, primary metal, fabricated metal product, machinery, transit equipment, textiles materials, and electrical equipment. The lowest monthly average growth rates range from -0.23% to 0.10% monthly growth rates. The growth rates for motor vehicles, motor vehicles and parts, transit equipment, and primary metal have a larger variance than that for other sectors.

Table 2 shows energy intensity for selected NAICS industries. Energy intensity is calculated as the ratio of energy consumption (measured in Trillion Btu) to gross output (measured in Billion 2000 Dollars). Both series have been obtained from the Manufacturing Energy Consumption Survey (2006) of the U.S. Energy Information Administration. Our sample includes a mix of energy intensive and non-energy-intensive sectors. The sectors with the highest energy intensity are paper, petroleum and coal, chemicals, and primary metal. Other sectors that are energy intensive are food, beverage and tobacco, textiles and products, and total manufacturing.[3]

The chemical industry is the largest energy consuming industry in the industrial sector. In 2003, the chemical industry consumed 6.3 quadrillion Btu of energy. This number is expected to

[3] It is worth observing that the sectors with the high energy intensity have seen a significant decline in energy intensity over the years. While this may be in part due to redefinition of industries over the years due to the switch from SIC to NAICS, some may be attributed to improvements in efficiency (Issues in Focus, Annual Energy Outlook 2007). This is consistent with an overall decline in energy intensity of GDP.

grow to 7.5 quadrillion Btu in 2025. The chemical sector depends on natural gas and petroleum as material inputs and as fuel for heat and power (Issues in Focus, Annual Energy Outlook 2007). Petroleum refining is the most energy intensive manufacturing industry in the U.S. The petroleum refining industry uses energy both to supply heat and power for plant operations and as a raw material for the production of petrochemicals and other non-fuel products (Manufacturing Energy Consumption Survey, Industry Analysis Briefs).

It should be noted that most sectors with high average growth rates are also sectors that have high energy intensity either in terms of production or in terms of use. For example, while chemicals are energy intensive in terms of production, motor vehicles is a sector that is energy intensive in terms of use. However, some energy intensive sectors such as primary metal and textiles have some of the lowest monthly average growth rates in our sample. Nevertheless, most sectors that have the low energy intensity also have low average growth rates; examples include apparel and leather goods, fabricated metal product, machinery, and electrical equipment.

3. Methodology

While traditionally oil supply shocks have been deemed to be the factor driving oil prices, recent literature has shown a surprising result. Unanticipated oil supply disruptions have only a small transitory positive effect on the real price of oil (See Kilian (2009), Kilian and Park (2009), and Kilian and Lewis (2009)). In addition, new findings suggest that historically, oil supply shocks have contributed relatively little to changes in the real price of oil compared to oil demand shocks. Previous models of the oil-price macroeconomy relationship have treated oil prices as exogenous and being mainly influenced by oil supply shocks.

These findings make it necessitate an examination of how the U.S. industries are affected by each of this shocks. Demand and supply side oil shocks may have different impacts on the US industries through both direct effects and indirect effects through the real price of oil. Therefore, we extend the work done by Kilian (2009).by separating the effect of oil demand shocks from oil supply shocks on U.S. industrial production indices. We compute different structural shocks in the oil market and examine their impact on different IP indices.

We look at two different cases. In the first case, the global crude oil production measures the supply side effects and the demand side effects are measured by the real price of oil and the Kilian index of global real economic activity (Kilian 2009). This case is discussed in Section 3.1. In the second case, a measure of oil supply shocks driven by political events is explicitly included in addition to the global crude oil production to measure the supply side effects. This case is discussed in Section 3.2.

3.1 Case1: Separating demand shocks from supply shocks

We use a structural VAR (vector autoregression) model of the global crude oil market that addresses issues related to both endogeniety and separation of supply and demand shocks. This structural VAR has been proposed by Kilian (2009) and includes $z_t = (\Delta prod_t, rea_t, rpo_t)'$ where $\Delta prod_t$ is the percent change in global crude oil production, rea_t, denotes real economic activity, and rpo_t represents the real price of oil. The last two series are expressed in logs.

We estimate the following structural representation:

$$A_0 z_t = \mu + \sum_{j=1}^{24} A_j z_{t-j} + v_t \quad (1)$$

where v_t denotes the vector of serially and mutually uncorrelated structural innovations.

The reduced form errors are decomposed as:

$$u_t \equiv \begin{pmatrix} u_t^{\Delta prod} \\ u_t^{rea} \\ u_t^{rpo} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & 33 \end{bmatrix} \begin{pmatrix} v_t^{O1} \\ v_t^{O2} \\ v_t^{O3} \end{pmatrix} \quad (2)$$

where *O1*, *O2*, and *O3* refer to the 3 structural shocks: oil supply shock, shock to world aggregate demand for industrial commodities (hereafter referred to as an aggregate demand shock), and oil-specific demand shock respectively. This helps us determine what drives the price of oil and that further helps us in accurately predicting the implications of higher oil price on the economy.

So in the next step, we estimate the effects of the above shocks on U.S. industrial production indices using the regression:

$$\Delta y_{i,t} = \mu + \sum_{j=1}^{p} \theta_j \, v_{s,t-j} + \eta_t \quad (3)$$

where s=1,2,3 refers to the 3 structural shocks and $\Delta y_{i,t}$ refers to growth rate of industrial production indices for i=1 to 29.

The impulse response coefficients correspond to θ_{jh} for horizon h. The number of lags and the maximum horizon of the impulse response function are set at 36 months. The number of bootstrap replications used is 20000.

3.2 Case 2: Separation of political supply shock and other supply shocks

In order to separate oil supply shocks from the oil demand shocks, we now include another variable to represent the supply side. We specify a structural near-VAR model based on monthly data for $x_t = (ex_t, \Delta prod_t, rea_t, rpo_t)'$ where ex_t denotes the series of oil supply shocks driven by exogenous political events in OPEC countries.

We estimate the following structural representation

$$A_0 x_t = \mu^x + \sum_{j=1}^{24} A_j x_{t-j} + v_t^x \qquad (4)$$

where the first row of A_j has been restricted to zero, reflecting the exogeneity of ex_t and its lack of serial correlation (see Kilian 2009 for further explanations) and v_t denotes the vector of serially and mutually uncorrelated structural innovations.

The reduced form errors are now decomposed as:

$$u_t \equiv \begin{pmatrix} u_t^{x,ex} \\ u_t^{x,\Delta prod} \\ u_t^{x,rea} \\ u_t^{x,rpo} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{pmatrix} v_t^{O1} \\ v_t^{O2} \\ v_t^{O3} \\ v_t^{O4} \end{pmatrix} \qquad (5)$$

where *O1*, *O2*, *O3*, and *O4* refer to political oil supply shock, other oil supply shock, aggregate demand shock, and oil-specific demand shock respectively.

In the second step, the impact of monthly shocks on US industrial production indices is computed.

$$\Delta y_{i,t} = \mu^x + \sum_{j=1}^{p} \theta_j^x \, v_{s,t-j}^x + \eta_t^x \qquad (6)$$

where *s*=1,2,3,4 refers to the 4 structural shocks.

The impulse response coefficients correspond to θ_{jh}^x for horizon h. The number of lags and the maximum horizon of the impulse response function are set at 36 months. The number of bootstrap replications used is 20000.

4. Results

Until recently oil supply shocks have been deemed to be the driving factor behind the real price of oil. However, findings in recent literature suggest that historically, oil supply shocks have contributed relatively little to changes in the real price of oil compared to oil demand shocks. Therefore, we examine how demand and supply side oil shocks have different impacts on 29 U.S. industries.

The first case is discussed in Section 4.1. In the first case, the demand side effects are measured by the real price of oil and the Kilian index of global real economic activity (Kilian 2009) and the supply side effects are measured by the global crude oil production. Section 4.1 first discusses the impact of oil supply shocks, followed by the impact of aggregate demand shocks, and then oil-specific demand shock. We find that impact of oil supply shocks, although significant for a few sectors, is not as important as that of aggregate demand shock and oil-specific demand shock. We also find that the effect of an aggregate demand shock, while positive and significant at first, eventually becomes negative. The oil-specific demand shock is more important than other shocks since it leads to significant responses for more horizons and more sectors than the other shocks. The results for the second case are discussed in Section 4.2. We find that the inclusion of a political supply shock does not change the overall results.

4.1 Case 1: Separating demand shocks from supply shocks

Figures 2a-2f present results for the first case. While the highest number of significant values arise from an oil-specific demand shock for most sectors, aggregate demand shocks and supply shocks matter more for some other sectors. In particular, supply side oil shock leads to significant responses for more horizons than other types of shocks for sectors such as machinery, fabricated metal, transit equipment, paper materials, and paper. The impulse response functions to a supply side shock can be seen the first panel of Figures 2a-2f. Interestingly, while the response of machinery, fabricated metal, and transit equipment to a supply shock is significant for 32 months or more, the response of paper materials and paper is only significant for nearly a year. Note that, the former 3 sectors are low-energy-intensity sectors while paper is a high energy intensity sector. The response of machinery is found to be highly significant with significant values found for all horizons implied by the one standard deviation confidence band.

In addition, the response of total index to a supply shock is significant for slightly more than two years. While Kilian (2009) found a negative and significant response from U.S. GDP for the first two years, our results indicate that the response of total index, while negative for all horizons, is significant for the first 8 months and horizons 15 to 31 as implied by the one-standard-error bands. Additionally, total manufacturing (both SIC and NAICS) does not have significant response for all horizons during the first two years. On the other hand, the supply shock leads to hardly any significant response from sectors like foods and tobacco, clothing, paper products, chemical materials, motor vehicles and parts, foods, beverage and tobacco, printing and related, petroleum and coal, plastics and rubber, primary metal, and electrical equipment; the impulse response for these sectors is significant for 6 horizons or less.

Similarly, aggregate demand shock seems to matter more than other shocks for sectors such as foods and tobacco, nondurable consumer goods, paper products, chemical products, food, beverage, and tobacco, printing and related, and chemicals. However, the response of foods and tobacco and food, beverage, and tobacco to an aggregate demand shock is significant for only 5 horizons. In this case the response of paper products, chemical products, printing and related, and chemicals is significant for 23 months or more. Three of these four sectors are energy intensive sectors. The impact of the aggregate demand shock can be viewed in the middle panel of Figures 2a-2f. The sector with the highest number of horizons with significant responses is chemical products, with the number of significant horizons being 34. In addition, in contrast to the results for supply shock, the response of several sectors is significant for two or more years including total index, durable consumer goods, miscellaneous durable goods, manufacturing (SIC and NAICS), textile materials, textiles and products, plastics and rubber, electrical equipment, and motor vehicles. Moreover, the impulse response of sectors such as clothing, paper materials, motor vehicles and parts, and paper was not significant or only significant for 5 or fewer months.

The third panel of Figures 2a-2f shows the impact of an oil-specific demand shock. For 17 sectors in our sample, oil-specific demand shocks lead to more significant responses than other shocks. These sectors include total index, clothing, durable consumer goods, miscellaneous durable goods, manufacturing (SIC and NAICS), textiles materials, chemical materials, motor vehicle and parts, textiles and products, apparel and leather, petroleum and coal, plastics and rubber, furniture and related, primary metal, electrical equipment, and motor vehicles. Of these, clothing, apparel and leather, petroleum and coal, primary metal, and electrical equipment are the only sectors with fewer than 30 horizons that have significant responses. In addition to the 17 sectors, machinery and fabricated metal had a significant response to an oil-specific demand shock for 2 or more years. These results are in line with those found by Kilian (2009). However, an oil-specific demand shock fails to bring about a significant response from a few sectors including nondurable consumer goods, paper products, chemical products, transit equipment, food and tobacco, and food beverage and tobacco. For these sectors the response is significant for no horizons or only significant for 6 or fewer horizons.

