UHERO
THE ECONOMIC RESEARCH ORGANIZATION AT THE UNIVERSITY OF HAWAIʻI

Not All Regions Are Alike: Evaluating the Effect of Oil Price Shocks on Local and Aggregate Economies

BY

ARLAN BRUCAL AND MICHAEL J. ROBERTS

Working Paper No. 2018-4
June 6, 2018

UNIVERSITY OF HAWAIʻI AT MANOA
2424 MAILE WAY, ROOM 540 • HONOLULU, HAWAIʻI 96822
WWW.UHERO.HAWAII.EDU

Not All Regions Are Alike: Evaluating the Effect of Oil Price Shocks on Local and Aggregate Economies

Arlan Brucal and Michael J. Roberts*

This Version: June 2018

Abstract

Using a sample of 48 contiguous U.S. states for the period 1973-2013, we study how oil price shocks influence state-level economic growth. The analysis incorporates (1) a structural decomposition of the supply and demand factors that drive the real price of crude oil; (2) heterogeneity of states in terms of their production and consumption of oil and natural gas; and (3) economic spillovers across neighboring states. Oil price effects vary across states, depending on the underlying source of the price shock and a state's average production of oil relative to its average consumption. Oil-exporting states are more vulnerable to unanticipated changes in oil prices, and the direct effect of oil price shocks can magnify or temper effects on neighboring states. Aggregated predictions from the state-level model also differ modestly from stand-alone aggregate model (Kilian, 2009). The aggregated state-level model implies that the recent (2005-2016) decline in U.S. dependence on foreign oil reduced aggregate sensitivity to exogenous supply shocks by more than a third.

JEL-Classification: E32,Q43

Keywords: Oil price shocks, economic spillovers, dynamic

*Brucal: Grantham Research institute on Climate Change and the Environment, London School of Economics and Political Science, Houghton St., London WC2A 2AE, UK, a.z.brucal@lse.ac.uk. Roberts: Department of Economics, University of Hawaii at Manoa, 2424 Maile Way, Saunders Hall 542, Honolulu, HI 96822, USA, mjrobert@hawaii.edu. The authors acknowledge support from the Lawrence Berkeley National Laboratory, the Grantham Foundation and the Economic and Social Research Council (ESRC) through the Centre for Climate Change Economics and Policy The authors thank Peter Fuleky and participants at seminars at UH Manoa and LSE for useful comments and suggestions.

1 Introduction

Due to the 2014-2015 drop in oil and gasoline prices, U.S. households saved an average of $700. Although consumers spent half of these savings on other goods and services (Farell and Greig, 2015), the resulting stimulus to the U.S.economy was less than many expected (Hamilton, 2016). Meanwhile, oil producers were severely harmed by the price drop, resulting in a loss of about 35,000 jobs from October 2014 to April 2015 (US EIA, 2015) and a decline in capital expenditure by about half a percent of GDP (Hamilton, 2016). A similar pattern was observed during the 1986 oil price collapse, which had no significant effect on the U.S. macroeconomy but brought regional recession to major oil-producing states (Hamilton and Owyang, 2012). The oil price declines in 1986 and 2014 show how the aggregate effect of oil price shocks can obscure more prominent, opposing effects at the regional level.

States differ in their responses to oil prices because they are endowed with different resources and specialize in different economic activities (Melichar, 2013). Growth in oil- and gas-rich states in the Gulf Coast region export crude oil and petroleum products and tend to benefit from higher oil prices, while manufacturing industries in the Great Lakes region and urban centers like New York import oil, and therefore tend to benefit from lower prices, holding all else the same. The source of the price shock matters, however. One the one hand, a price rise driven by worldwide growth in aggregate demand would presumably increase demand for manufactured goods and services, benefiting the Great Lakes and New York, even while oil prices rise. One the other hand, supply disruption or threat of one, stemming from unrest in the Middle East, could benefit the Gulf Coast states while hurting oil-importing regions.

Through trade, migration and state-energy interdependence, an economic shock to one state will also have spillover effects on other states. Carlino and Inman (2013) find that a state's own deficits stimulate neighboring economies in addition to its own economy. They estimate a considerable spillover effect, averaging about two-thirds of each state's direct impact. In aggregate, we should probably expect that exogenous oil price spikes are bad for the U.S. economy because the country still imports oil. At the same time, it would be useful to unpack regional differences and identify spillover effects. Engemann et al. (2014) did a similar analysis on oil-price macroeconomy, but did not connect heterogeneous impacts to oil dependence, or account for regional spillovers. This new approach leverages a reasonable assumption for how these oil-price effects arise, when then allows us to extrapolate to predict consequences of changing oil dependence, such as that stemming from growth in hydraulic fracturing.

A number of empirical studies consider how oil price shocks influence the aggregate U.S. economy (see, for example, Hamilton, 1983; Bernanke et al., 1997; Barsky and Kilian, 2004; Kilian, 2008, 2009). Few studies, however, consider oil price-macroeconomy relationships at the state level. Important exceptions are Brown and Yucel (1995), Penn et al. (2006), Melichar (2013) and Engemann et al. (2014).[1] A limitation of these earlier studies is that they take oil price shocks as exogenous, an assumption that more recent aggregate studies no longer make. The modern literature recognizes that price shocks are symptoms of more fundamental economic developments that drive demand and supply of oil (Barsky and Kilian, 2002, 2004; Kilian, 2009), with different drivers having different effects. It is also likely that different kinds of shocks have different effects on different states, depending on the states comparative advantage in oil production.

In this study we build upon Kilian (2009)'s work that disentangles the underlying demand and supply shocks in the global crude oil market, but extend it to account for varying responses of shocks on different local economies, as well as economic spillovers across neighboring states. We find that oil price shocks have substantially different impact on different states. For example, an exogenous (supply-driven) 10 percent decline in oil price causes an estimated 0.40 percentage point decrease to growth in Wyoming and an estimated 0.12 percentage point increase in New York. However, the direct effects are attenuated or magnified via spillover effects, such that within one year, the total effect for Wyoming diminishes to about 0.3 percentage point decline in growth while the effect in New York increases to 0.45 percentage point. These two states see the most extreme effects; others states lie between these two.

Results from this study may have implications for how governments address macroeconomic fluctuations that derive from oil price shocks in the US. Monetary policy can be a crude tool in this context, given the heterogeneity of effects across states and regionally-varying need for stimulus. More broadly, our study has implications on the current effort towards a more integrated energy market in some regions, such as the EU Energy Union and the ASEAN Energy Market Integration. The indirect effect of global energy shocks through cross-border linkages, which manifest though international trade or cross-border migration, may be magnified with the pursuit to have a regional integrated energy market. It is therefore important to improving our understanding of the economic disturbances from energy price shocks in a setting with cross-border interaction and heterogeneity in oil-based energy dependence.

The remainder of the paper is as follows. Section 2 discusses how we estimate the impact of oil price shocks to different states in the US. In this section, we update Kilian (2009)'s work to cover the oil price drop in 2008. The section also characterizes different states based on their relative oil consumption and production and presents evidence of spatial correlation of economic growth amongst neighboring states. Section 3 presents the impact of oil price shocks to states' economic growth. We conclude in section 4 with a discussion and policy implications.

[1]There are also studies that use industry-level data to analyze the influence of oil price shocks to the economy. See, for example, Davis and Haltiwanger, 2001; Lee and Ni, 2002; Kilian and Park, 2009.

2 Empirical Strategy

2.1 Accounting for the Endogeneity of Oil Price Changes

Historically, researchers assumed that oil price shocks were exogenous, possibly because most of these shocks concurred with war-driven oil production shortfalls and geopolitical uncertainties in oil-exporting countries (Hamilton, 1983; Guo et al., 2005; Melichar, 2013; Rahman and Serletis, 2010). However, there is an increasing recognition that oil price shocks are driven not only by surprises in the current physical availability of oil, but also with unanticipated changes in aggregate demand, and with shocks driven by speculation about future supply and demand (Barsky and Kilian, 2004; Kilian, 2009; Kilian and Murphy, 2014). Evidence indicates that after the late 1970s, exogenous changes in oil production have had less influence on oil prices as compared to changes in speculative demand for oil (Kilian, 2008). Both kinds of price shocks have had less influence on growth due to greater energy efficiency and a falling income share of fuel expenditure. Shocks to aggregate demand may also affect oil prices, effectively reversing both the sign of the relationship and direction of causality. One channel is through monetary policy, which can affect both aggregate demand for goods and carryover of stored inventories through interest rate changes, and thus oil prices (Barsky and Kilian, 2002; Frankel, 2008, 2014).

