Revisiting the Oil Price – Macro Relationship in the US

The Role of Model Specification and Sample Period

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Motivation

Energy shocks and the macroeconomy

- Long-run growth and development depend on resilience and susceptibility to shocks (Balassa, 1986; Martin, 2012; Romer and Romer, 2004)

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- Heavy global dependence on non-renewable energy sources considered a significant threat to sustainable economic growth
- Hamilton (1983): most US recessions were preceded by drastic increases in oil prices
- For net importers of oil, an oil price hike should, *ceteris paribus*, slow down economic growth through more expensive imports and other channels

Brief background

- Many believe that the negative correlation between oil price increases and output growth dissipated after the 1980s

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- Many believe that the negative correlation between oil price increases and output growth dissipated after the 1980s
- Model specification, variable choice, and sample period have been key points of wide discussion
- Bernanke et al. (1997) noted that "it is surprisingly difficult to find an indicator of oil price shocks that produces the expected responses of macroeconomic and policy variables in a VAR setting."

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- Hooker (1996) investigated the stability of the relationship
- Kilian (2009) argued that the underlying causes of oil price shocks change over time and that this matters for the relationship in question

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3. Is there asymmetry in the oil price-macroeconomy relationship? (as investigated by Hamilton (2003))
4. Does volatility of oil prices immediately preceding a shock affect estimated parameters and, ultimately, the outcome? (as introduced in Lee et al. (1995))

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- This paper proposes a potential solution: a normalisation process and asymmetric split of price changes
- This approach does not require unreliable proxies and is self-contained within the model

Data and Methods

Empirical framework

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- Base model, similar to Hamilton (1983), extended to incorporate ideas by Mork (1989) and Lee et al. (1995)
- Further, time-varying parameters estimated using a rolling-window technique $\rightarrow$ evolution of the relationship over time

Empirical framework

- Base model: a 7-variable VAR system consisting of GDP growth, oil price changes, GDP implicit deflator inflation, 3-month Treasury Bill (TB) rate, real wage inflation, unemployment, and import price inflation

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-
$$o^{+} = \begin{cases} x & \text{if } x > 0 \\ 0 & \text{if } x \leq 0 \end{cases}$$

$$o^{-} = \begin{cases} 0 & \text{if } x \geq 0 \\ x & \text{if } x < 0 \end{cases}$$

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- Univariate generalised autoregressive conditional heteroscedasticity, GARCH(1,1), process to calculate the conditional variance of oil price changes and use this to normalise oil prices
- Underlying idea: no impact on economic activity from anticipated shocks $\rightarrow$ agents not "surprised"

Empirical framework

- The unanticipated shocks are constructed as follows:

$$z_t = \alpha_0 + \sum_{i=1}^{4} \alpha_i z_{t-i} + \varepsilon_t \tag{1}$$

$$h_t = \gamma_0 + \gamma_1 \varepsilon_{t-1}^2 + \gamma_2 h_{t-1} \tag{2}$$

where $\varepsilon_t | I_{t-1} \sim N(0, h_t)$ and z_t are oil prices

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where $\varepsilon_t | I_{t-1} \sim N(0, h_t)$ and z_t are oil prices

- The unexpected part of the price shock is simply the residual term of equation (1), $\hat{\varepsilon}_t = z_t - \hat{z}_t$

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- The normalised variable (ε_t^*) is predicted to have a "more systematic causal relation to real GDP than either z_t or $\hat{\varepsilon}_t$" (Lee et al., 1995)
- Net oil price increases (NOPI) à la Hamilton (1996) are estimated as a robustness check ▸ NOPI

Empirical framework

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- VAR models used to test for Granger causality between oil price fluctuations and US GDP growth rate
- Orthogonalised impulse responses calculated following Cholesky decomposition to interpret parameter estimates in VAR systems
- Impulse response functions (IRFs) cover a 20-quarter period