A striking similarity is noted between results that we find for industrial production indices and the results found by Kilian and Park (2010) for industry stock returns for the sectors plastics and rubber, chemicals and paper. Both find that even though the energy intensity of plastics and rubber is far lower than that of chemicals, and paper, the impact of an oil-specific demand shock has a bigger impact on plastics and rubber than the other two sectors. Moreover, like us, they note that non-energy-intensive sectors such as machinery and electrical equipment have the same response as energy intensive sectors. These and other results in our paper show that there is no apparent relationship between energy intensity and the response of a sector.

To summarize, there are 14 sectors for which few horizons (7 or fewer) have significant response as a result of a supply shock. These include food and tobacco, clothing, nondurable consumer goods, paper products, textiles materials, chemical materials, motor vehicle and parts, food beverage and tobacco, apparel and leather goods, printing and related support industries, petroleum and coal products, plastics and rubber products, primary metal, and electrical equipment. This is far greater than the number of sectors with little impact in response to an aggregate demand shock or an oil-specific demand shock. The former has a significant impact on fewer than 5 horizons in case of food and tobacco, clothing, paper materials, motor vehicle and parts, food beverage and tobacco, apparel and leather goods, and paper. Similarly, there are 7 sectors for which oil-specific demand shocks have a significant impact on fewer than 8 horizons: food and tobacco, nondurable consumer goods, paper products, chemical products, transit equipment, food beverage and tobacco, and paper. Note that the sector food beverage and tobacco and the sector food and tobacco both do not have a significant impact in response to any of the shocks.

Also, note that petroleum and coal -which is highly energy intensive- is not significantly affected by supply side shocks. The impact of aggregate demand shock is positive and significant for about 1 year and the impact of an oil-specific demand shock is negative and significant for most horizons. This result again highlights that oil-specific shock is more important than other shocks. The results for the response of industrial production in petroleum and coal are different from the response of stock returns of the petroleum and gas industry estimated in Kilian and Park (2010). They find that the impact of an oil supply shock is negative and significant after the first 7 horizons, the impact of an aggregate demand shock is positive and significant for all horizons, and that the oil-specific demand shock does not matter.

4.1.1 Is the response of the IP indices positive or negative?

A few points should be noted about the positive impact on the shocks, especially on energy intensive sectors and the broad aggregates in our sample. First, supply side shocks have a positive and significant effect from the fourth quarter of the second year on consumer durables and motor vehicles - sectors which are energy intensive by use. Second, the immediate impact of the aggregate demand shock on the aggregates is positive and then becomes negative for manufacturing (SIC and NAICS) and total index. In the beginning, a positive world demand shock has a positive impact on U.S. industries, but as increased world demand increases prices of industrial commodities, a negative impact occurs. Interestingly, while Kilian (2009) does not find the initial positive response of GDP to be significant, we find that immediate impact of the aggregates is positive as well as significant. This also holds true for sectors such as electrical equipment, fabricated metal, chemicals, textiles and products, textile materials, and miscellaneous durable goods. This result is different from that observed for other countries in

Lagalo (2011), where it is shown that while the response of total index in most countries is negative when significant as a result of a crude oil supply shock, the response of total index to an aggregate demand shock does not ultimately become negative.

Third, the aggregate demand shock leads to an increased growth in industrial production for certain sectors, but unlike the previous group of sectors does not eventually lead to a decline. This group includes several energy intensive sectors such as chemical materials, motor vehicles and parts, petroleum and coal, and primary metal, as well as non-energy-intensive sectors such as machinery. Therefore, an aggregate demand shock is actually beneficial for these sectors. It is puzzling why an increase in prices of industrial commodities would not lead to a decrease in industrial production in these sectors. However, an oil-specific demand shock does have an initial positive impact followed by a negative and significant impact on machinery.

Fourth, while the impact of certain oil shocks is positive on some sectors, other shocks may have a negative impact. This is noted for primary metal, petroleum and coal, chemical materials, machinery, and fabricated metal, where while the aggregate demand shock has a mostly positive and significant impact, other shocks may have either no impact or a negative impact. On the other hand, while supply shocks cause a positive and significant impact on motor vehicles and durable consumer goods, other shocks have a negative impact on these two sectors. Fifth, there are only two cases where a negative and significant impact of a shock is followed by a positive and significant response. As a result of a supply shock, both textiles and products and furniture experience this phenomena. However, the impulse response is only significant for ten or fewer horizons in both cases.

There are several cases where the shocks lead to only a negative response from the sectors. Using a supply shock we find a negative and significant response from total index, manufacturing (SIC and NAICS), chemical products, transit equipment, paper materials, fabricated metal, machinery, miscellaneous durable goods, and chemicals. As a result of an aggregate demand shock, a negative response is observed for durable consumer goods, nondurable consumer goods, paper products, chemical products, plastics and rubber, furniture, motor vehicles, and printing and related. In case of an oil-specific demand shock, a negative response is observed for 20 out of the 29 sectors (total index, clothing, durable consumer goods, miscellaneous durable goods, manufacturing (SIC and NAICS), textile materials, paper materials, chemical materials, motor vehicle and parts, textile and products, apparel and leather, chemicals, petroleum and coal, plastics and rubber, furniture, primary metal, fabricated metal, electrical equipment, and motor vehicles). These results are different from Lagalo (2011) where they find a negative and significant response for total index as a result of an oil-specific demand shock for only a handful of countries out of the 20 countries in their sample. In fact, they find that the response for some countries is actually positive and significant during the first year.

4.2 Case 2: Separation of political supply shock and other supply shock

Figures 3a-3f show the impulse response functions for Case 2 when political supply shocks are included. When political supply shocks are explicitly included, the oil-specific demand shock still leads to significant responses for more horizons for most sectors than any other shocks. This however, is not true for apparel and leather, foods and tobacco, and clothing. For these three sectors a political supply shocks results in a greater number of significant horizons than any other shock. In particular, both the response of apparel and leather and clothing is significant for 31 or more horizons as a result of a political supply shock. However, the number of horizons for which significant values are observed for foods and tobacco is only 3.

Chemical products, textile materials, textiles and products, chemical materials, and paper have a significant response to a political supply shock for at least 11 months. The remaining sectors have either no significant reaction or have a significant reaction for fewer than 6 horizons in response to a political supply shock. These results can be seen in the first panel of Figure 3a-3f.

The response of other supply shocks is similar to that of total supply shocks in the previous subsection even when political supply shocks are included. The results for other supply shocks can be seen in the second panel of Figures 3a-3f. As a consequence of other supply shocks, more significant values are observed for transit equipment, paper materials, paper, and machinery than as a result of any other shock. While significant values are found for more than 20 quarters for transit equipment and machinery, the sectors paper materials and paper have significant values for only 5 quarters. Like in the previous subsection, the response of total index to other supply shocks in significant for a little over two years. In addition, 8 sectors (fabricated metal, manufacturing (SIC), paper products, chemical products, chemical materials, chemicals, primary metal, manufacturing (NAICS)) have significant responses for at least a year in response to other supply shock. However, 13 sectors experience little (fewer than 7 significant horizons) or no impact as a result of other supply shocks. These include clothing, miscellaneous durable goods, nondurable consumer goods, motor vehicle and parts, food beverage and tobacco, textiles and products, apparel and leather goods, printing and related support industries, petroleum and coal products, plastics and rubber products, furniture and related products, electrical equipment, and motor vehicles.

The response to aggregate demand shock is somewhat alike to that seen in the previous section with only 5 sectors that have a larger number of horizons with significant values than in response to other shocks (see panel 3 of Figures 3a-3f). These sectors include nondurable consumer goods, paper products, chemical products, textiles materials, and chemicals. While the number of significant horizons for textiles materials is 32 months, that for paper products, chemical products, and chemicals is 2 years. However, nondurable consumer goods only have significant values for about a year in response to an aggregate demand shock. In addition, the response of total index, textiles and products, durable consumer goods, miscellaneous durable goods, manufacturing (SIC), plastics and rubber products, furniture and related products, fabricated metal product, machinery, and manufacturing (NAICS) to an aggregate demand shock is significant for at least two years. However, the response of foods and tobacco, food beverage and tobacco, printing and related, motor vehicle and parts, paper materials, and apparel and leather goods is only significant for 7 or fewer horizons.

There are no significant differences in the response of IP indices to oil-specific demand shock in the two cases. There are 17 IP indices whose response has more significant horizons as a result of an oil-specific demand shock than other shocks (see last panel of Figures 3a-3f). This includes sectors that are energy intensive in terms of production (food, beverage and tobacco, petroleum and coal, primary metal, and chemical materials) and in terms of use (motor vehicles and motor vehicle and parts). This also includes aggregates such as manufacturing (SIC and NAICS), total index, durable consumer goods and miscellaneous durable goods and some non-energy-intensive manufacturing sectors such as electrical equipment, fabricated metal product, plastics and rubber products, furniture and related products, printing and related support industries, and textiles and products. While the response of food, beverage, and tobacco is only significant for 4 months, the response of the remaining 16 sectors is significant for at least two years. In addition, there are 7 industries (clothing, textiles materials, paper materials, apparel and leather goods, paper, chemicals, and machinery) whose response is significant for at least 1 year.

There are very few sectors whose response to an oil-specific demand shock is significant for only a few months (foods and tobacco, nondurable consumer goods, paper products, and chemical products for 3 months or fewer).

4.2.1 Is the response of the IP indices positive or negative?

A few observations are made regarding the positive response of some IP indices. First, in response to a political supply shock, food and tobacco, nondurable consumer goods, food, beverage and tobacco, and chemical products have a positive and significant response. However, with the exception of chemical products, the positive response is significant only for a few horizons. Second, in response to other supply shocks, the response of durable consumer goods, motor vehicles, and motor vehicles and parts is mostly positive when significant; although the response of the latter two is significant only for a few horizons. While the response of paper products and primary metal is positive and significant for a few months during the first 6 horizons, it becomes negative and significant thereafter. Third, there are seven sectors for which aggregate demand shocks lead to a positive and significant response during the first year; these are transit equipment, paper materials, chemical materials, motor vehicles and parts, paper, petroleum and coal, and primary metal.

Additionally, there are 15 sectors (total index, miscellaneous durables, manufacturing (SIC and NAICS), textile materials, textiles and products, chemicals, plastics and rubber, motor vehicles, machinery, electrical equipment, fabricated metal, furniture and related, and durable consumer goods) for which the immediate response as a consequence of an aggregate demand shock is positive and significant; however, it becomes negative, especially by the third year. Fourth, an oil-specific demand shock brings about a positive and significant response during the first six months from nondurable consumer goods, paper products, and food, beverage and tobacco, but it is only significant for fewer than 5 months. There are 16 other sectors whose response is positive and significant for a few months during the first 2 quarters. However, it is negative and significant during the second and third year for these sectors. Lastly, some sectors have a negative and significant response to some shocks while others have a positive and significant response to some other shocks. For example, while transit equipment, paper materials, chemical materials, and paper have a negative and significant response to other supply shocks and oil-specific demand shocks, the response to an aggregate demand shock is positive. Similarly, the response of petroleum and coal to an oil-specific demand shock is negative, and the response to an aggregate demand shock is positive.

Having said the above, the response of most sectors for almost all shocks is negative when significant. The response of 19 and 21 sectors is negative and significant in response to a political supply shock and other supply shock, respectively. There are 16 sectors that start out with a positive and significant response due to an oil-specific demand shock, but ultimately the response becomes negative during the second and third year. in addition to these sectors, an oil-specific demand shock leads to a purely negative response when significant from durable consumer goods, transit equipment, textiles materials, textiles and products, apparel and leather goods, plastics and rubber products, primary metal, and motor vehicles. In response to an aggregate demand shock, clothing, nondurable consumer, paper products, chemical products, and apparel and leather have a mostly negative response when significant.