The endogeneity of oil prices has implications on how researchers evaluate the influence of crude oil price changes on macroeconomic aggregates. Identifying the underlying demand and supply shocks in the global crude oil market helps us determine how macroeconomic aggregates are affected (Kilian, 2009). Here we take this reasoning down to regional level, since different kinds of shocks will have different effects on regions that tend to import or export oil. We focus on U.S. states due to their substantial heterogeneity in oil production and trade dependence.

To account for the endogeneity of crude oil prices, we replicate Kilian (2009)'s vector autoregression (VAR) model to extract the structural innovations underlying price shocks. We updated the sample period to 2015 to cover recent oil price changes. The model uses monthly data of $z_t = (prod_t, rea_t, rpo_t)'$, where $prod_t$ refers to global crude oil production from the Energy Information Administration (EIA), rea_t denotes the index of real economic activity derived from the bulk dry cargo shipping rate index developed in Kilian (2009), and rpo_t is the refiner's acquisition cost of imported crude oil provided by EIA, which serves as proxy to global crude oil price. Except for rea_t, which is stationary by construction, all of the series are period-to-period log-transformed differences. The sample period covers the period from January 1974 through October 2015. We account for seasonal variation by using monthly dummies.

Following Kilian (2009), the following exclusion restrictions are imposed to the reduced form errors, e_t:

$$e_t = \begin{pmatrix} e_t^{prod} \\ e_t^{rea} \\ e_t^{rpo} \end{pmatrix} = \begin{bmatrix} \alpha_{11} & 0 & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{oil\ supply\ shock} \\ \varepsilon_t^{aggregate\ demand\ shock} \\ \varepsilon_t^{oil\text{-}specific\ demand\ shock} \end{pmatrix}$$

where ε_t^k denotes the serially and mutually uncorrelated structural shocks in each VAR equation $k = 1, 2, 3$.

The exclusion restrictions imply that *oil supply shocks*, which are denoted by unanticipated innovations in global crude oil production, are assumed to be unaffected by any innovation in the demand for oil within the same month. The assumption reflects the slow response of global crude oil production to demand shocks because of costly adjustment in production and uncertainties in the future state of the crude oil market.

Shocks to global real economic activity are referred to as *aggregate demand shocks*.[2] The exclusion restriction implies that oil-specific demand shocks, which increase oil price, will not lower real economic activity within the same month but only with a delay of at least one month. This exclusion restriction is consistent with the sluggish response of the macroeconomy to major oil price increases observed in the sample period as illustrated by Hamilton (1983) and Kilian (2009).

Finally, unanticipated oil price changes, here referred to as *oil-specific demand shocks*, denote shocks to changes in demand for crude oil not already captured by instantaneous shifts in aggregate demand for industrial commodities and supply of oil. These shocks include changes in speculative storage demand for oil due to shifts in expectations about future demand relative supply. For example, crude oil prices started to escalate in 1979, even though there was no significant disruption in the global crude oil production. The increase in crude oil price in 1979 is associated to the outbreak of the Iran-Iraq War in 1980 (Kilian, 2009).[3] While the residual shocks in the model may also include other shocks such as unexpected weather patterns and changes in preferences, there is evidence to support that the residual shock largely represents exogenous shifts in precautionary or storage demand for oil.[4]

Figure 1 plots the historical decomposition of structural shocks implied by the VAR model. The shocks are expressed as annual averages for better readability. A key takeaway from this figure is that spikes and drops capture key historical oil price shocks documented in previous research

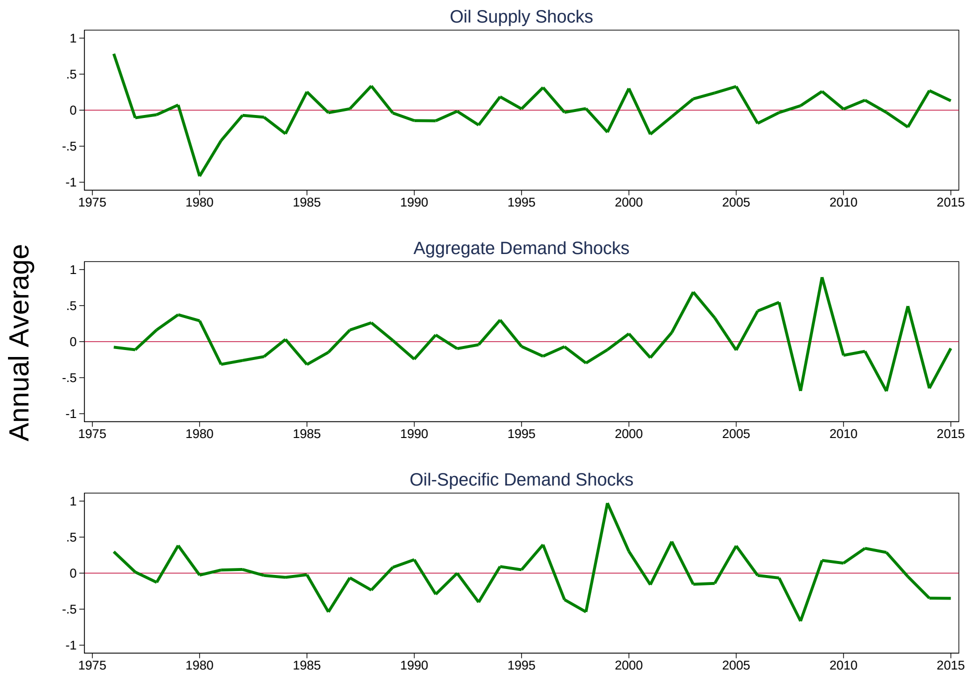
[2] Kilian (2009) distinguishes aggregate demand for industrial commodities in this context as opposed to aggregate demand for overall goods and services, but these are likely correlated.

[3] The 1978-1979 Iranian revolution brought insignificant change in the global production of oil as Iranian cutbacks were more than offset by increased production elsewhere (Kilian, 2009; Hamilton, 2013).

[4] For detailed discussion, see (Kilian, 2009).

by Kilian (2009) and Hamilton (2013)). For example, there was a global oil supply disruption in 1980 associated with the outbreak of the Iran-Iraq war. Meanwhile, the years 1978, 1979, and 1980 experienced large positive economic shocks attributed to the growing global economy. There is also an unanticipated increase in oil-specific demand in 1979, consistent with increased uncertainties the future supply that was likely brought about from the geopolitical conflicts in the Middle East. The estimated structural shocks also capture the 2008 unanticipated fall in aggregate demand following the Great Recession, which also coincides with a drop in oil-specific demand due to lower expectation of future demand for oil. Meanwhile, U.S. oil production increased in 2014, causing a slight unexpected uptake in global oil production.

Figure 1: Replicated Decomposition of Aggregate Oil Price Shocks, 1976-2015.



Notes: The figure illustrates that estimated structural residuals from the VAR model, averaged to annual frequency. A figure showing the historical trend of the variables used in the VAR is presented in Table A.I.

Data Sources: State Energy Data System (SEDS), EIA.