Data

- All data are in quarterly frequency, and most series are available from 1950:1 through 2015:2 – exceptions are refiner's acquisition cost (RAC), import price index, and 3-month TB rate, which are available from 1974:1, 1982:3, and 1972:1, respectively

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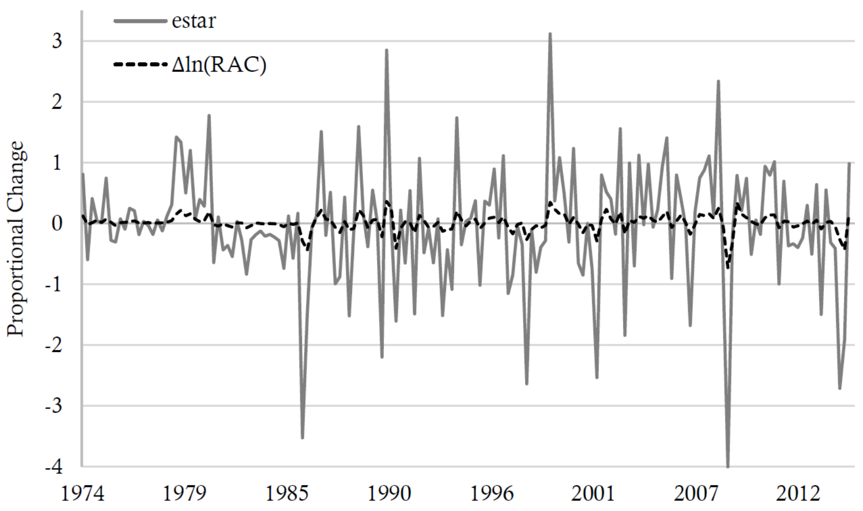
- All series are expressed in first-differenced natural logarithm except for real wage growth, which is only first-differenced
- The sample period stops in mid-2015 to avoid potential biases from the rapid increase in oil production as part of the shale revolution

Results

Effect of normalisation

Normalisation rescales the oil price fluctuations based on price behaviour in the preceding four quarters:



Effect of normalisation

- Sample period is split into four parts: (i) 1950:1 through 1985:4, (ii) 1974:1 through 2015:2, (iii) 1986:1 through 2015:2, (iv) whole sample period

Effect of normalisation

- Sample period is split into four parts: (i) 1950:1 through 1985:4, (ii) 1974:1 through 2015:2, (iii) 1986:1 through 2015:2, (iv) whole sample period
- Statistical significance in this part of the analysis refers to Granger causality based on a null hypothesis with a binary outcome:

$$H_0 \implies \text{no Granger causality}$$
$$H_a \implies \text{Granger causality}$$

Base model

Proxy	Variable	1950:1-1985:4	1974:1-2015:2	1986:1-2015:2	1950:1-2015:2
PPI	Oil Price Change	27.959*** (0.000)	18.326*** (0.001)	9.598** (0.048)	21.632*** (0.000)
RAC	Oil Price Change	–	22.807*** (0.000)	11.190** (0.025)	–

Table 1: Exclusion tests for the base modelwith GDP growth as the dependent variable. The values in parentheses are p-values. Statistical significance is shown at the 10% level (*), 5% level (**) and 1% level (***).

Asymmetric effects model - PPI

Proxy	Variable	1950:1-1985:4	1974:1-2015:2	1986:1-2015:2	1950:1-2015:2
PPI	Oil Price Increase	32.186*** (0.000)	19.140*** (0.001)	10.211** (0.037)	25.313*** (0.000)
	Oil Price Decrease	1.583 (0.812)	12.629** (0.013)	8.425* (0.077)	8.632* (0.071)
	Inflation	2.676 (0.613)	8.131* (0.087)	3.349 (0.501)	16.023*** (0.003)
	3-m TB rate	–	1.952 (0.745)	5.616 (0.230)	–
	Unemployment rate	9.932* (0.080)	14.392*** (0.006)	12.374** (0.015)	13.917*** (0.008)
	Real wage inflation	7.779 (0.100)	2.356 (0.671)	2.269 (0.686)	5.519 (0.238)
	Import price inflation	–	–	1.049 (0.902)	–

Table 2: Exclusion tests of asymmetric effects model with GDP growth as the dependent variable. The values in parentheses are p-values. Statistical significance is shown at the 10% level (*), 5% level (**) and 1% level (***). ▸ RAC Table

Normalised oil price model

- GARCH(1,1) representation of oil prices appropriate to compute conditional variance of oil price shocks (▸ Table)
- So applying this gives...