4.2.2 Differences between the two cases

A few important differences in the results described in the two cases are observed. First, for textiles and products, fabricated metal product, motor vehicles, and durable consumer goods other supply shocks result in significant responses for fewer horizons than when total supply shocks are considered in Section 4.1. Second, in the case of fabricated metal, other supply shocks result in significant responses for only about 13 horizons, whereas when total supply shocks are considered, significant responses are seen for 32 horizons. Oil-specific demand shock now results in a larger number of horizons (31) with significant responses compared to other supply shocks (13) for fabricated metal. Third, there are four sectors (primary metal, chemicals, paper products, and chemical materials) for which very few significant horizons were observed in response to supply shocks in the Section 4.1; however, these sectors have significant responses for at least a year in response to other supply shocks when political supply shocks are included separately.

Fourth, while the responses of clothing, transit equipment, apparel and leather goods, fabricated metal product, and machinery to an aggregate shock have a larger number of horizons that are significant compared to the results seen in Section 4.1, the responses of motor vehicle, printing and related support industries, and chemical products have a lot fewer horizons that are significant. Fifth, while aggregate demand shock no longer leads to the largest number of significant responses from printing and related compared to all other shocks, aggregate demand shock does lead to more number of significant responses for textiles materials than any other shock. Sixth, political supply shocks have a significant impact on a few sectors, especially apparel and leather and clothing. There are no notable differences between the results for an oil-specific demand shock in the two cases.

5. Conclusion

While energy prices were fairly stable in the 1990s, increasing energy prices in 2000s have led to the question about growth in industrial production, specifically in energy intensive industries (Issues in Focus, Annual Energy Outlook 2007). While previous models of the oil-price macroeconomy relationship have treated oil prices as being mainly influenced by oil supply shocks, Kilian (2009) finds that the real price of oil is mainly influenced by aggregate demand and oil-specific demand shocks, and not crude oil production disruptions. These findings make it necessary to study how the U.S. industrial sector is affected by each of this shocks since each of these shocks have different impacts on US industries through both direct effects and indirect effects through the real price of oil. Therefore, we extend the work done by Kilian (2009).by separating the effect of oil demand shocks from oil supply shocks on U.S. industrial production indices. We compute different structural shocks in the oil market and examine their impact on different IP indices.

To summarize our results, oil supply shocks lead to a decline in 10 sectors, but an increase in case of motor vehicles and durable consumer goods. However, in case of the remaining 17 sectors, the response to an oil supply shock is not significant. Aggregate demand shocks lead to an initial positive impact on 9 sectors but soon after the impact becomes recessionary. The impulse response of 8 other sectors due to an aggregate demand shock is negative throughout. Lastly, the impact of oil-specific demand shock is negative and significant for most horizons for 20 out of the 29 sectors in our sample. In general, we confirm the finding by other authors that oil supply shocks are less important for studying changes in industrial production for several sectors than other aggregate demand shocks and oil-specific demand shocks. The results don't change much when political supply shocks are explicitly included. The results from the latter case studied exemplify that the political supply shocks do not seem to matter for most sectors.

For industrial production, the literature has generally focused on the energy intensive industries such as chemicals, petroleum, and primary metal while non-energy intensive sectors have received less attention.[4]

However, it has been observed that non-energy-intensive sectors accounted for more than 50 percent of the projected increase in industrial natural gas consumption from 2004 to 2030. (Issues in Focus, Annual Energy Outlook 2007). In addition, our results have shown that energy intensity of a sector is not necessarily correlated to response of a sector to an oil shock. The response of sectors that are energy intensive in terms of production (e.g. chemicals) and in use (e.g. motor vehicles) is significant for all types of oil shocks for at least 1 year. These are also sectors with relatively high average monthly growth rates. This result is similar to that in Herrera, Lagalo, and Wada (2011), where chemicals and motor vehicles have a significant response to a nonlinear measure of oil price. However, the results in this paper also find a significant response from non-energy-intensive sectors such as machinery and fabricated metal as seen in Section 4. Our results, therefore, highlight the importance of studying the impact of oil shocks on both energy intensive and metal-based non-energy-intensive sectors.

To summarize, using industry-level production data we illustrate that the impact of an oil price shock can be expansionary, recessionary, or insignificant on a sector depending on the nature of the shock. In addition, our findings about the demand shocks demonstrate that for industries in the U.S., an oil shock may be perceived more as a demand shock for their products

[4] The energy cost averages 4.8 percent and 1.9 percent of annual operating cost for energy intensive sectors and non-energy-intensive manufacturing industries, respectively (Issues in Focus, Annual Energy Outlook 2007).

than a shock to their costs of production. These results are consistent with other results in the existing literature (See, for instance, Kilian (2009), Lee and Ni (2002), Edelstein and Kilian (2007, 2009), Apergis and Miller (2009)). Further, it confirms the view discussed in Kilian and Park (2010) that the Federal Reserve should not respond to an oil shock but to the underlying supply or demand shock. Our results show that forecasting models for several industries need to be revised in order to not only reflect the recent oil price trends, but also take into account the nature of the oil shock. Moreover, these changes may have an important impact on the forecast for industrial energy consumption by each of these sectors. Our results also show that further research efforts need to focus on developing theoretical models that do not treat oil shock as purely an aggregate supply shock, which is treated as exogenous.

Table 1. Industry Code and Sample Statistics (1975.1-2004.9)

Sector	Industry code	Mean	Median	Standard Deviation	Minimum	Maximum
Total Industrial Production	B50001	0.22%	0.27%	0.01	-2.54%	2.08%
Foods and tobacco	B51211	0.12%	0.09%	0.01	-3.04%	3.02%
Clothing	B51212	-0.23%	-0.15%	0.01	-5.57%	4.94%
Durable consumer goods	B51100	0.29%	0.28%	0.02	-6.55%	12.54%
Miscellaneous durable goods	B51123	0.16%	0.25%	0.01	-4.48%	3.11%
Non durable consumer goods	B51200	0.14%	0.16%	0.01	-2.47%	2.16%
Manufacturing (SIC)	B00004	0.25%	0.30%	0.01	-3.08%	2.65%
Paper products	B51214	0.16%	0.15%	0.01	-3.28%	4.41%
Chemical products	B51213	0.28%	0.23%	0.01	-4.87%	3.77%
Transit equipment	B52110	0.04%	-0.04%	0.03	-9.89%	10.03%
Textiles materials	B53210	0.05%	0.14%	0.01	-4.56%	5.15%
Paper materials	B53220	0.11%	0.17%	0.01	-6.17%	5.91%
Chemical materials	B53230	0.19%	0.28%	0.01	-6.03%	4.30%
Motor vehicles and parts	G3361T3	0.21%	0.28%	0.04	-20.46%	28.48%
Food, beverage and tobacco	G311A2	0.13%	0.07%	0.01	-2.93%	3.01%
Textiles and products	G313A4	0.09%	0.12%	0.01	-4.00%	4.64%
Apparel and leather	G315A6	-0.21%	-0.18%	0.01	-5.15%	4.93%
Paper	G322	0.11%	0.19%	0.02	-5.05%	6.11%
Printing and related	G323	0.18%	0.18%	0.01	-3.00%	4.19%
Chemicals	G325	0.21%	0.23%	0.01	-3.56%	3.00%
Petroleum and coal	G324	0.08%	0.12%	0.02	-6.10%	7.23%
Plastics and rubber	G326	0.32%	0.35%	0.02	-9.00%	13.19%
Furniture and related	G337	0.21%	0.22%	0.01	-5.14%	4.12%
Primary metal	G331	-0.04%	0.16%	0.03	-9.96%	10.75%
Fabricated metal	G332	0.09%	0.20%	0.01	-4.71%	1.98%
Machinery	G333	0.08%	0.23%	0.01	-5.18%	4.16%
Electrical equipment	G335	0.10%	-0.01%	0.01	-5.91%	4.39%
Motor vehicles	G3361	0.36%	0.22%	0.07	-30.18%	48.77%
Manufacturing (NAICS)	GMF	0.26%	0.31%	0.01	-3.25%	2.67%

Table 2. Energy intensity for selected NAICS industries and for selected years

Sector	1998	2002	2006
Food, beverage and tobacco	2.17	2.19	1.95
Textiles and products	3.46	3.46	3.47
Apparel and leather	0.75	0.72	0.47
Paper	17.72	15.48	13.82
Printing and related	0.98	1.02	0.85
Chemicals	14.55	14.24	7.83
Petroleum and coal	53.06	31.47	12.5
Plastics and rubber	2	2.03	1.59
Furniture and related	1.26	0.84	0.7
Primary metal	15.4	15.11	7.46
Fabricated metal	1.75	1.57	1.25
Machinery	0.77	0.7	0.62
Electrical equipment	1.23	1.65	0.86
Motor vehicles	0.8	0.67	0.68
Manufacturing (NAICS)	6.11	5.81	4.2

Notes: Energy intensity is calculated as the ratio of energy consumption (Trillion Btu) to Gross Output (Billion 2000 Dollars). Values in bold represent high energy intensity sectors, values in italics represent other energy intensive sectors, and the remaining sectors are non-energy-intensive.

Figure 1a: Monthly data on demand and supply side measures of oil from 1973.2 to 2004.9

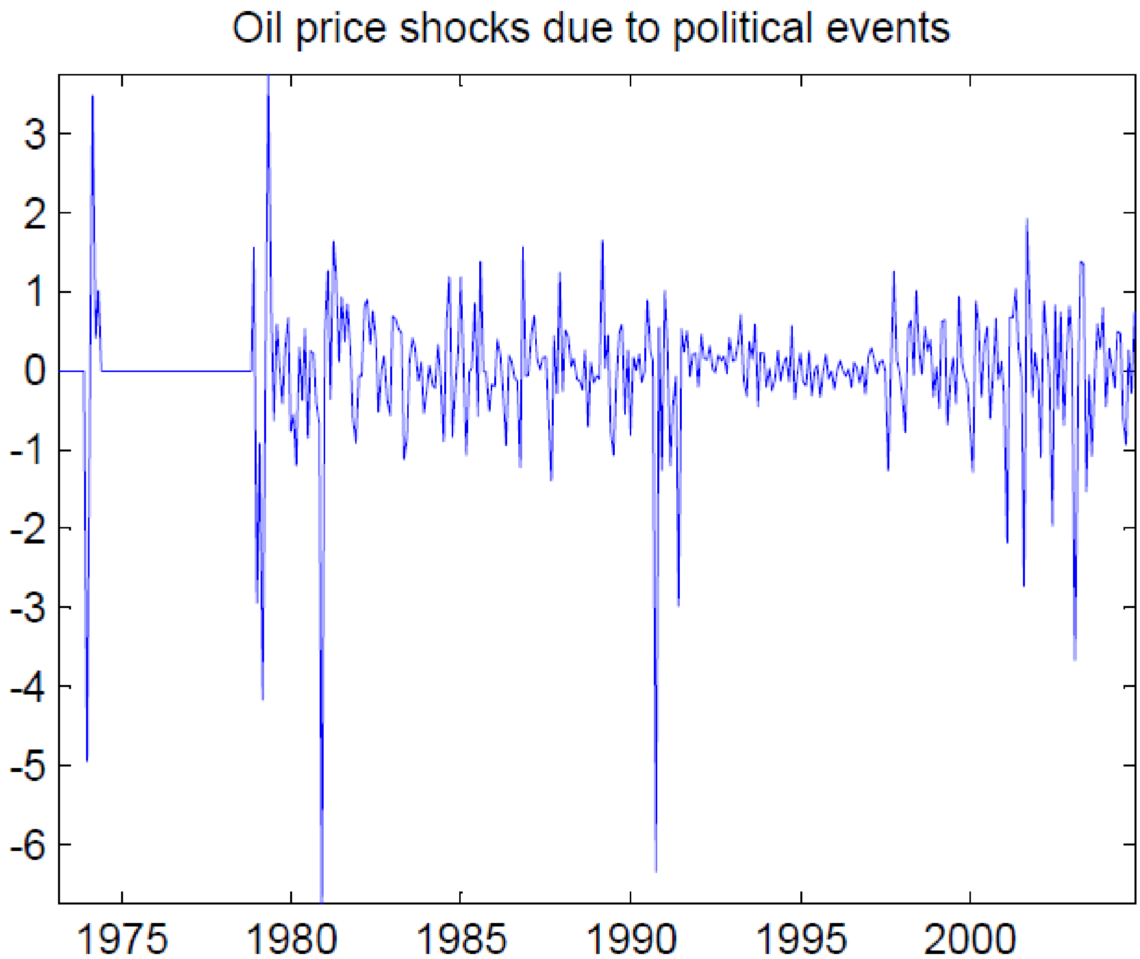


Figure 1b: Monthly data on demand and supply side measures of oil from 1973.2 to 2004.9