2.2 Accounting for the Heterogeneity of States

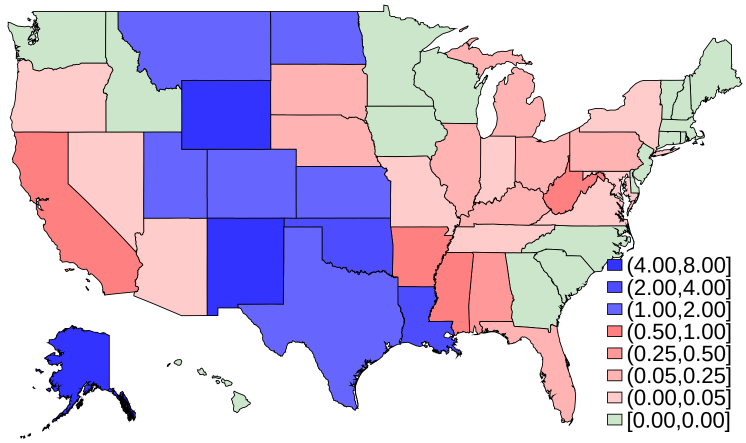
We characterize heterogeneity across states using each states' average oil production relative to its average consumption.[5] The ratio is calculated by taking the sum of the energy content (in British Thermal Units) of crude oil and natural gas produced by the state from 1963-2013 divided by the sum of energy consumed from crude oil and petroleum at end-use level. The idea is to account for each states relative comparative advantage in oil production. A ratio greater than 1 implies that the state tends to be a net exporter of oil, and a net importer if otherwise. This measure is partly endogenous, because a state may increase production in response to changing oil demand. We therefore use a long run average of the ratio that is fixed over time. The data on crude oil production do not include Federal offshore production from 1981 forward. Petroleum Administration for Defense District (PADD) 5 makes up about 10-percent of California's production over time, and will not make significant change in California's long-run production-consumption ratio. Meanwhile, the states in PADD 3 that have the most of offshore production (i.e. Texas and Louisiana) are already net producers and adding the offshore production will not make the states net importers.

Figure 2 illustrates the heterogeneity of theU.S.economy based on state-level average oil production-consumption ratios from 1963 to 2013. Major net oil producers include Alaska, Wyoming and New Mexico. Large state economies (i.e. California and New York) are both net consumers, while a number states (e.g. Hawaii and Washington) do not have any production of oil or natural gas over the sample period.

Since states are heterogeneous, the response of each state to oil price shocks also differs, depending on their oil endowment relative to the size of the local economy. To consider the size of this effect, we show the trend of average Gross State Product (GSP) growth rates of net oil-producing and -consuming states in periods of major oil price changes. Figure 3 summarizes the result. From 1975-1986, considerable differences in GSP growth paths occurred between net producers and net consumers. For example, the oil price hike in 1980 is associated with high positive GSP growth of net oil-producers, and negative GSO growth of net oil-consumers. When real oil price plunged to about $30/barrel in 1986, net producing states experienced negative GSP growth rates while net consumers experienced positive growth. In the 1990s up to 2002, the growth path of the two groups follow a somewhat similar pattern. Differences in the pattern start to appear in 2003. During the Great Recession in 2007-2008, when real oil price drops from $100 to about $60 per barrel, all states experienced negative GSP growth, with net oil-producing states suffering disproportionately more.

[5] Another way to characterize heterogeneity is to use shares of industry gross value added to total Gross State Product (GSP). However, the industry classification changed from SIC to NAICS in 1997 and created discontinuity in the series, making comparison across years difficult.

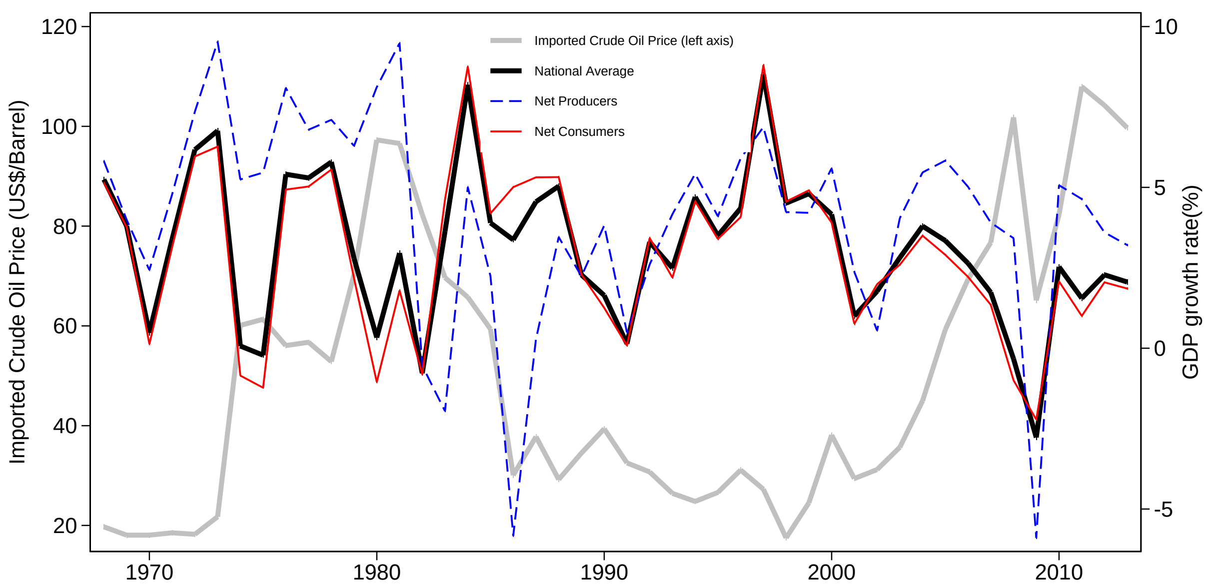
Figure 2: Oil-based energy production-consumption ratio, by state



Notes: The figure shows the energy production-consumption ratio of each state in the US. The ratio is generated by taking the sum of all energy produced within the state from 1960-2013 (in British Thermal Units or BTUs) divided by the sum of all energy consumed (end-use). Oil based sources include crude oil and natural gas.

Source: State Energy Data System (SEDS), EIA.

Figure 3: Gross state product growth rate (average, net importers, net producers) and crude oil price.



Imported crude oil price (solid gray line) denotes refiners' acquisition cost (in 1981 US$). Net producers are those with average energy production/consumption≥1 from 1960 to 2013.

Source: (Energy Production-Consumption) SEDS, EIA; (Crude Oil Price) EIA, (GSP) BEA.

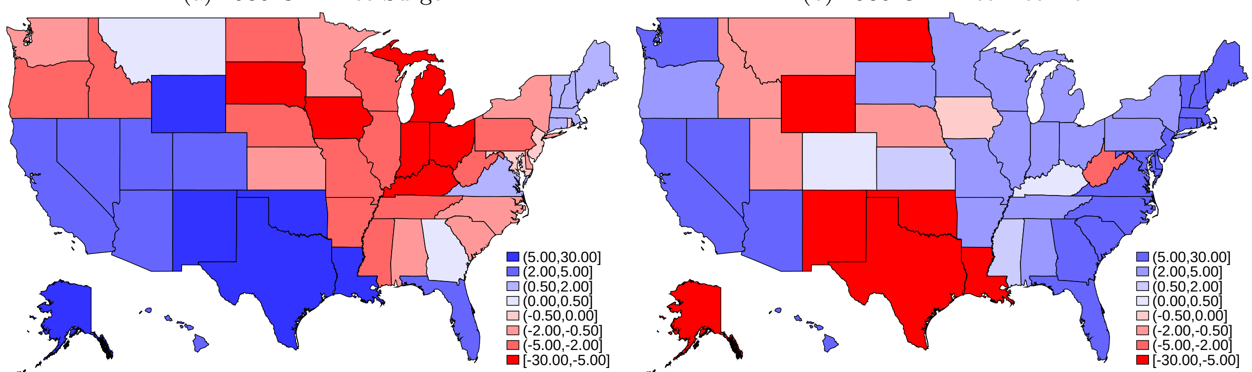
2.3 Accounting for Economic Spillovers Across Neighbors

State economies are connected to one another through factor mobility and trade of goods. For example, the sharp increase in shale extraction in North Dakota resulted in rapid population increase from 2010 to 2013, largely due to influx of young adults moving from other states seeking employment in the oil fields. Evidence also suggests that state-specific policies, including welfare spending, have significant positive spillover effect on neighboring states (Baicker, 2005; Figlio et al., 1999).

To consider how the channels of state interconnection affect transmission of oil price shocks across states, we show the spatial patterns of growth during periods of major oil price changes. Figure 4 shows the GSP growth rate of different states in the United Statesduring the oil price surge in 1980 and the 1986 oil price collapse. In 1980, when prices spiked, we see patterns of regional recessions in the Great Lakes region coincident with remarkable regional growth around the Gulf Coast area. We see the opposite pattern in 1986, when oil prices fell. There is a general indication that clusters of negatively- or positively-affected states emerge during periods of major oil price changes. This is consistent with the findings of Hamilton and Owyang (2012) supporting the existence of regional groupings based on comovement of state employment growth rates during periods of economic recession.