▸ GARCH details

Normalised oil price model

Specification	Proxy	Variable	1950:1-1985:4	1974:1-2015:2	1986:1-2015:2	1950:1-2015:2
6-variable system 1	PPI	Oil Price Change	5.353 (0.253)	7.932* (0.094)	11.293** (0.023)	12.568** (0.014)
		Normalised Oil Price Shock (ε^*)	25.408*** (0.000)	4.159 (0.385)	5.388 (0.250)	28.266*** (0.000)
	RAC	Oil Price Change	–	5.220 (0.265)	2.939 (0.568)	–
		Normalised Oil Price Shock (ε^*)	–	1.612 (0.807)	3.780 (0.437)	–
7-variable system 1	PPI	Oil Price Change	–	8.713* (0.069)	11.648** (0.020)	
		Normalised Oil Price Shock (ε^*)	–	4.533 (0.339)	5.723 (0.221)	
	RAC	Oil Price Change	–	6.004 (0.199)	3.065 (0.547)	–
		Normalised Oil Price Shock (ε^*)	–	2.085 (0.720)	4.567 (0.335)	–

Table 3: Exclusion tests for normalised oil price shocks. P-values in parentheses. Statistical significance is shown at the 10% level (*), 5% level (**) and 1% level (***). ▸ Model Specifications

Normalised oil price model with asymmetry

Specification	Proxy	Variable	1950:1-1985:4	1974:1-2015:2	1986:1-2015:2	1950:1-2015:2
6-variable system 2	PPI	Norm. +'ve oil price shock (ε^{*+})	62.376*** (0.000)	11.238** (0.024)	13.112** (0.011)	67.683*** (0.000)
		Norm. -'ve oil price shock (ε^{*-})	0.816 (0.936)	2.614 (0.624)	3.648 (0.456)	1.859 (0.762)
	RAC	Norm. +'ve oil price shock (ε^{*+})	–	18.513*** (0.001)	19.877*** (0.001)	–
		Norm. -'ve oil price shock (ε^{*-})	–	0.539 (0.970)	4.222 (0.377)	–
7-variable system 2	PPI	Norm. +'ve oil price shock (ε^{*+})	–	11.487** (0.022)	14.855*** (0.005)	
		Norm. -'ve oil price shock (ε^{*-})	–	2.898 (0.575)	6.042 (0.196)	
	RAC	Norm. +'ve oil price shock (ε^{*+})	–	18.896*** (0.001)	21.980*** (0.000)	–
		Norm. -'ve oil price shock (ε^{*-})	–	0.725 (0.948)	6.158 (0.188)	–

Table 4: Exclusion tests for specifications with normalised oil price changes with asymmetry. P-values in parentheses. Statistical significance is shown at the 10% level (*), 5% level (**) and 1% level (***).

▸ Model Specifications

So is there asymmetry?

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Table 5: Exclusion tests for specifications with normalised oil price changes with and without asymmetry. P-values in parentheses. Statistical significance is shown at the 10% level (*), 5% level (**) and 1% level (***). ▸ Model Specifications

Brief summary

- Strong evidence of asymmetry $\rightarrow$ positive price shocks matter and negative ones do not

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- Averaging out effect when positive and negative shocks are combined in one variable → need for non-linear modelling of prices

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- Strong evidence of asymmetry $\rightarrow$ positive price shocks matter and negative ones do not
- Averaging out effect when positive and negative shocks are combined in one variable $\rightarrow$ need for non-linear modelling of prices
- ...but what is happening over time? Is the relationship really weakening? $\rightarrow$ time-varying parameters using a rolling-window technique