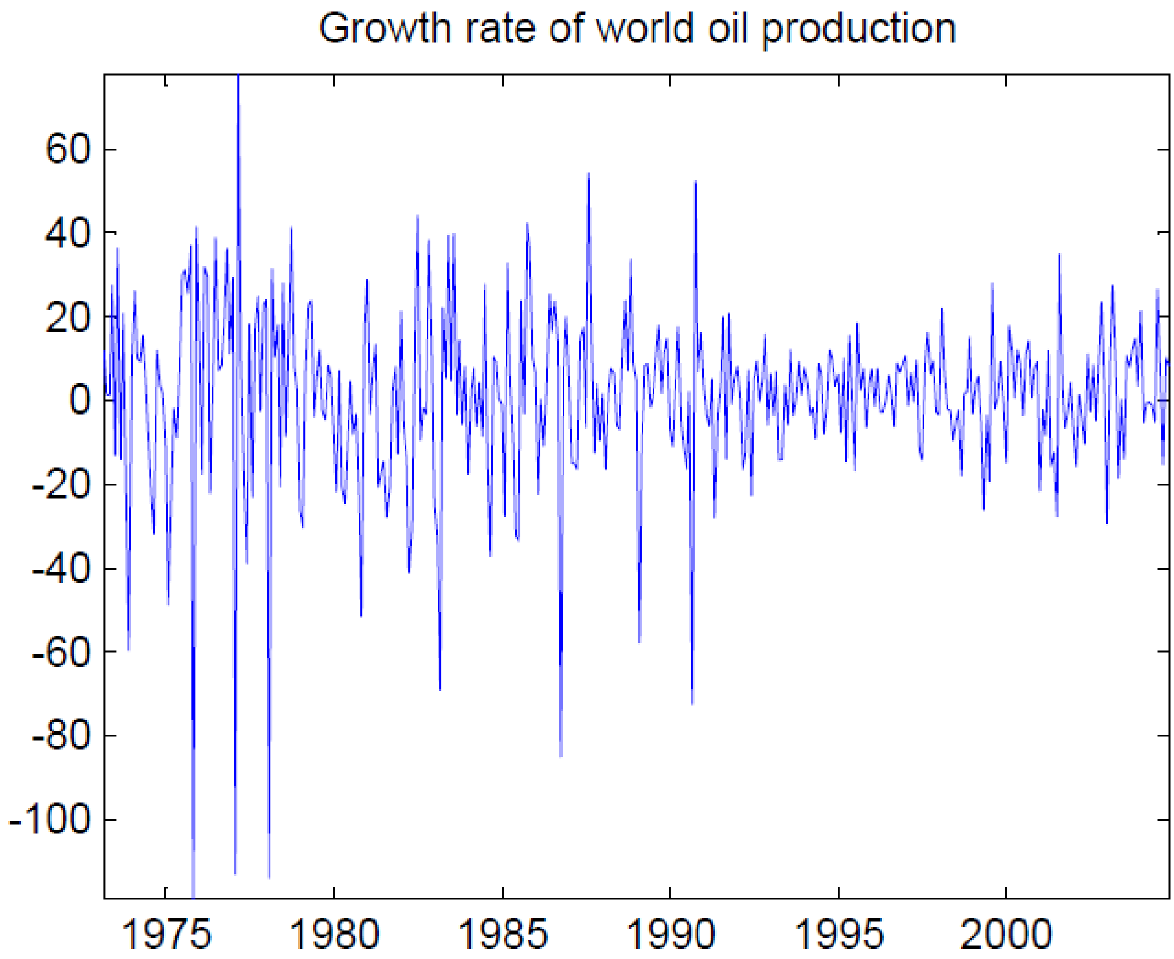


Figure 1c: Monthly data on demand and supply side measures of oil from 1973.2 to 2004.9

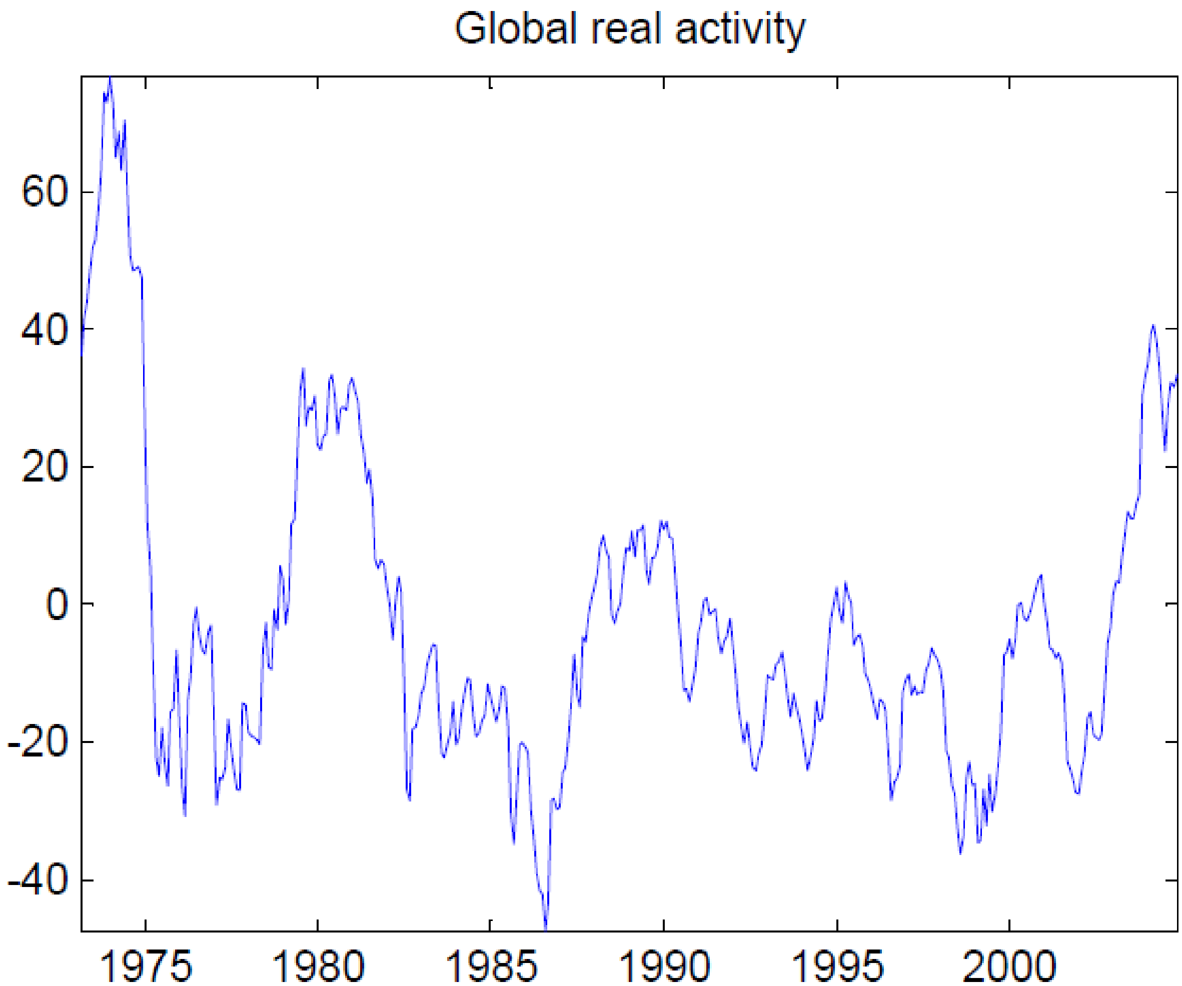


Figure 1d: Monthly data on demand and supply side measures of oil from 1973.2 to 2004.9