Figure 4: Gross State Product Growth Rates, 1980 and 1986

(a) 1980 Oil Price Surge (b) 1986 Oil Price Decline



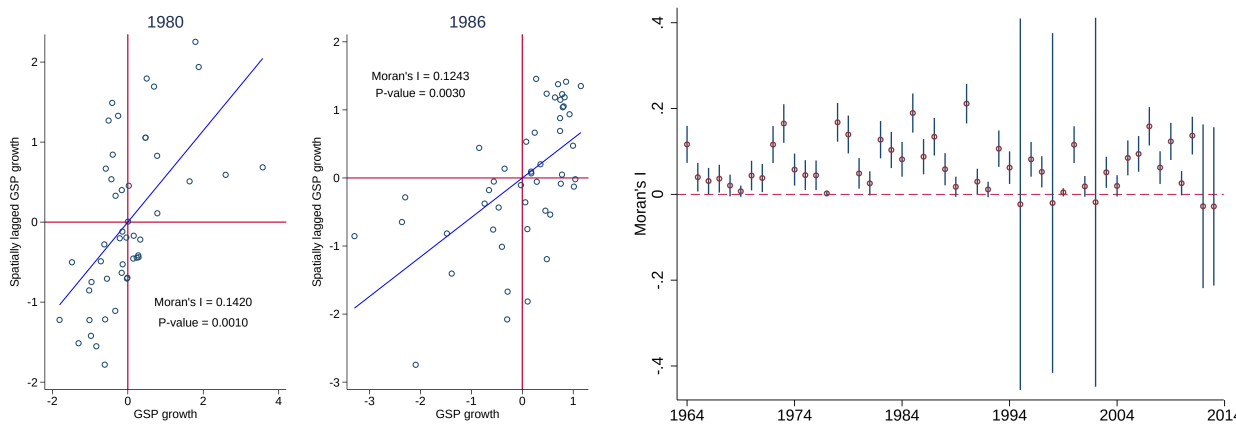
Source: BEA.

To obtain some sense of the size of the geographic spillover effect, we show the Moran scatter plot during the oil price surge in 1980 and the price decline in 1986 (left panel of Figure 5). The Moran scatter plot shows the relation between the individual state's GSP growth rate (in standardized form) in the horizontal axis and the average growth rates of neighboring states weighted by the spatial lag vector W in the vertical axis. W assumes that the spillover effect of state's neighbor is inversely related to the geographic distance between the two states and positively related to the economic size of the neighboring state, assumptions consistent with the gravity model of trade. We provide a more detailed discussion on this spatial lag vector in the next section. The scatter plot is centered around zero because of standardization. The upper right quadrant shows the states that have GSP growth rates above the cross-sectional mean, where the average of neighboring states are also above the mean. The lower left quadrant shows the states and its neighboring states' GSP growth rates that are both below mean.

The scatter plot indicates a positive correlation between state GSP growth rate and that of neighboring states in both periods. Indeed, the Moran's I statistic, a metric often used to formally test for spatial dependence, is positive and statistically significant (the alternative in this test is that the slope is zero, indicating no spatial dependence). We also calculate the Moran's I statistic for all time periods and they are generally positive and statistically significant (right panel of Figure 5), which suggests that there is positive comovement in GSP among neighboring states.

Figure 5: Moran scatter plot and Moran's I-statistic

(a) Moran Scatter Plot, 1980, 1986 (b) Moran's I-statistic, 1963-2013.



The left panel shows the Moran scatter plot during the oil price surge in 1980 and the price collapse in 1986. The right panel presents that calculated Moran's I-statistic from 1963 - 2013. The whiskers denote 95 percent confidence interval.

Source: (GSP) BEA, (Moran's I-statistic) Authors' calculation.

2.4 A Model with Inter-State Spillovers

After estimating the monthly structural shocks in the crude oil market in Section 2.1, we take the annual average of the shocks in order to match the frequency of GSP estimates provided by the Bureau of Economic Analysis (BEA):

$$\hat{\zeta_{jt}} = \frac{1}{12}\sum_{i=1}^{12} v_{j,i,t}, \quad j = 1, 2, 3 \tag{1}$$

where $v_{j,i,t}$ refers to the estimated residual in the j^{th} equation in the VAR model in the i^{th} month of the t^{th} year of the sample. We examine the influence of these structural shocks on U.S. state-level economies using the specification:

$$y_t = \tau y_{t-1} + \lambda W y_t + \rho W y_{t-1} + X_t \beta + \alpha I_N + u_t \tag{2}$$

where y_t is a $n \times 1$ vector denoting GSP growth rate for each state at period t, X_t is a $m \times (nt)$ matrix of m-explanatory variables containing estimated structural shocks $\hat{\zeta_{kt}}$ and their interaction with states' long-run average oil production-to-consumption ratio, α is an $n \times 1$ vector of state fixed effects, and u_t is the usual error. We include a spatial lag variable Wy_t and Wy_{t-1} to capture the spatial dependence among states. The spatial lag variable, W, is defined as as

$$W = \begin{pmatrix} 0 & w_{1,2} & w_{1,3} & \dots & w_{1,n} \\ w_{2,1} & 0 & w_{2,3} & \dots & w_{2,n} \\ w_{3,1} & w_{3,2} & 0 & \dots & w_{3,n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ w_{n,1} & w_{n,2} & w_{n,3} & \dots & 0 \end{pmatrix} \tag{3}$$

$$w_{i,j} = \frac{M_i M_j}{d_{ij}^2} \tag{4}$$

where M denotes the economic size of states i & j (measured as average GSP from 1960-2014, in 2014 U.S.$), and d is the distance (measured in terms of geographic and economic distance) between the most populous urban areas of states i and j. For economic distance, we take the average value of inbound and outbound zone-based cargo freight rates from FedEx in 2015 to approximate shipping costs from and to different states. The shipping cost is based on a hypothetical 15,000 lb cargo. We also use spatial contiguity as a measure of W to test for the robustness of our estimates. This kind of spatial lag matrix takes the value of 1 for $w_{i,j}$ if two states share a common border and 0 otherwise. The sum of each row takes the value of 1 (row standardization), which implies that the spillover effect for each state is the weighted average effect of all other states.

Equation 2 implicitly assumes that there is no reverse causality between the estimated oil price shocks and the states' GSP growth rates. We validate this assumption by eliminating large state economies such as California, New York and Texas, which may influence crude oil price through changes in state-level demand. Results are robust to elimination of these states.[6]

We estimate equation 2 via generalized method of moments (GMM) following Lee and Yu (2014). The procedure involves eliminating state fixed effects through forward orthogonal deviation (FOD) transformation, which calculates deviations of a variable using its forward mean. Thus, equation 2 becomes

$$y_t^* = \sum_{k=1}^{3} \phi_k \hat{\zeta}_{kt}^* + \tau y_{t-1}^* + \lambda W y_t^* + \rho W y_{t-1}^* + X_t^* \beta + v_t^* \tag{5}$$

where y_t^*, $\hat{\zeta}_{kt}^*$, y_{t-1}^*, Wy_t^*, Wy_{t-1}^*, X_t^* and v_t^* are FOD-transformed variables. We estimate equation 5 using all strictly exogenous variables X_s for $s = 1, \ldots T-1$ and the time lag variables as instrumental variables (IV) for y_{t-1}^* and WX_s for $s = 1, \ldots T-1$ and Wy for $s = 0, \ldots t-1$ as IVs for Wy_{t-1}^*.

3 Results

3.1 Impact of Oil Price Shocks on State Growth

Table 1 summarizes results from estimation of equation 5. Each column reports a separate regression predicting the first difference of log-transformed GSP. Different columns report results with different accounts of spatial dependence and error correlation. Coefficients of spatial lags (λ and ρ) are significant, indicating the presence of economic spillovers across neighboring states and/or spatially correlated unobserved factors. The coefficients of structural shocks using OLS are generally larger in magnitude suggesting the potential upward bias of the estimates, because variations from spatial dependence are being attributed to individual shocks. Estimates from the SAR models are fairly robust and the qualitative results remain regardless of the spatial lag matrix used. Based on stability condition following LeSage (2008) (i.e. $\lambda < 1$ in the short run), we choose SAR using spatial contiguity weight matrix as our preferred model.