The relationship over time

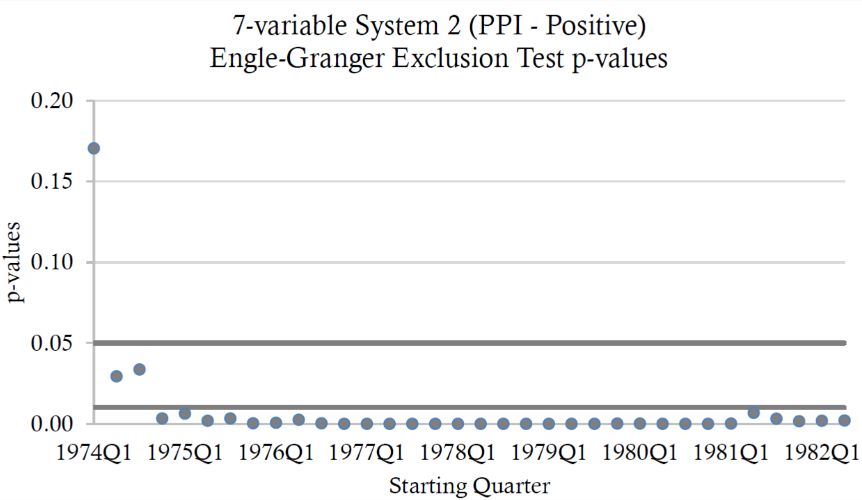

Figure 1: Exclusion test p-values for RAC-based normalised positive oil price shocks in 7-variable system 2 using a rolling window against starting quarter

The relationship over time

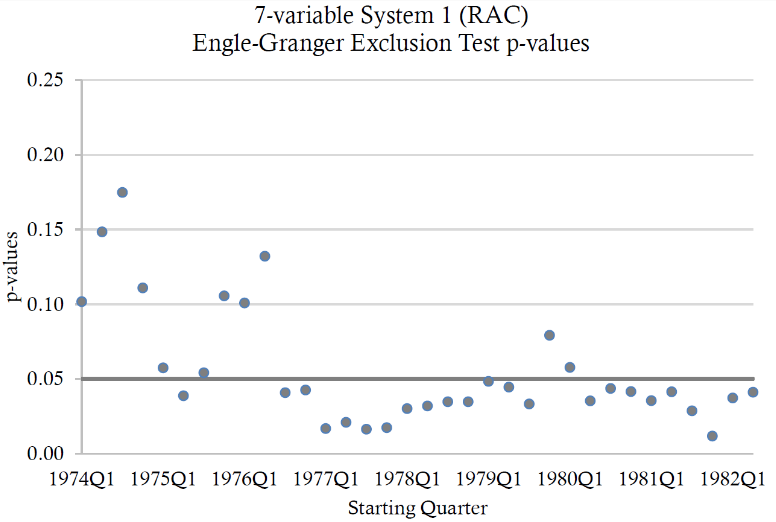

Figure 2: Exclusion test p-values for PPI-based oil price shocks in 7-variable system 1 using a rolling window against starting quarter.