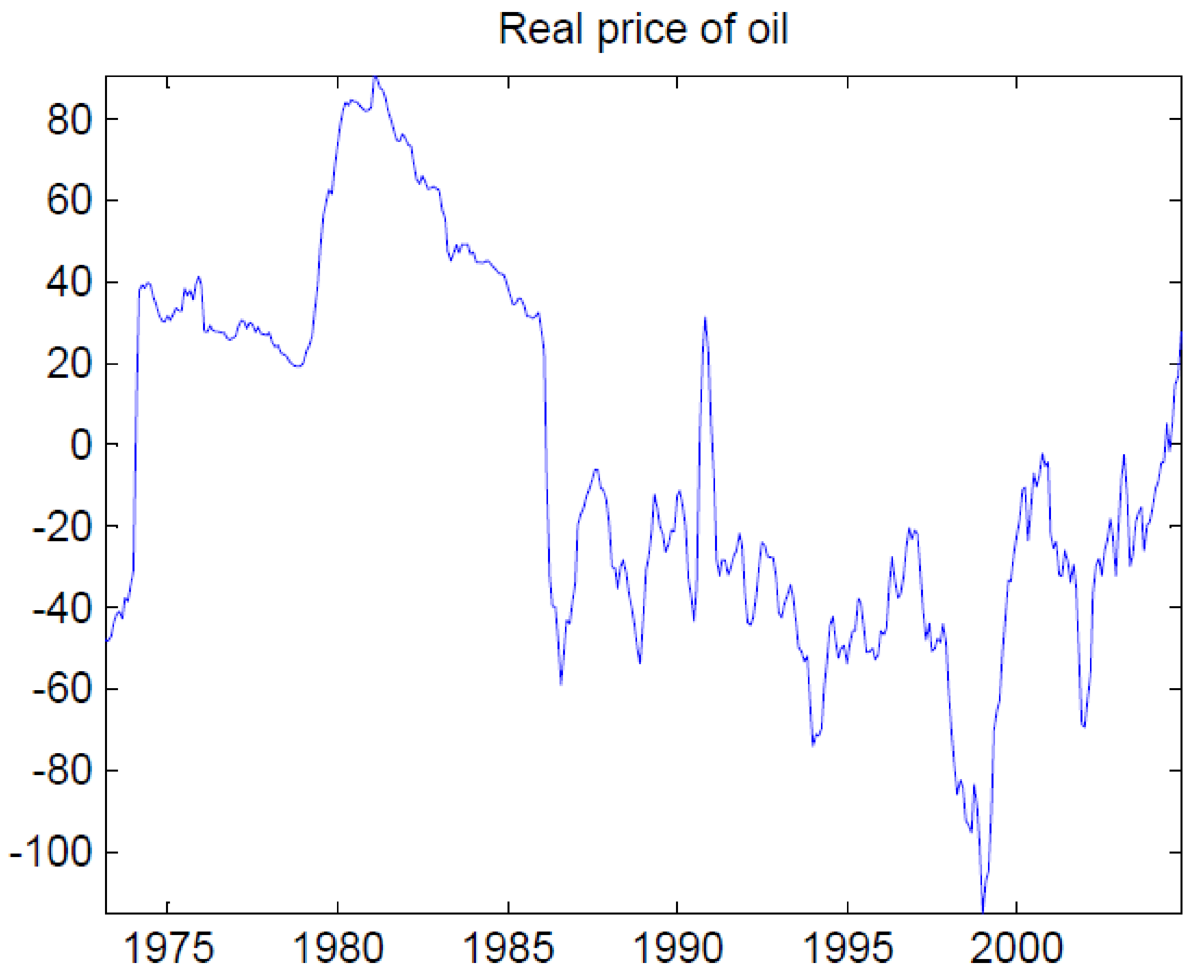
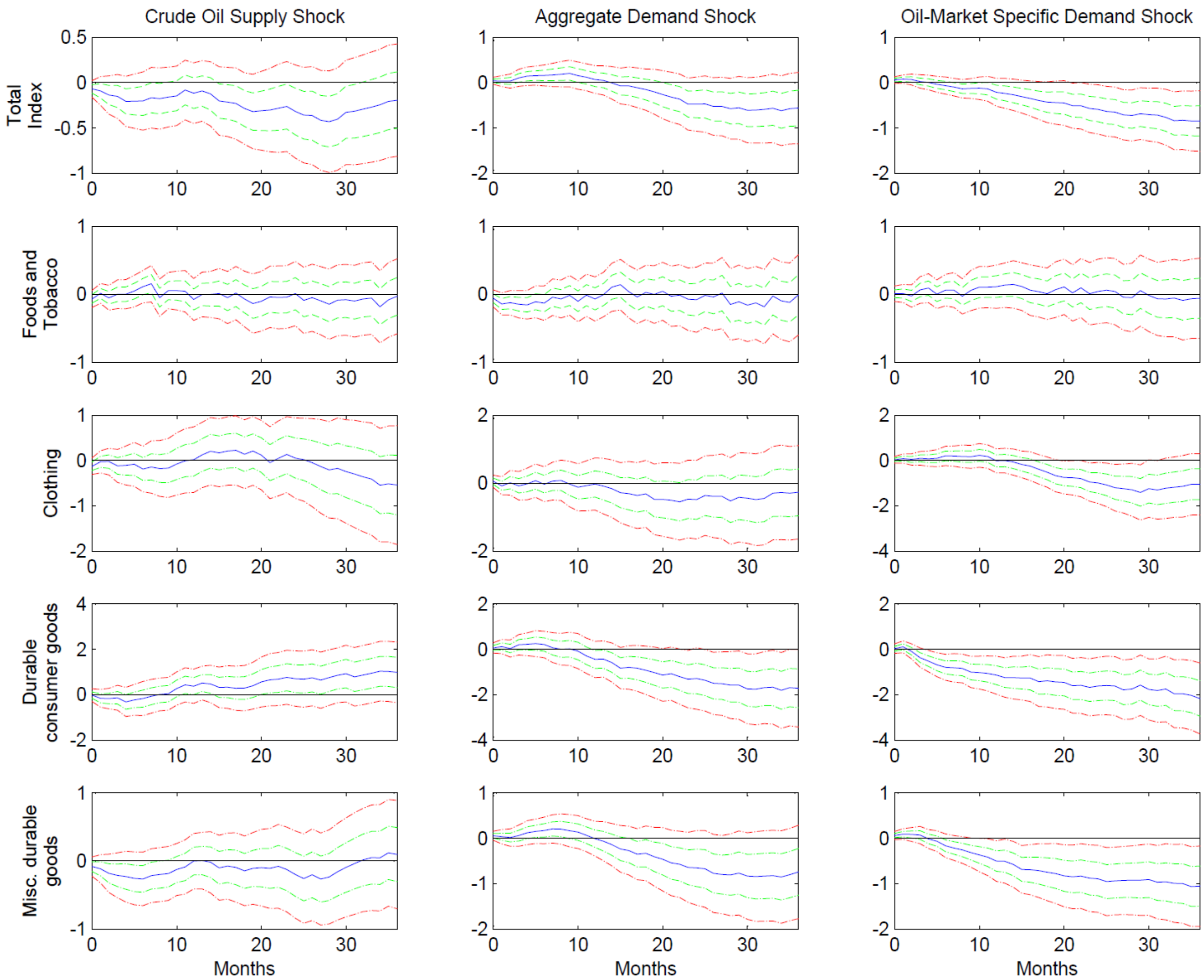
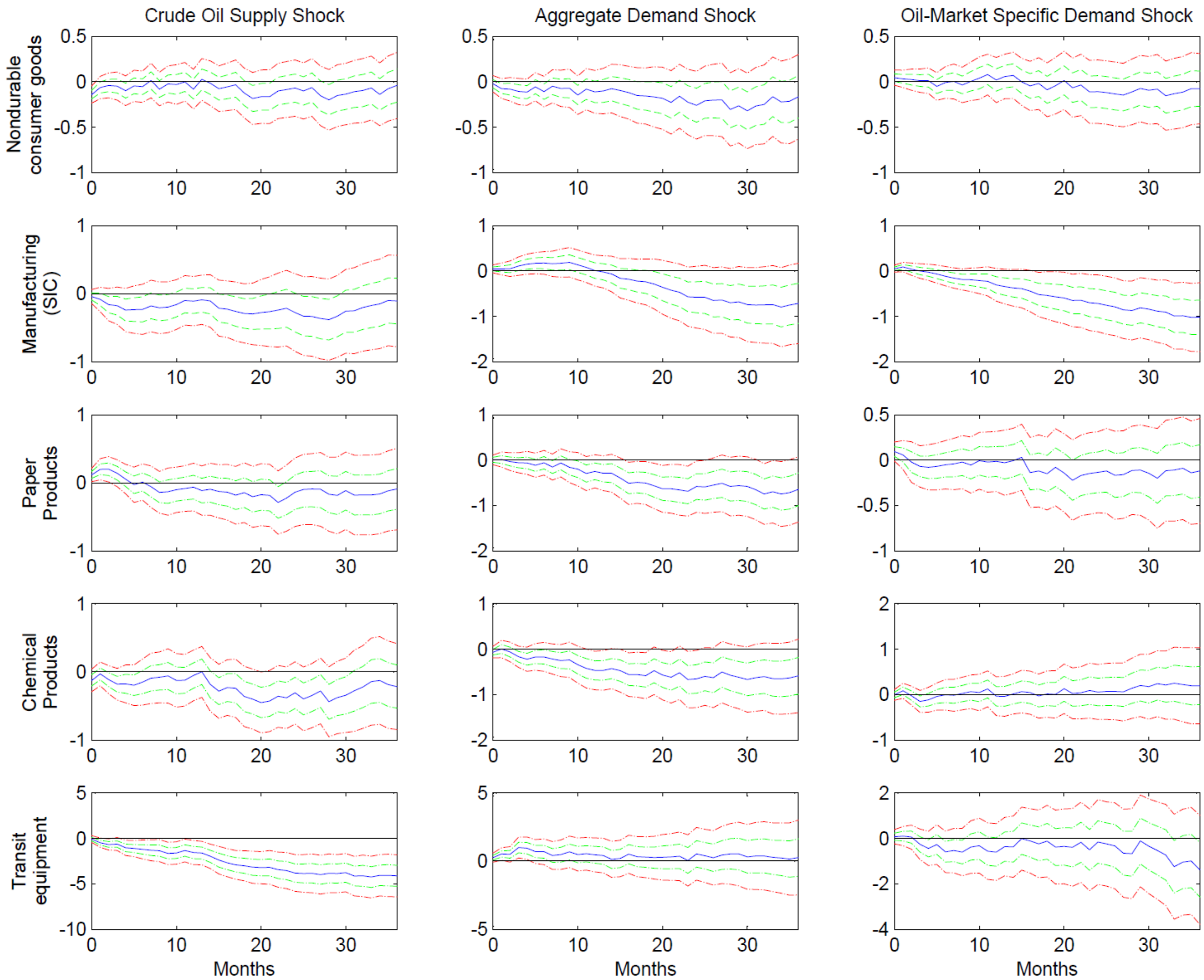


Figure 2a: Responses of industrial production indices to each structural shock: Case 1



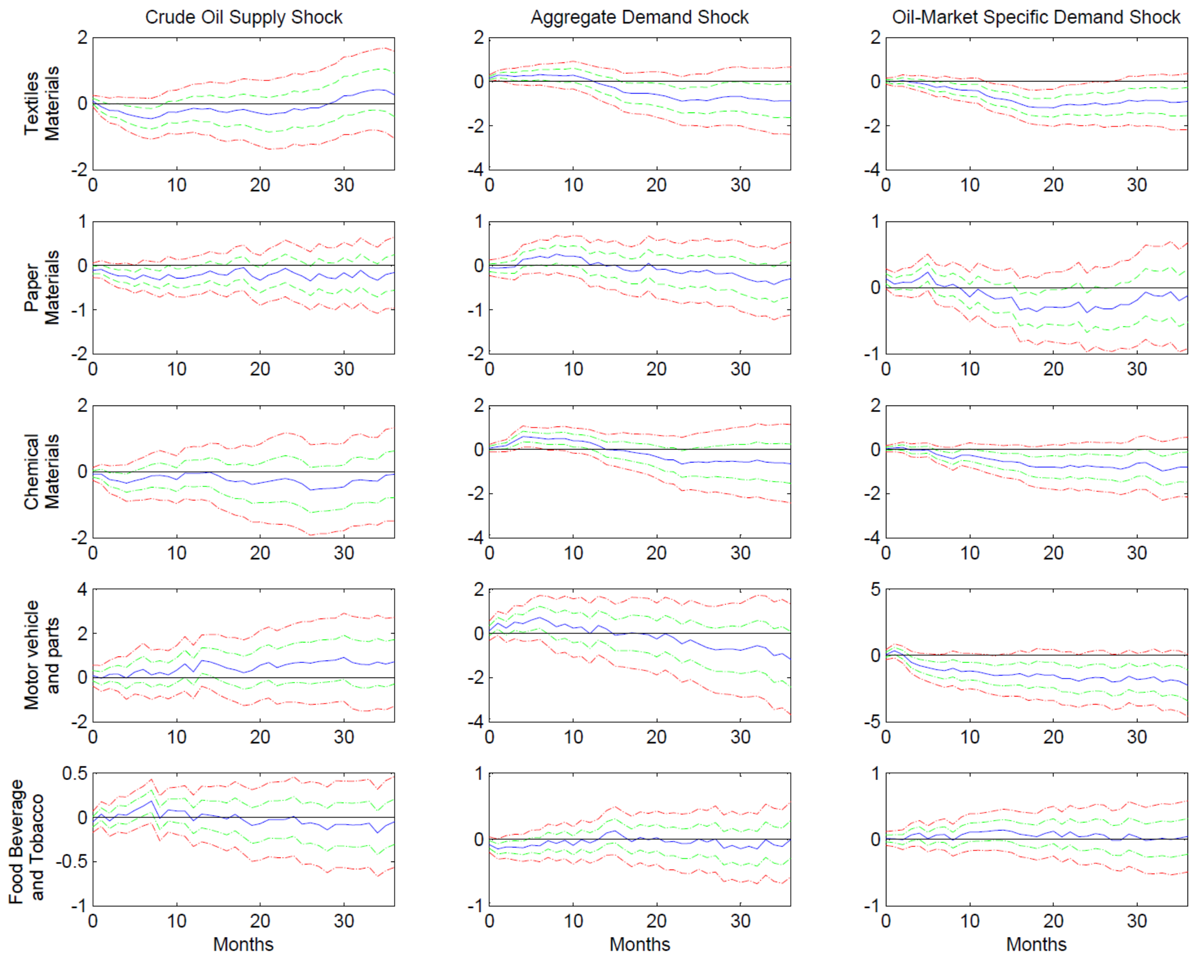
Notes: Estimates are based on the regression in (3) where the number of bootstrap replications to obtain the IRFs equal 20000.