We derive the marginal effects of each underlying shock controlling for the characteristic of each individual state by rewriting the spatial econometric model:

$$Y_t = (I - \lambda W)^{-1}(\tau I + \rho W)(Y_{t-1}) + (I - \lambda W)^{-1}(\sum_{k=1}^{3} \phi_k \hat{\zeta_{kt}} + X_t \beta) + R \tag{6}$$

[6]See Table A.A.I in Appendix for the robustness check of the results.

where R is a rest term containing state fixed effects and error term. All other variables are as previously defined.

To simplify the analysis, we first consider the direct effect without spillovers (i.e. $\lambda = \rho = 0$).[7] The matrix of partial derivatives with respect the k^{th} explanatory variable –the measure of marginal impact– is illustrated below. Each partial derivative denotes the effect of a unit change of a particular oil price shock in a particular state. We express the direct effects over both short-term and long-term horizons.

$$\left[\frac{\partial Y}{\partial \hat{\zeta}_{1k}} \cdots \frac{\partial Y}{\partial \hat{\zeta}_{Nk}}\right]_t = \phi_k I_N \qquad \text{(short term)}$$

$$\left[\frac{\partial E[Y]}{\partial \hat{\zeta}_{1k}} \cdots \frac{\partial E[Y]}{\partial \hat{\zeta}_{Nk}}\right] = (I_N - \tau I)^{-1} \phi_k I_N \qquad \text{(long term term)}$$

Next we consider the effect of oil price shocks on GSP growth rate while taking into account spillovers across states (i.e. assume that $\lambda \neq 0; \quad \rho \neq 0$). The matrix of partial derivatives with respect the k^{th} explanatory variable is expressed below. The partial derivatives denote the effect of a unit change in each underlying oil price shock in a particular state on the economic growth of all other states in the short term.

$$\left[\frac{\partial Y}{\partial \hat{\zeta}_{1k}} \cdots \frac{\partial Y}{\partial \hat{\zeta}_{Nk}}\right]_t = (I - \lambda W)^{-1}[\phi_k I_N] \tag{7}$$

Figure 7 illustrates the short-run impact of a unit increase in each kind of shock to state-level economic growth while considering non-zero spillover effects. For positive oil supply shocks, we find that states that neighbor net-oil-consuming states gain significantly through positive spillovers. For example, the direct effect of the supply shock to New York grows from 0.12 to 0.45 percentage point increase within the year. Texas and New Mexico, in contrast, do not gain from spillovers because they are surrounded by net oil-producing states. Meanwhile, the direct impact of the supply shock on Wyoming's growth is attenuated by the spillovers from neighboring net oil consuming states, from 0.40 to about 0.30 percentage point decline. We observe a similar pattern for unanticipated increase in the precautionary or speculative demand for oil, although the spillover effect is more pronounced for major oil-producing states. Aggregate demand shocks do not have significant on states' GSP growth, even if we account for spillover effects between neighboring states.

[7] Our definition of direct effects here (i.e. no spatial dependence) is different from LeSage (2008)'s direct effects, which are the diagonal elements of the matrices $(I - \lambda W)^{-1}[\phi_k I_N]$.

Table 1: Dependent variable: first difference in log-transformed Gross State Product

Variables	OLS		SAR					
	50 states	48 states	Economic Distance		Geographic Distance		Spatial Contiguity	
Oil Supply	0.030***	0.030***	0.005*	0.007**	0.005*	0.007**	0.007**	0.008**
	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)
REA	0.005***	0.005**	0.001	0.003	0.000	0.002	0.001	0.004
	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)
Oil-Specific Demand	-0.011***	-0.009***	-0.004**	-0.007***	-0.003*	-0.007***	-0.004*	-0.006***
	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)
Oil Supply* Prod/Cap	-0.015***	-0.012***	-0.010***	-0.008***	-0.011***	-0.009***	-0.008***	-0.007***
	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)
REA*Prod/Cap	-0.003*	-0.004	-0.002	-0.002	-0.002	-0.002	-0.001	-0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
Oil-Specific*Prod/Cap	0.013***	0.009***	0.007***	0.005***	0.007***	0.006***	0.006**	0.005***
	(0.004)	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)
GSP growth$_{t-1}$ (τ)	0.228***	0.268***	0.175***	0.616***	0.169***	0.573***	0.148***	0.700***
	(0.047)	(0.038)	(0.036)	(0.105)	(0.035)	(0.095)	(0.035)	(0.111)
Spatial lag (λ)			1.026***	1.056***	1.036***	1.072***	0.786***	0.934***
			(0.032)	(0.040)	(0.031)	(0.041)	(0.040)	(0.063)
Spatial lag$_{t-1}$ (ρ)				-1.038***		-0.985***		-1.066***
				(0.269)		(0.234)		(0.212)
Observations	1,850	1,776	1,776	1,776	1,776	1,776	1,776	1,776
Time Period (years)	37	37	37	37	37	37	37	37
No. of Panels	50	48	48	48	48	48	48	48
GMM-AIC	0.000	0.000	-1.573	-8.111	-3.772	-8.685	-0.093	-9.465
GMM-BIC	0.000	0.000	-34.466	-35.522	-36.665	-36.096	-32.985	-36.875
Pseudo-Adj. R.sq	0.109	0.112	0.454	0.454	0.446	0.446	0.465	0.464
Hansen J-statistic	0.000	0.000	10.427	1.888	8.228	1.315	11.907	0.535
p-value of J-statistic	-	-	0.108	0.864	0.222	0.933	0.064	0.991

Oil Supply, Real Economic Activity (REA) and Oil Specific Demand are described in the text. Prod/Cap is state-level long-run ratio of energy (BTUs) produced and consumed from crude oil and petroleum form 1963-2013. The 48 states refer to 48 contiguous states in the US. Regression results are derived using GMM following Lee and Yu (2014). GMM-AIC and GMM-BIC are calculated following Andrews (1999). Standard errors clustered by state are in parentheses. ***, **, * denote statistical significance at 1, 5 and 10 percent respectively.