The relationship over time

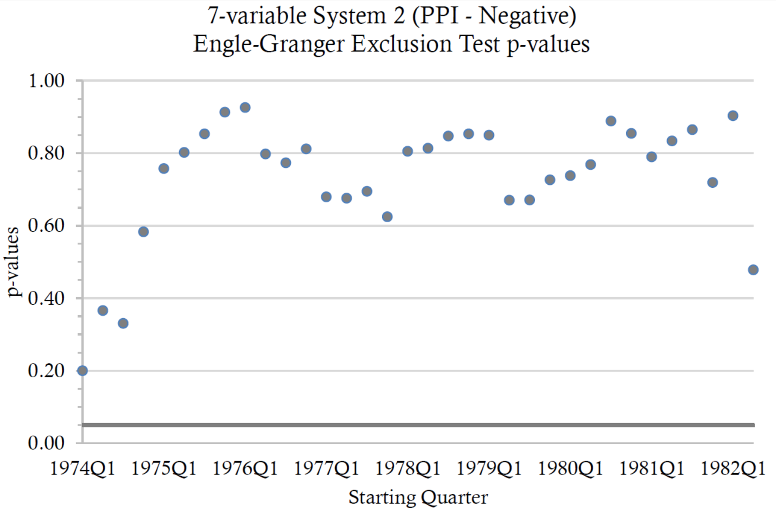

Figure 3: Exclusion test p-values for PPI-based normalised negative oil price shocks in 7-variable system 2 using a rolling window against starting quarter

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- In a Granger-causality sense, there is little evidence here that the link between oil prices and output growth has vanished over the past few decades
- ...but how much difference does asymmetry make?

The relationship over time

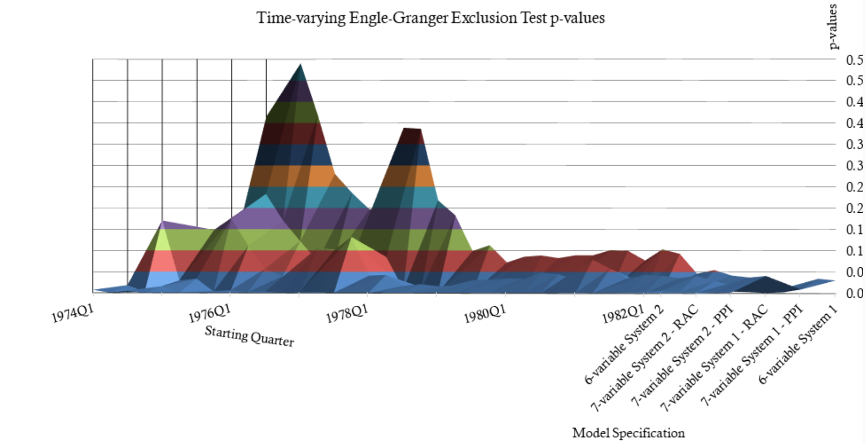

Figure 4: Exclusion test p-values (z-axis) across model specification (y-axis) with varying starting quarter (x-axis). Each colour contour on the z-axis represents an increment of 0.05. Model Specifications

Impulse response analysis

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Impulse response analysis

- Orthogonalised impulse response functions with a 20-quarter horizon
- Impulse = 10% shock to oil price
- Overall result: oil price increases have a negative impact on GDP growth; price falls have an ambiguous effect
- General pattern: negative impact on GDP growth in quarter 1 just after the impulse followed by an overshooting effect in quarter 2 and a return to negative in quarter 3

Impulse response analysis

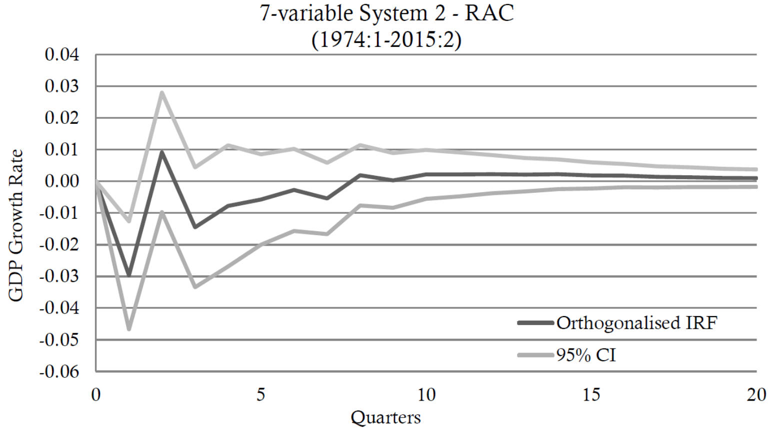

Figure 5: IRF with a 10% PPI-based normalised positive oil price shock.