Figure 2b: Responses of industrial production indices to each structural shock: Case 1



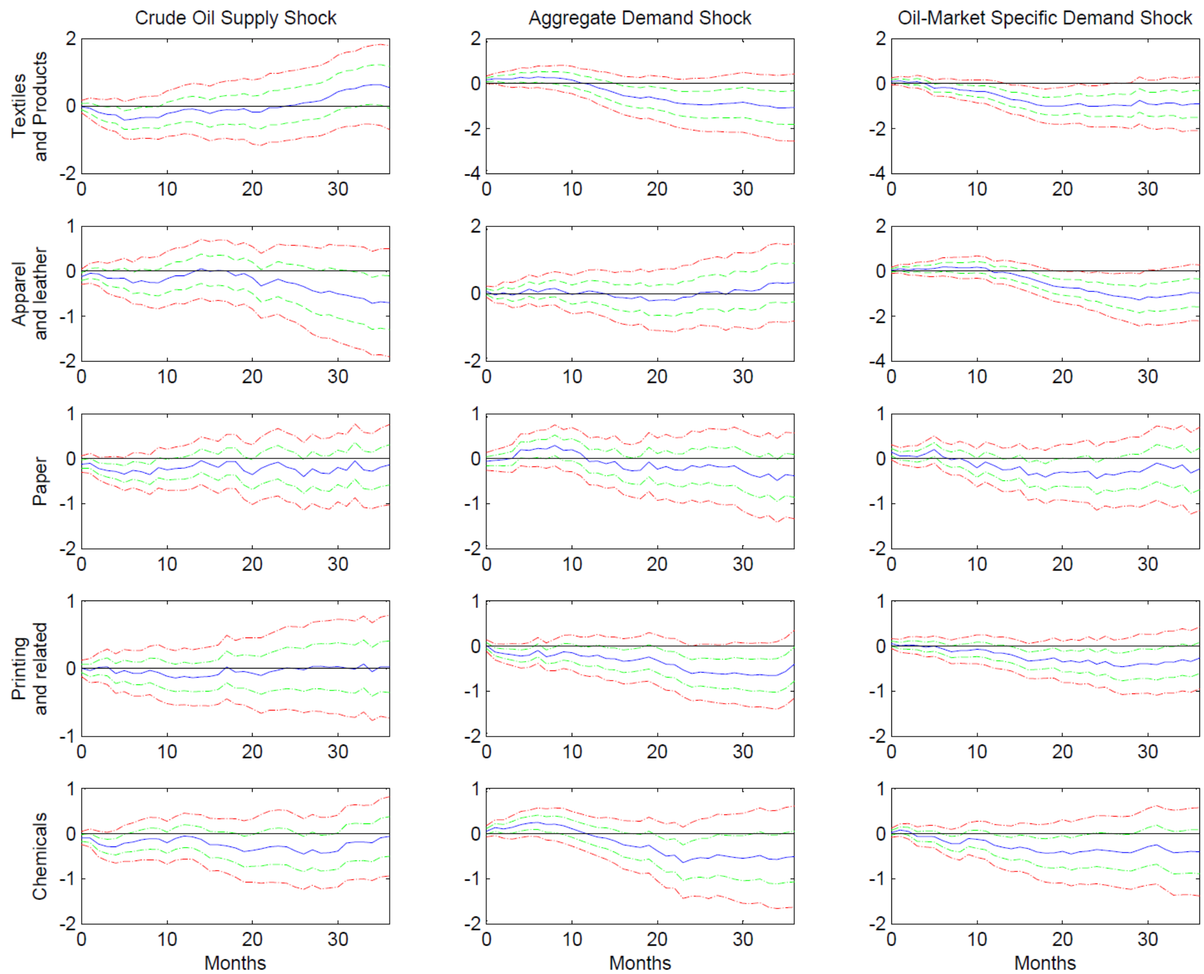
Notes: Estimates are based on the regression in (3) where the number of bootstrap replications to obtain the IRFs equal 20000.

Figure 2c: Responses of industrial production indices to each structural shock: Case 1



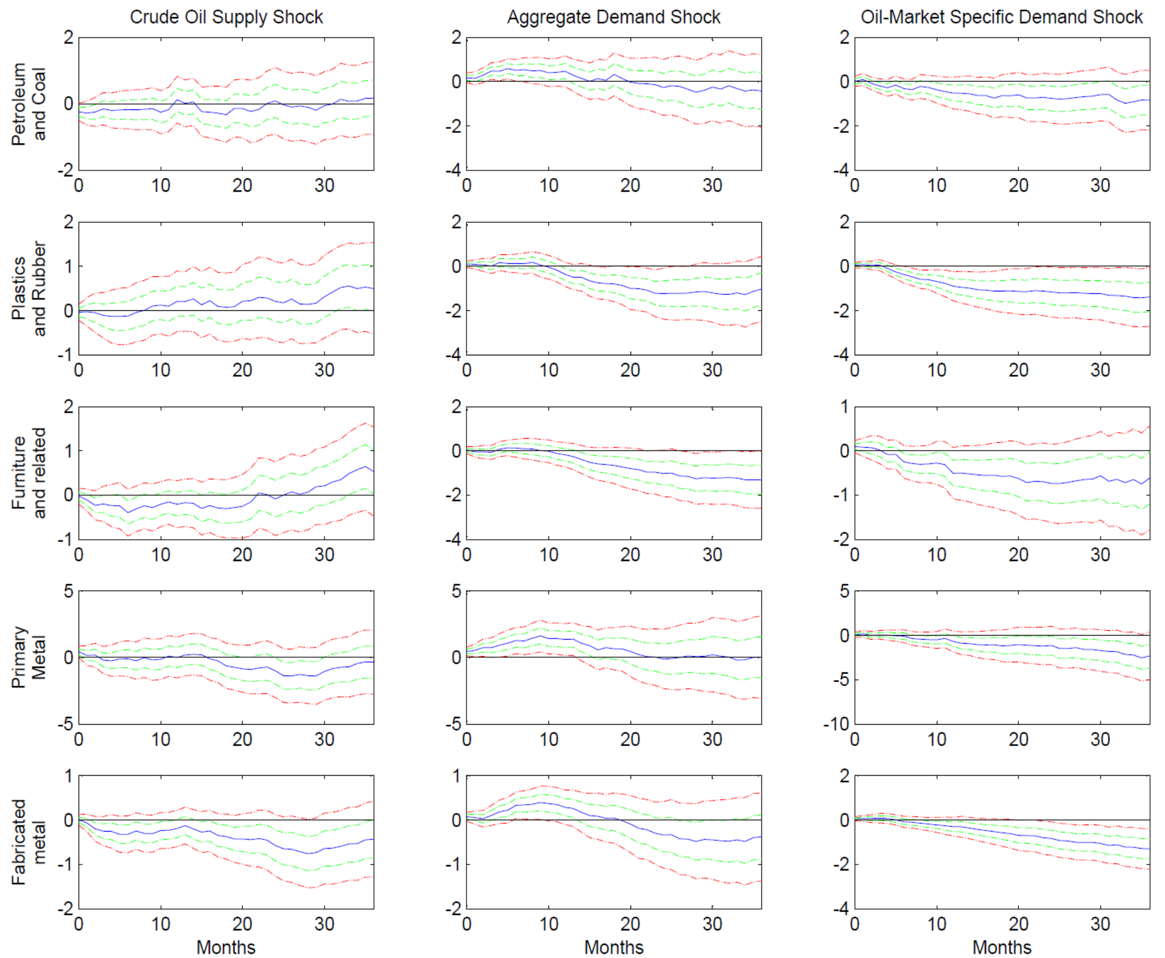
Notes: Estimates are based on the regression in (3) where the number of bootstrap replications to obtain the IRFs equal 20000.

Figure 2d: Responses of industrial production indices to each structural shock: Case 1



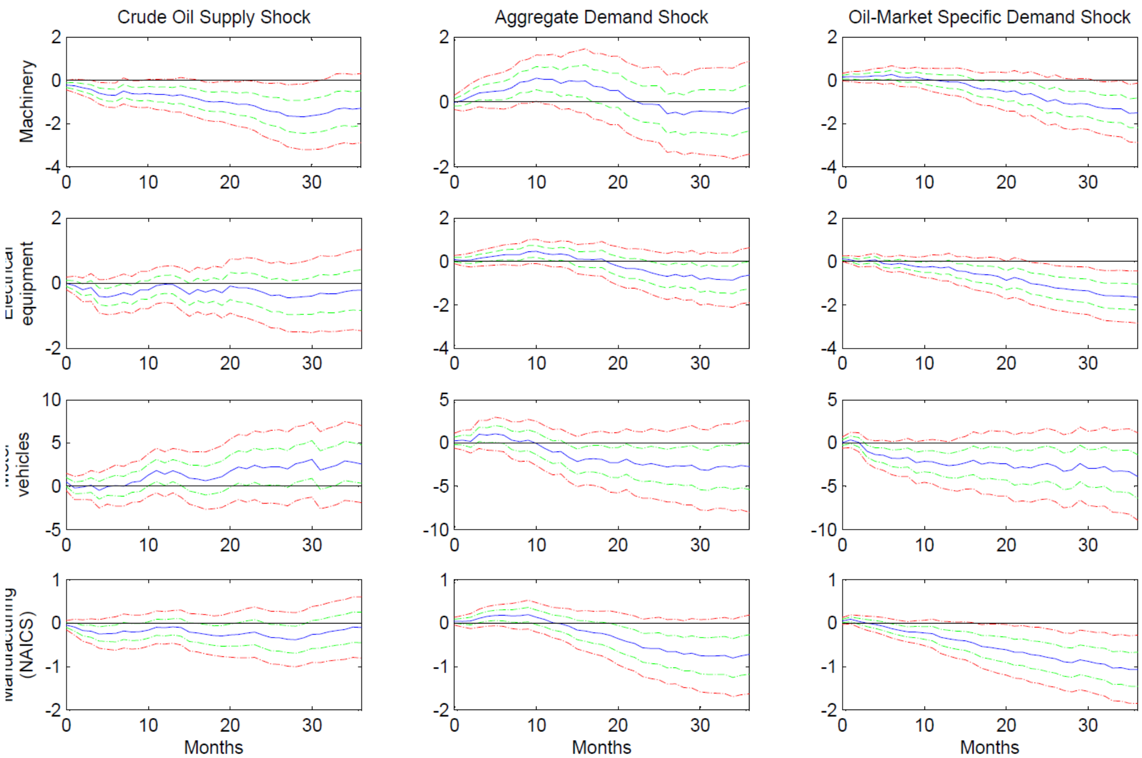
Notes: Estimates are based on the regression in (3) where the number of bootstrap replications to obtain the IRFs equal 20000.