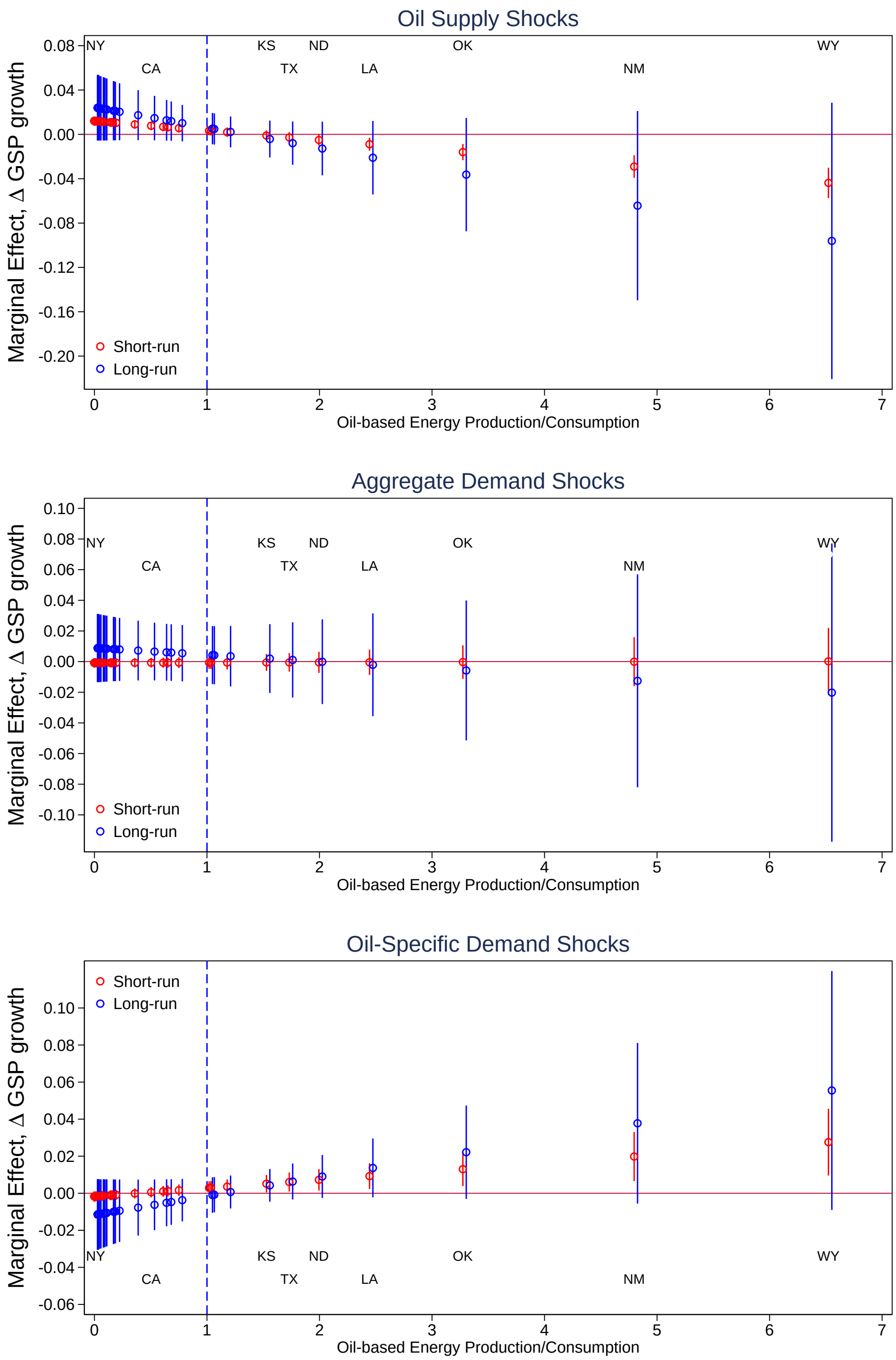
Figure 6 shows short-run and long-run estimated elasticities of state-level output in response to each type of oil market shock. The results are similar to Kilian (2009). Unanticipated oil supply disruptions decrease state-level economic growth for non-producers but increase growth for major oil producers in the short run. For example, a 10 percent decline in the growth of oil price causes an estimated 0.40 percentage point decrease to growth in Wyoming and an estimated 0.12 percentage point increase in New York. The same result holds for unanticipated increases in oil-market specific demand. These results are intuitive because both shocks increase oil price, translating to revenue gains for net producers, while increasing costs for net oil consumers.

Unanticipated increases in real economic activity have no significant impact on economic growth for both net-producing and net-consuming states. Kilian (2009) suggests that increases in aggregate demand have two opposing pressures on GSP growth: a positive income-growth effect and a negative effect due to inflationary pressures. For net importing states, this intuition makes sense. For net-producing states, this explanation would only make sense if the coincidental price adjustment of all other goods and services in these states are sufficiently large to offset the positive effect of increased oil revenues. It is also possible that increased oil revenues do not stay at the state and are remitted to owners in other states. Finally, while there seems to be asymmetric effect between net oil-producing and net-oil consuming states, none of the shocks have a statistically significant long-term effect on GSP growth.

We also look at the average residuals from estimating equation 2 for net-producing and net-consuming states during periods of major oil price changes. By construction, the residuals capture the effects of other factors influencing growth that are not captured by the underlying oil price shocks and the spillover effects between states. These factors mainly have to do with speculation about future supply and demand, or changing uncertainty, which can affect current price via storage demand. These shocks may lead to higher or lower capital expenditures on oil-extraction industries or changes in precautionary savings of households in oil-producing states.

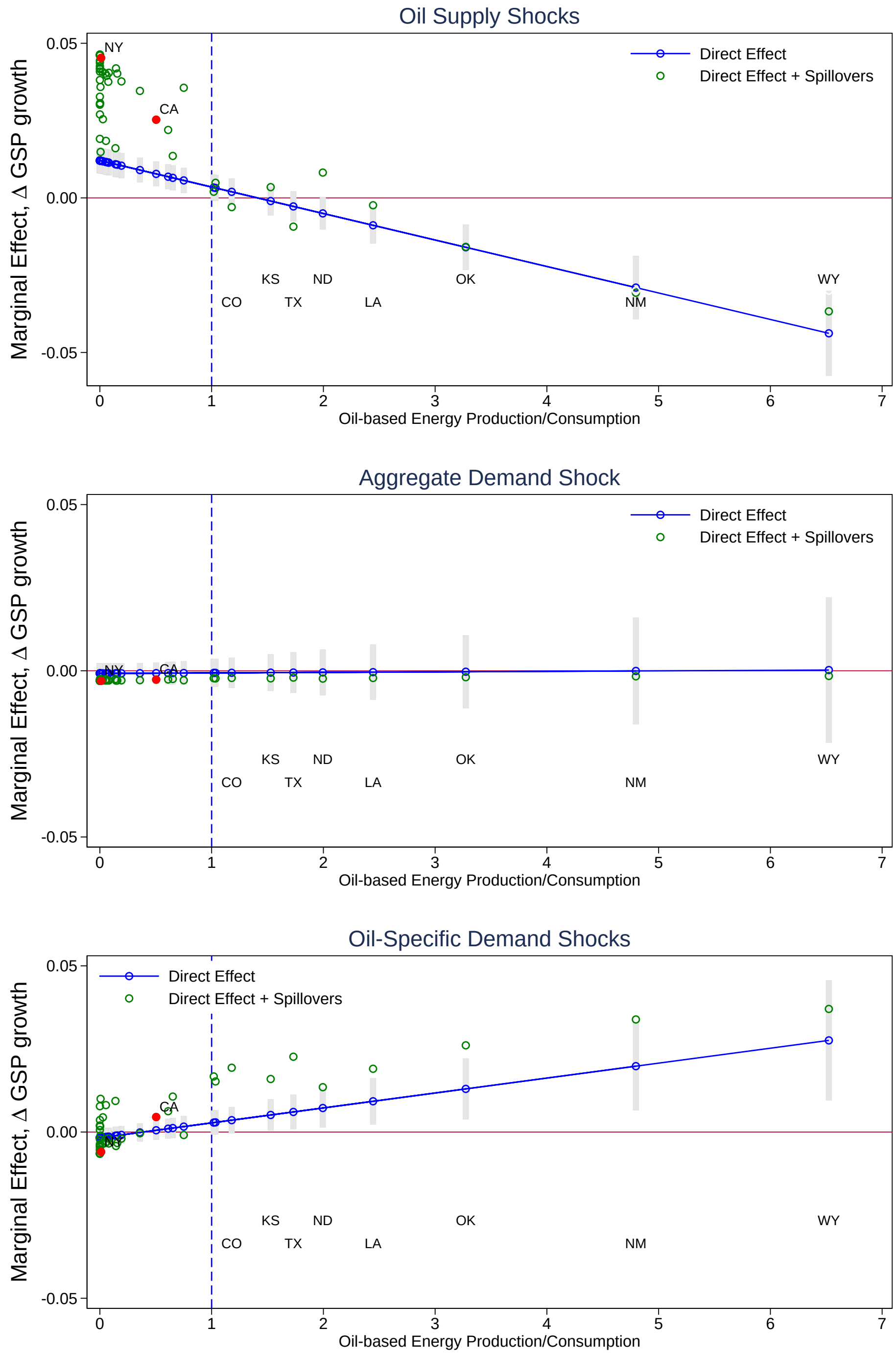
Figure 8 indicates that net producers have higher residual volatility compared to net consumers, particularly around periods of major oil price drops. During the 1986 oil price collapse, for example, growth for net-oil producing states is slower compared to what would have been predicted from the historical relationship between GSP growth and oil price shocks. The larger volatility implies that net producing states are more vulnerable to oil price shocks not only in terms of predictable effects but also in the form of increased uncertainties.