- A 10% increase in oil price is expected to reduce real GDP growth by 0.2% over a five-year horizon

Impulse response analysis

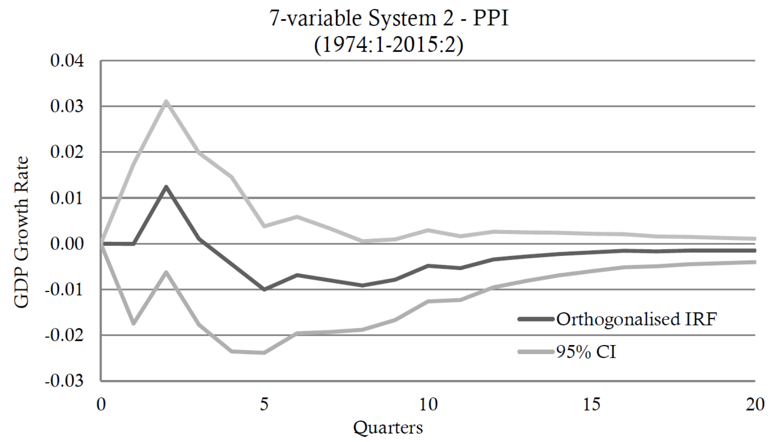

Figure 6: IRF with a 10% PPI-based normalised negative oil price shock.

Rolling impulse responses

- Time-varying parameters based on rolling impulse responses: rolling window of 132 quarters estimated sequentially from 1974:1 onwards

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- Rolling IRFs allow richer insights across multiple dimensions
- A key finding: larger impact in the middle of the sample period than later
- General pattern visible across time and model specification: negative impact in quarter 1 and an overshooting effect in quarter 2
- … and most of the effect dies out by quarter 8

Rolling impulse responses

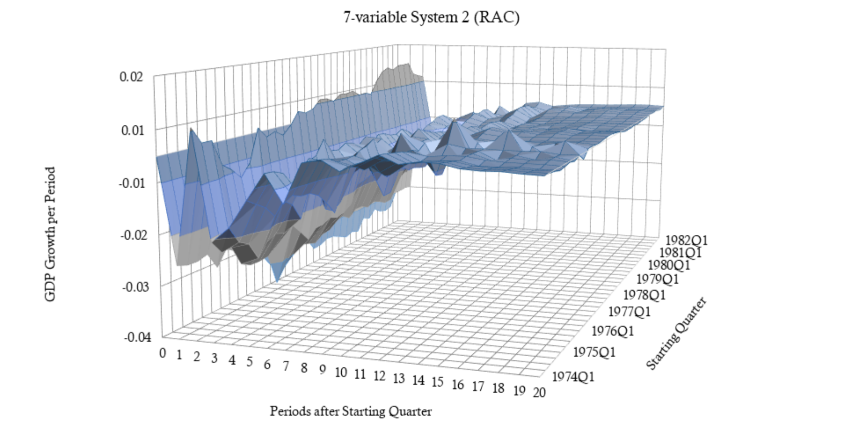

Figure 7: Rolling IRFs with a 10% RAC-based normalised positive oil price shock. ▸ Model Specifications

▸ Estimated Impact

Conclusion

Back to the four questions

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    - Limited evidence that the oil price shocks do not Granger-cause fluctuations in output growth rate in recent samples

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2. Does the sample period matter?
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    - Impact of the shocks higher in post-1986 data, and model specification and sample period influence parameter estimates greatly, resulting in misleading outcomes

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2. Does the sample period matter?
    - Limited evidence that the oil price shocks do not Granger-cause fluctuations in output growth rate in recent samples
    - Impact of the shocks higher in post-1986 data, and model specification and sample period influence parameter estimates greatly, resulting in misleading outcomes
3. Is the relationship asymmetric?