Figure 2e: Responses of industrial production indices to each structural shock: Case 1



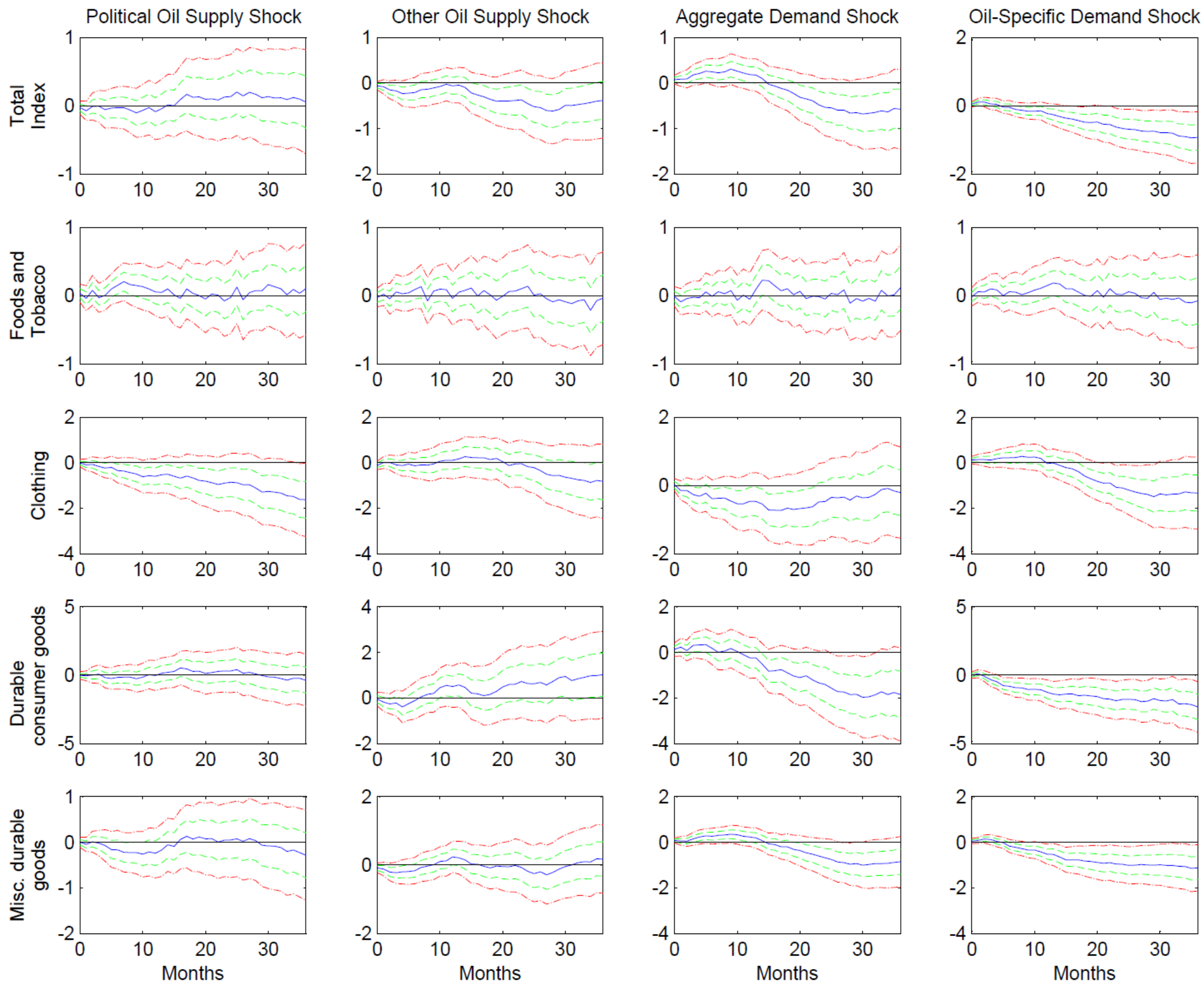
Notes: Estimates are based on the regression in (3) where the number of bootstrap replications to obtain the IRFs equal 20000.

Figure 2f: Responses of industrial production indices to each structural shock: Case 1



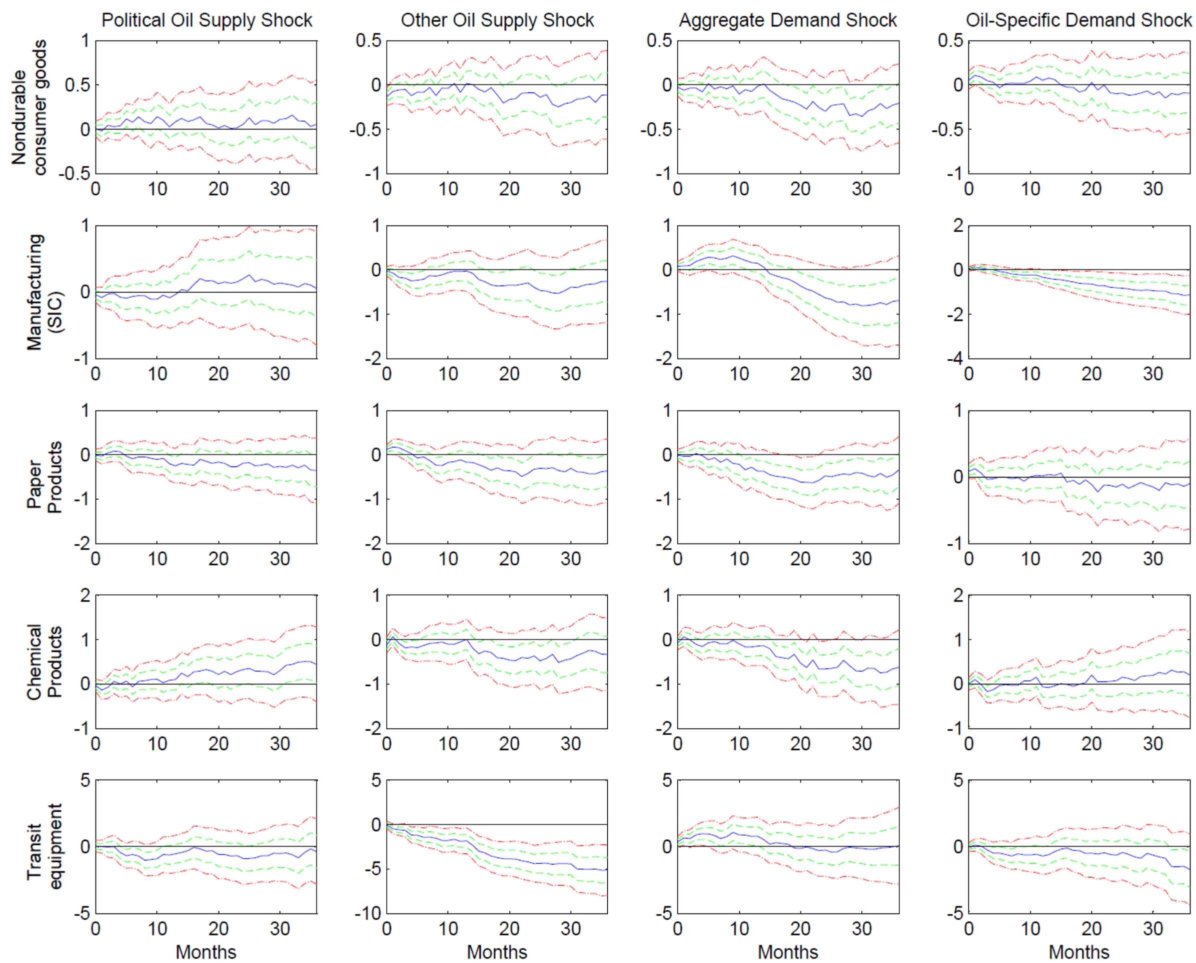
Notes: Estimates are based on the regression in (3) where the number of bootstrap replications to obtain the IRFs equal 20000.

Figure 3a: Responses of industrial production indices to each structural shock: Case 2



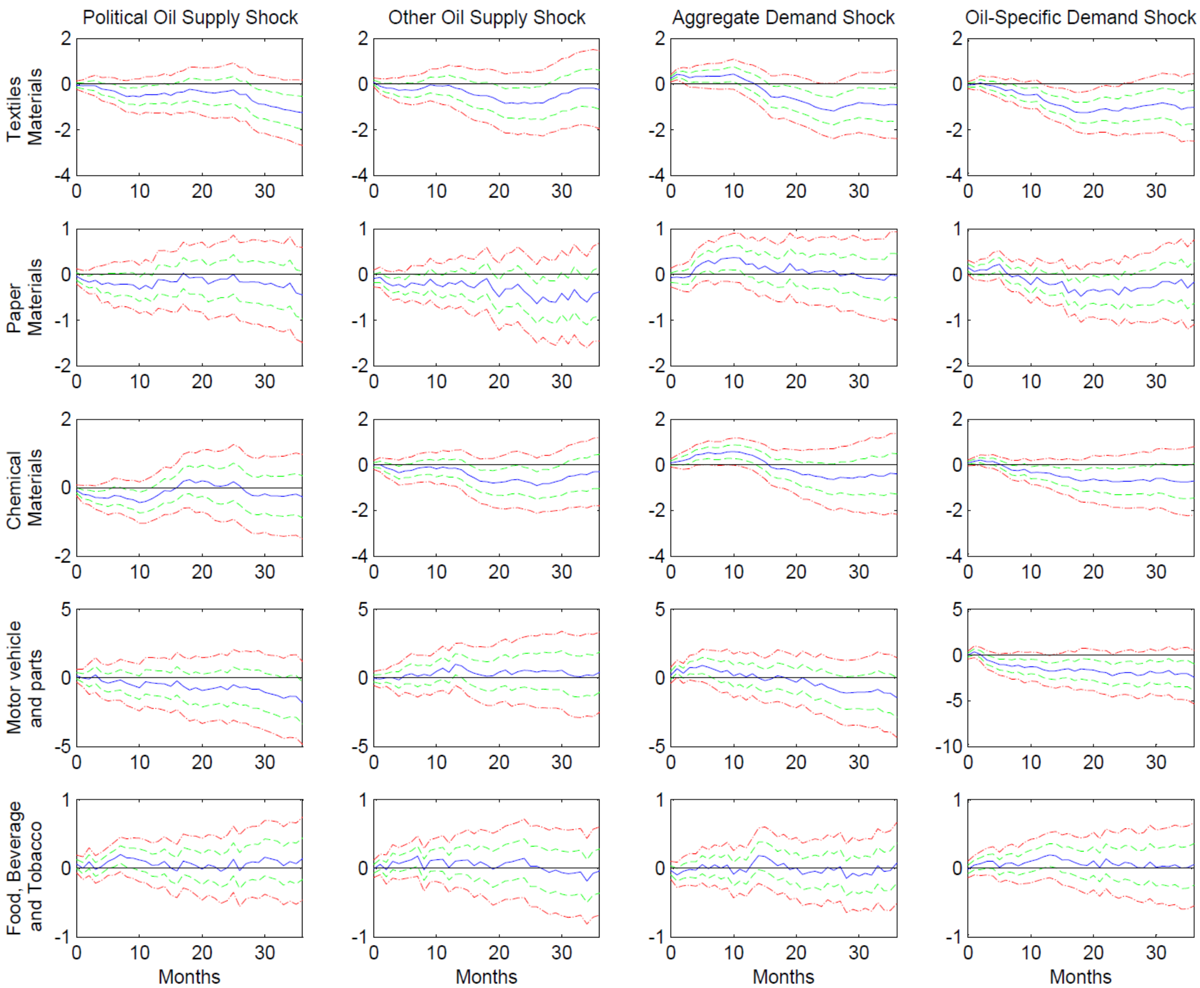
Notes: Estimates are based on the regression in (6) where the number of bootstrap replications to obtain the IRFs equal 20000.