Figure 6: Effect of underlying oil price shocks on state economies in the United States(direct effect only)



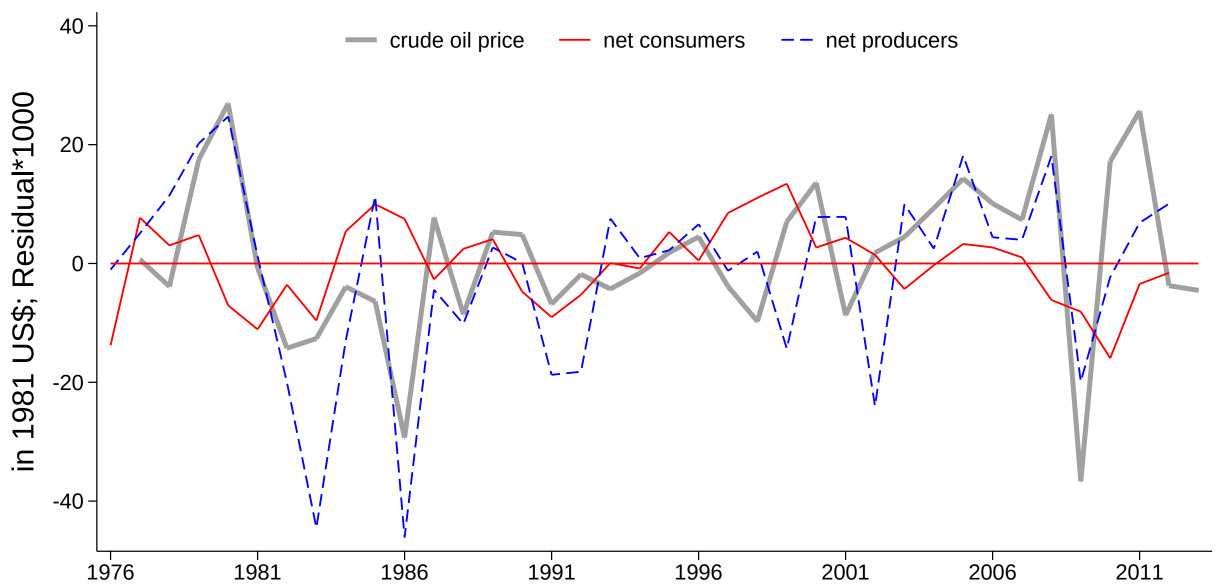
Note: Each graph shows the estimated elasticity of aggregate output with respect to a kind of oil market shock, conditional each states average production/consumption ratio from crude oil and natural gas. States to the right of the vertical dashed blue line are net exporters of oil and natural gas. The error bands indicate 95 percent confidence intervals.

Figure 7: Effect of underlying oil price shocks on state economies in the United States(direct effect and spillovers)



Each figure illustrates the marginal effect of a unit increase in each underlying oil price shock given each state long-run average energy production/consumption from crude oil and petroleum. The vertical spikes represent 95 percent confidence interval. States to the right of the vertical dash blue line are net exporters.

Figure 8: Average residuals from estimating equation 2 for net oil producing and net consuming states, and changes in imported crude oil price.



The solid and dash lines show the residuals from estimating equation 2 for net-producing and net-consuming states, respectively, and changes in the real price of imported crude oil (in 1981 US$). The residuals are multiplied by 1000.

3.2 The Effect of Changing Oil Dependence

Oil imports to the United States peaked in 2005 and began to decline more rapidly during the Great Recession and ensuing production boom connected to growth of hydraulic fracturing ("fracking). We can use parameter estimates from equation 2 to estimate how this change affected state and aggregate sensitivity to different kinds of price shocks.

In estimation, we fixed the production-consumption ratio of each state to its historical average to account for endogeneity. Given parameter estimates, we can extrapolate from the estimated relationship to see how sensitivity to oil price shocks changes with a change in the production-to-consumption ratio. To do this, we feed estimated innovations (the residuals) into the estimated model (equation 7), while augmenting the production-consumption ratio by 2, 1.5, .9, .75, and .5. Results are presented in Tables A.V-A.VII. We also summarize the results for production-consumption ratios with 100% increase and 50% reduction relative to the baseline in Figure A.III.

The results indicate that increasing the oil production-consumption ratio for all oil-producing states increases sensitivity to oil supply shocks and oil-specific demand shocks for both major oil-producing states and their neighbors. For example, at baseline ratios, states with a production-to-consumption ratio between one to two have roughly zero response to exogenous global supply shocks (which reduce oil prices), while states with larger or smaller ratios have negative and positive responses, respectively. If, however, production-consumption ratios are doubled, many more states are negatively affected by supply shocks, including several states with ratios less than 0.5 before the hypothetical doubling. These states (Idaho, South Dakota, Arizona, and Nebraska) are negatively affected due to spillover effects from nearby oil exporting states with larger production-to-consumption ratios (New Mexico, Wyoming, and North Dakota).

In aggregate, a doubling domestic production, which would transform the United States from a modest importer of oil to an international exporter, changes the sensitivity of the country's GDP to oil supply shocks to 0.01 percentage point change per unit shock. This is much lower relative to the sensitivity of 0.03 percentage point change per unit of oil supply shock at the baseline domestic production level. Conversely, a halving of domestic production would make all states, even those that would remain net exporters, positively affected by world oil supply shocks. The positive effect most of the country would help to compensate for the negative effect on the exporting states.

Similar but opposite patterns emerge for oil-specific demand shocks (oil prices increase with positive oil-specific demand shocks and decrease with supply shocks). But aggregate demand shocks have much smaller effect on growth for any state, regardless of the production-to-consumption ratio, or whether the ratio changes uniformly across states. Because oil-specific demand shocks concern speculation about future events that could be positive or negative for aggregate growth, this result is not surprising.

In reality, the fracking boom has increased the production-to-consumption ratios for many states, but the increase has been less uniform or as large as a full doubling. Substituting production-to-consumption ratios into the estimated model, we evaluate how the aggregate short-run responses have changed over time (Table 2 and Figure 9). The aggregate responses to supply shocks and oil-specific demand shocks, which were fairly stable until 2005, diminished by a third by 2015. Today, the aggregate U.S. economy is less susceptible to spikes in world oil prices but oil-exporting states and neighboring states will have countervailing, increased sensitivity.

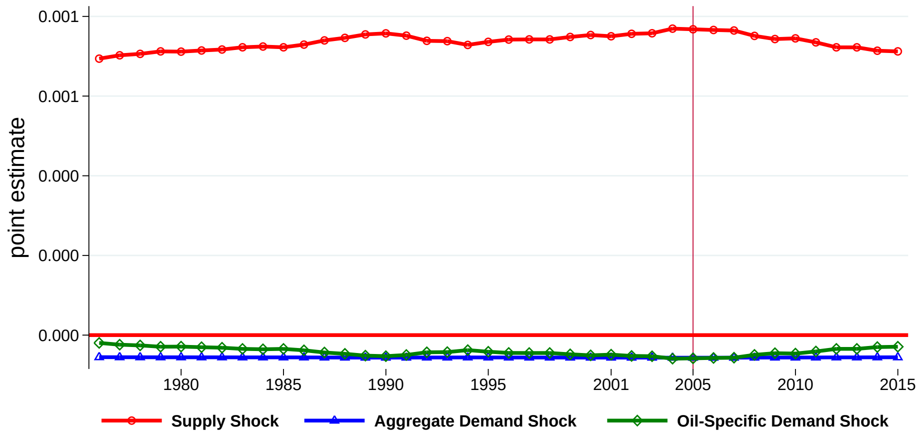
Table 2: Estimates of aggregate short-run sensitivity to different shocks at different point in time, depending on time-varying production-to-consumption ratio.