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   - RAC more robust than PPI in crude petroleum
2. Does the sample period matter?
   - Limited evidence that the oil price shocks do not Granger-cause fluctuations in output growth rate in recent samples
   - Impact of the shocks higher in post-1986 data, and model specification and sample period influence parameter estimates greatly, resulting in misleading outcomes
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    - Yes, normalised positive oil price shocks are more highly correlated with output growth rate than any other oil price variable considered

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- The magnitude of the effect changes over time: greater effect in 1970s than 1980s but this reversed after 1986
- Impulse responses indicate most of the effect dies out by the 8th quarter after the shock
- Using unreliable proxies can give misleading results $\rightarrow$ normalisation solution offered here is a robust alternative

Revisiting the Oil Price – Macro Relationship in the US

The Role of Model Specification and Sample Period

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Additional material - oil price modelling

- Modelling oil prices accurately has been debated widely with exogeneity receiving particular attention
- Oil price fluctuations traditionally viewed as exogenous
- However, 2007-2008 price hike due to strong demand and stagnating production

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Brief background - oil price modelling

- Further, Mory (1993) and Lee et al. (1995) found evidence for an asymmetric effect of oil price changes on the US economy
- The latter also found that volatility of oil prices matters for the relationship
- Blanchard and Galí (2007) observed that the nature of the relationship evolved over time
- Gronwald (2008, 2012) concluded that oil price shocks need to be sufficiently large to have a significant impact on macro variables
- Exogeneity of oil prices has also received attention, as Kilian (2009) and Hamilton (2009) argued that underlying causes for price fluctuations matter – ▸ OP Modelling

▸ Back

Additional material - net oil price increases

- With quarterly data, this variable is defined as the amount by which log oil prices in quarter *t* exceed the maximum value over the past four quarters
- If log oil price in the current quarter does not surpass any of the previous 4 values, NOPI takes on the value of 0
- Therefore:

$$NOPI_t = max(0, 100 \times \{ln(o_t) - ln[max(o_{t-1}, o_{t-2}, o_{t-3}, o_{t-4})]\})$$

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Normalised oil price model

- GARCH(1,1) representation of oil prices appropriate to compute conditional variance of oil price shocks (Table)
- Main observation: ARCH and GARCH terms (γ_1 and γ_2 in table) statistically significant in several sample periods
- Recent time periods exhibit GARCH behaviour in errors and show lower persistence → GARCH more appropriate in recent subsamples
- Bollerslev et al. (1992): low-order GARCH models outperform alternative methods → GARCH(1,1) adopted as a parsimonious representation of the conditional variance of ε_t in equation 1 above

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Additional material - model specifications

Model Specification	GDP Growth	Oil Price Change	Oil Price Increase	Oil Price Decrease	Normalised Oil Shock	Normalised Positive Oil Shock	Normalised Negative Oil Shock	Net Oil Price Increase	GDP Deflator Inflation	3m TB rate	Unemp. Rate	Real Wage Inflation	Import Price Inflation
Base Model	✓	✓							✓		✓	✓	
Asym. Eff. Model	✓		✓	✓					✓	✓	✓	✓	✓
6-variable System 1	✓	✓			✓				✓		✓	✓	
6-variable System 2	✓					✓	✓		✓		✓	✓	
6-variable System 3	✓				✓				✓	✓	✓	✓	
7-variable System 1	✓	✓			✓				✓	✓	✓	✓	
7-variable System 2	✓					✓	✓		✓	✓	✓	✓	
7-variable System 3	✓					✓	✓		✓	✓	✓	✓	
8-variable System 1	✓	✓			✓				✓	✓	✓	✓	✓
8-variable System 2	✓					✓	✓		✓	✓	✓	✓	✓
8-variable System 3	✓	✓				✓	✓		✓	✓	✓	✓	
NOPI System 1	✓							✓	✓		✓	✓	
NOPI System 2	✓							✓	✓	✓	✓	✓	
NOPI System 3	✓							✓	✓	✓	✓	✓	✓