Figure 3b: Responses of industrial production indices to each structural shock: Case 2



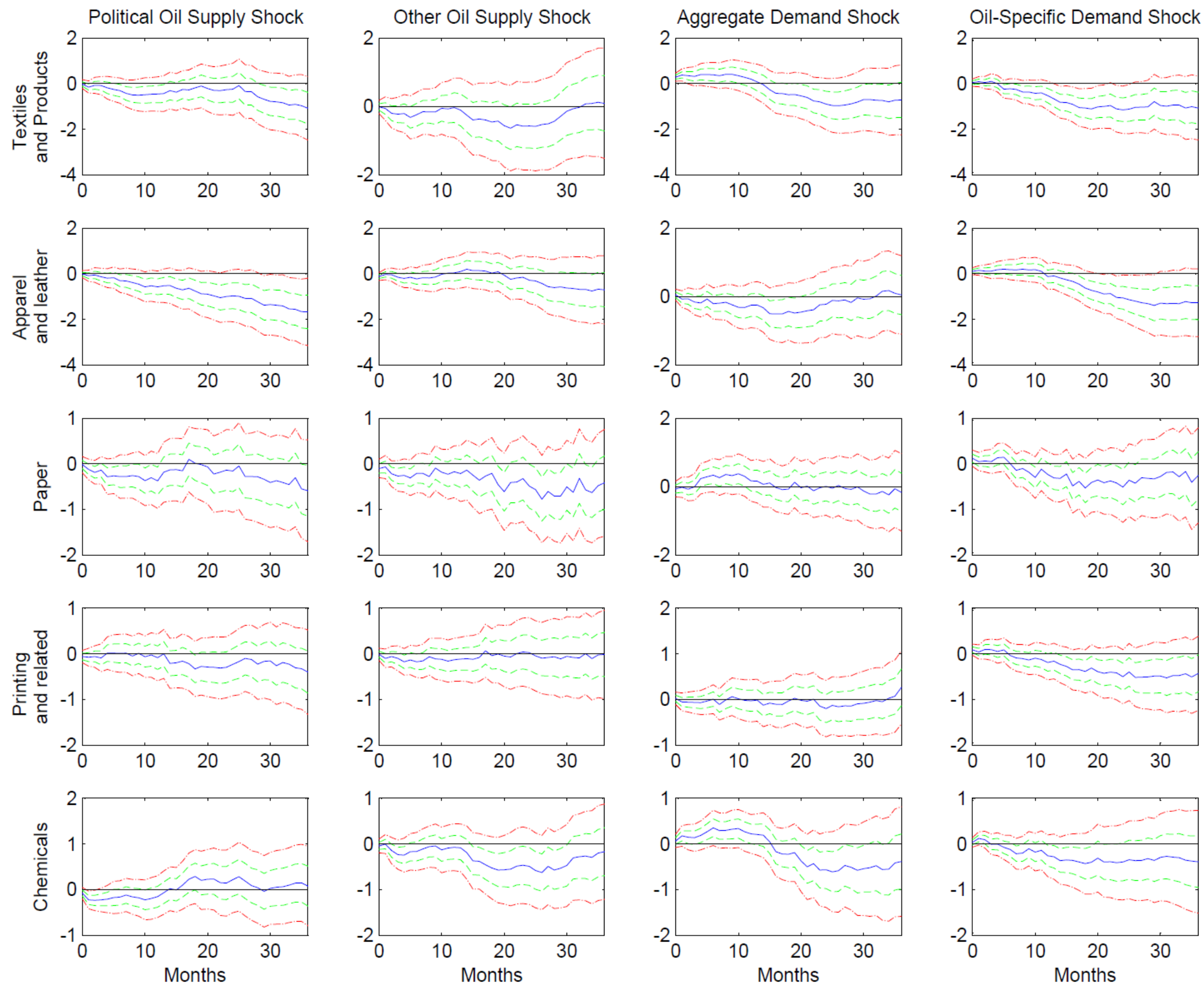
Notes: Estimates are based on the regression in (6) where the number of bootstrap replications to obtain the IRFs equal 20000.

Figure 3c: Responses of industrial production indices to each structural shock: Case 2



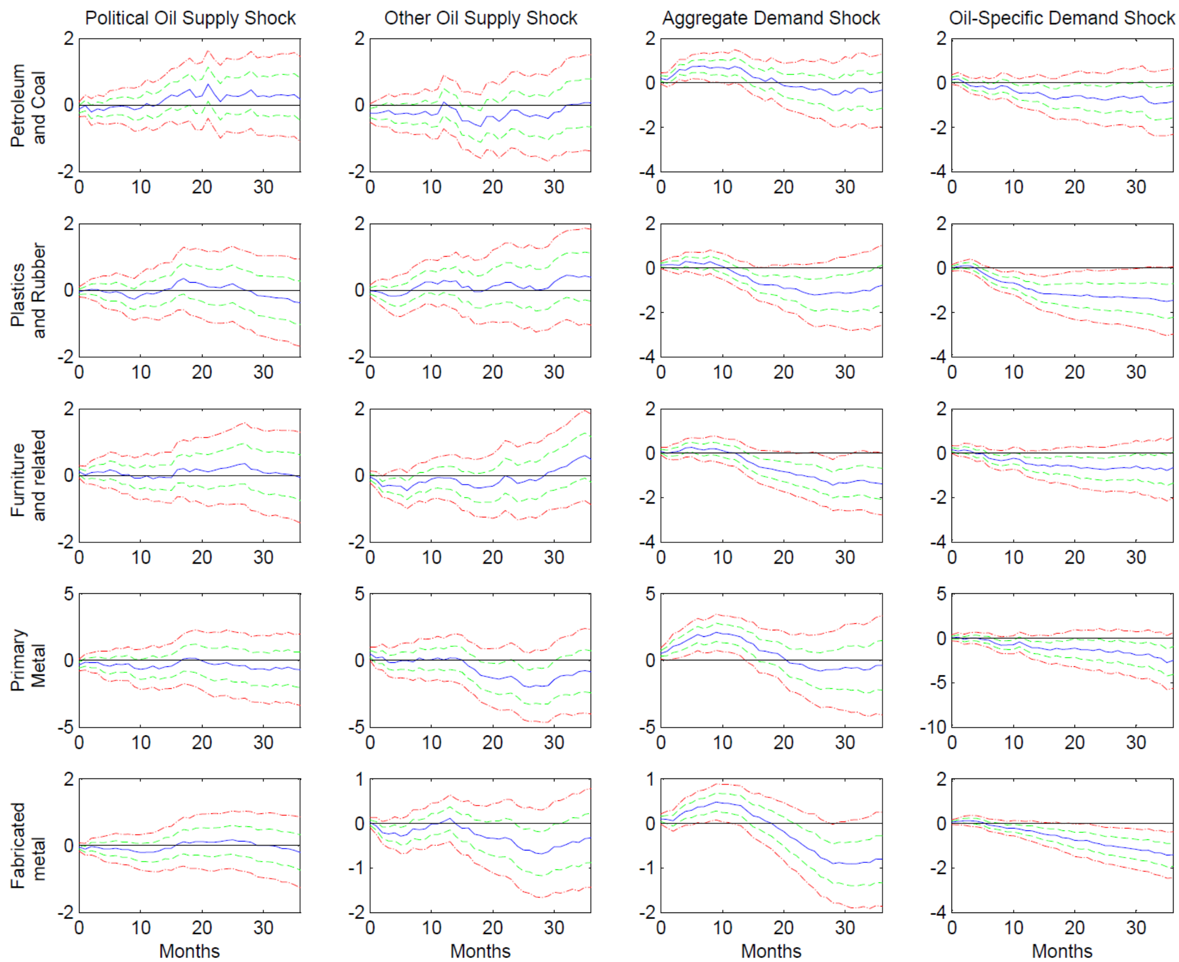
Notes: Estimates are based on the regression in (6) where the number of bootstrap replications to obtain the IRFs equal 20000.

Figure 3d: Responses of industrial production indices to each structural shock: Case 2



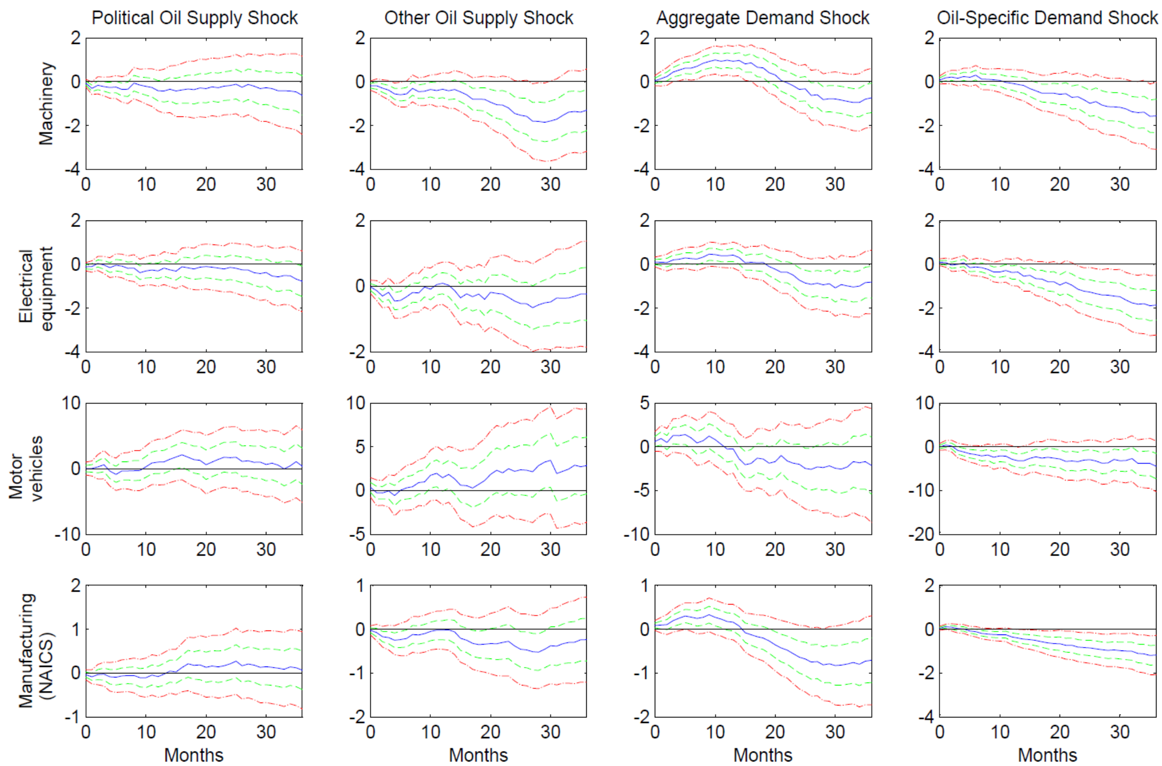
Notes: Estimates are based on the regression in (6) where the number of bootstrap replications to obtain the IRFs equal 20000.

Figure 3e: Responses of industrial production indices to each structural shock: Case 2



Notes: Estimates are based on the regression in (6) where the number of bootstrap replications to obtain the IRFs equal 20000.

Figure 3f: Responses of industrial production indices to each structural shock: Case 2



Notes: Estimates are based on the regression in (6) where the number of bootstrap replications to obtain the IRFs equal 20000.

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ABSTRACT

ESSAYS ON THE IMPACT OF OIL PRICE SHOCKS ON THE MACROECONOMY

by

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May 2013

Advisor: Dr. Ana María Herrera

Major: Economics

Degree: Doctor of Philosophy

This dissertation analyzes the relationship between oil price and industrial production. I use recently developed methods and techniques to investigate the functional form and structural stability of the relationship between oil prices and industrial production. In my first chapter, I use both slope-based tests and impulse response based tests to provide evidence of nonlinearity in the response of U.S. industrial production to oil price shocks. My second essay further empirically assesses the presence (or absence) of asymmetry in the response of industrial production to real oil price shocks using a sample of 18 industrialized economies using various nonlinear transformations of the price of oil. In my third essay I examine the impact of demand and supply shocks in the crude oil market on industrial production in the U.S. as opposed to treating oil price shocks as exogenous.

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