▸ Back ▸ Back to NOPI results ▸ Back to NOPI results with asymmetry ▸ TVP Figure ▸ IRF Figure

Asymmetric effects model - RAC

Proxy	Variable	1950:1-1985:4	1974:1-2015:2	1986:1-2015:2	1950:1-2015:2
RAC	Oil Price Increase	–	26.356*** (0.000)	15.754*** (0.003)	–
	Oil Price Decrease	–	8.758* (0.067)	8.116* (0.087)	
	Inflation	–	6.941 (0.139)	3.134 (0.536)	
	3-m TB rate	–	2.301 (0.681)	6.494 (0.165)	–
	Unemployment rate	–	11.835** (0.019)	11.471** (0.022)	
	Real wage inflation	–	2.111 (0.715)	2.123 (0.713)	
	Import price inflation	–	–	0.759 (0.944)	–

Table 6: Exclusion tests of asymmetric effects model with GDP growth as the dependent variable. P-values in parentheses. Statistical significance is shown at the 10% level (*), 5% level (**) and 1% level (***). Back

Additional material - GARCH results - PPI

Proxy	Parameter	1950:1-1985:4	1974:1-2015:2	1986:1-2015:2	1950:1-2015:2
PPI	α_0	0.011** (0.028)	0.017 (0.222)	0.013 (0.379)	0.003 (0.377)
	α_1	0.770*** (0.000)	0.258 (0.121)	0.264** (0.014)	0.394** (0.026)
	α_2	0.007 (0.959)	-0.300** (0.017)	-0.336** (0.011)	-0.393** (0.010)
	α_3	0.064 (0.244)	0.110 (0.419)	0.141* (0.097)	0.250 (0.274)
	α_4	0.035 (0.378)	-0.067 (0.505)	-0.161* (0.064)	-0.056 (0.792)
	γ_0	0.000 (0.333)	0.004 (0.617)	0.012*** (0.008)	0.000 (0.325)
	γ_1	5.951** (0.017)	0.433 (0.154)	0.217 (0.222)	1.220* (0.055)
	γ_2	0.014 (0.483)	0.497 (0.110)	0.328 (0.135)	0.493*** (0.000)

Parameter estimates for GARCH(1,1). P-values in parentheses. Statistical significance is shown at the 10% level (*), 5% level (**) and 1% level (***). Back

Additional material - GARCH results - RAC

Proxy	Parameter	1950:1-1985:4	1974:1-2015:2	1986:1-2015:2	1950:1-2015:2
RAC	α_0	–	0.016 (0.117)	0.015 (0.310)	–
	α_1	–	0.411*** (0.003)	0.309** (0.013)	–
	α_2	–	-0.371*** (0.004)	-0.318*** (0.005)	–
	α_3	–	0.230** (0.023)	0.318 (0.213)	–
	α_4	–	0.085 (0.145)	0.375*** (0.009)	–
	γ_0	–	0.004 (0.332)	0.009*** (0.003)	–
	γ_1	–	0.384* (0.054)	0.008** (0.020)	–
	γ_2	–	0.421 (0.128)	0.311** (0.039)	–

Parameter estimates for GARCH(1,1). P-values in parentheses. Statistical significance is shown at the 10% level (*), 5% level (**) and 1% level (***). Back

Estimated impact

Specification	Proxy	1974:1-2015:2	1986:1-2015:2
7-variable system 2	PPI	-0.16 (-0.03)	-0.34 (-0.07)
	RAC	-0.14 (-0.03)	-0.32 (-0.06)
8-variable system 2	PPI	–	-0.32 (-0.06)
	RAC	–	-0.30 (-0.06)

Table 7: IRF results: Annualised percent changes in output growth rate as a response to a 10 percent increase in oil prices over a 20-quarter horizon. Values in parentheses are average per year responses of output growth rate to the impulse.

- Estimates in line with literature
- 10% increase in the price of oil is expected to cause an average of 0.03% per year fall in GDP growth for five years in the early sample and 0.06% per year fall in the later sample. Back

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