Year	**Aggregate Prod/Cons**	**Point Estimates**			**US Imports (in '000 Barrels)**
		Supply	**Aggregate Demand**	**Oil-Specific Demand**	
1980	0.4219	0.0307	-0.0028	0.0017	1,926,162
1985	0.4389	0.0293	-0.0027	0.0024	1,168,297
1990	0.3514	0.0315	-0.0028	0.0012	2,151,387
1995	0.3320	0.0315	-0.0028	0.0013	2,638,810
2000	0.3046	0.0322	-0.0028	0.0009	3,319,816
2005	0.3056	0.0315	-0.0028	0.0013	3,695,971
2010	0.3716	0.0282	-0.0027	0.0030	3,362,856
2015	0.5950	0.0190	-0.0026	0.0078	2,687,409

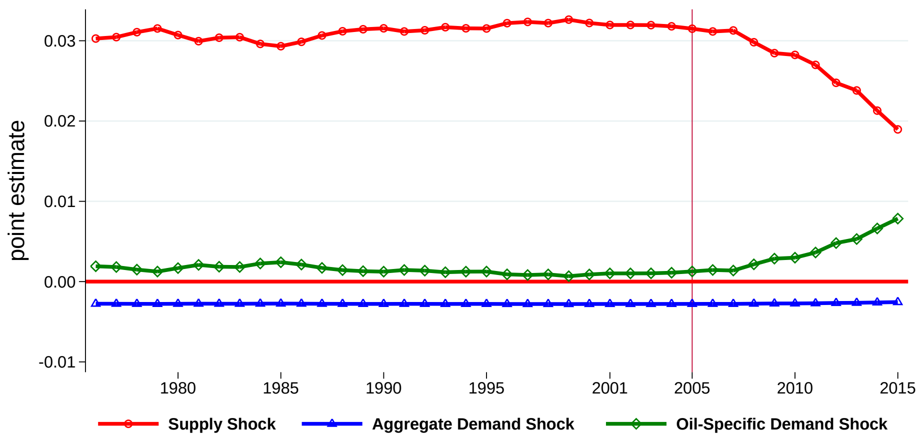
Note: Aggregate production-consumption ratio denotes average production of oil-based energy weighted by the maximum gross state product of each state. The point estimates presented here include the direct effect of each shock and the spillover effects from other states using a contiguity weight matrix.

Figure 9: Effect of a unit change in underlying oil price shocks on state economies in the United Statesunder different actual production-consumption ratios (weighted by max GDP)

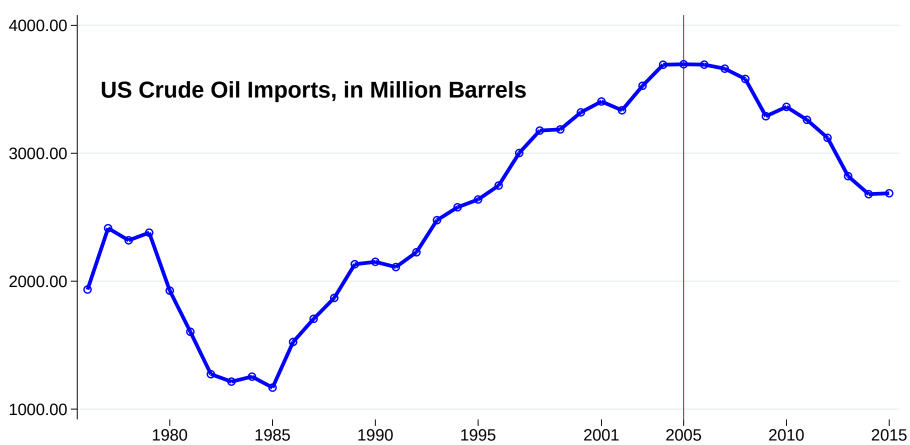
(a) Direct effects only



(b) Direct and spillover effects



(c)U.S.Crude Oil Imports



Source: Authors' calculation,U.S.Energy information Administration.

4 Conclusion

A number of studies consider theoretical and empirical links between oil prices and broader economic activity in the United States and other countries. There has been relatively little research that examines heterogeneous responses of different states or and regions to price, and those that do assume that price shocks are exogenous. We contribute to the literature by also accounting for (1) the endogeneity of oil prices, (2) that differences among states derive from their dependence on oil, and (3) that state economies are connected due to factor mobility, trade, and possibly other mechanisms.

Not all states are alike in oil dependence, and thus, their responses to various demand and supply shocks underlying oil price changes are also not alike. For example, an unanticipated increase in global production of crude oil, which reduces oil price, increases economic growth of net-consuming states while reducing growth of net-producing states in the short run. Aggregate demand shocks, on the other hand, have no direct effect on growth of state-economies, regardless of their oil production-consumption ratios. Net oil producing states have more pronounced cycles of positive and negative economic growth in comparison net oil consuming states, which have more stable growth paths and are more in line with the aggregate U.S.economy. Moreover, we find that the direct effect of oil price shocks may be amplified depending on direction and magnitude of the economic spillovers from neighboring states.

These results lend support to earlier findings on links between the oil market and aggregate economy, for it clarifies that these links are tied to oil dependence. The findings also affirm that the nature of the shocks driving oil price changes (e.g., speculative demand or supply) could matter for monetary policy. Another implication is that even well-crafted monetary policy may not be well targeted to oil-exporting regions in an oil-importing monetary regime, leaving exporting regions more susceptible to business cycle fluctuations. There may be a need for fiscal or other policies that can better account the differences in the response of the states. For example, a sufficient state-level "rainy day fund"— budget reserves for use when unanticipated a negative price shock occurs– could help states that are more vulnerable to oil price shocks, such as Wyoming, New Mexico and North Dakota.

More broadly, results of the study have implications on the effort of major trading blocks to establish an integrated energy market, such as the EU Energy Union and the ASEAN Energy Market Integration. Our results indicate significant spillovers from oil-price shocks that have countervailing effects on exporting versus importing regions. These spillover effects, which are connected to trade and market integration, help to homogenize and diminish regional sensitivity to shocks, and could help make monetary policies that target the aggregate economy better suited to regional economies. These findings therefore support the idea that improved market integration can make regional economies more stable.

References

Andrews, D. W. (1999). Consistent Moment Selection Procedures for Generalized Method of Moments Estimation. *Econometrica*, 67(3):543–563.

Baicker, K. (2005). The Spillover Effects of State Spending. *Journal of public economics*, 89(2):529–544.

Barsky, R. B. and Kilian, L. (2002). Do we really know that oil caused the great stagflation? a monetary alternative. In *NBER Macroeconomics Annual 2001, Volume 16*, pages 137–198. MIT Press.

Barsky, R. B. and Kilian, L. (2004). Oil and the Macroeconomy Since the 1970s. *Journal of Economic Perspectives*, 18(4):115–134.

Bernanke, B. S., Gertler, M., Watson, M., Sims, C. A., and Friedman, B. M. (1997). Systematic Monetary Policy and the Effects of Oil Price Shocks. *Brookings papers on economic activity*, 1997(1):91–157.

Brown, S. P. and Yucel, M. K. (1995). Energy Prices and State Economic Performance. *Economic Review-Federal Reserve Bank of Dallas*, page 13.

Carlino, G. A. and Inman, R. P. (2013). Local Deficits and Local Jobs: Can US States Stabilize Their Own Economies? *Journal of Monetary Economics*, 60(5):517–530.

Davis, S. J. and Haltiwanger, J. (2001). Sectoral Job Creation and Destruction Responses to Oil Price Changes. *Journal of Monetary Economics*, 48(3):465–512.

Engemann, K. M., Owyang, M. T., and Wall, H. J. (2014). Where is an oil shock? *Journal of Regional Science*, 54(2):169–185.

Farell, D. and Greig, F. (2015). How Falling Gas Prices Fuel the Consumer: Evidence from 25 Million People. Technical report, JPMorgan Chase Institute. Accessible at https://www.jpmorganchase.com/corporate/institute/document/jpmc-institute-gas-report.pdf.

Figlio, D. N., Kolpin, V. W., and Reid, W. E. (1999). Do States Play Welfare Games? *Journal of Urban economics*, 46(3):437–454.

Frankel, J. (2008). *The effect of monetary policy on real commodity prices*, chapter 7, pages 291–327. University of Chicago Press.

Frankel, J. (2014). Effects of speculation and interest rates in a "carry trade" model of commodity prices. *Journal of International Money and Finance*, 42:88–112.

Guo, H., Kliesen, K. L., et al. (2005). Oil price volatility and us macroeconomic activity. *Review-Federal Reserve Bank of Saint Louis*, 87(6):669.

Hamilton, J. (2013). Historical Oil Shocks. In Parker, R., , and Whaples, R., editors, *Routledge Handbook of Major Events in Economic History*, pages 239–265. Routledge Taylor and Francis Group, New York.

Hamilton, J. (2016). Why no economic boost from lower oil prices? http://econbrowser.com/archives/2016/04/why-no-economic-boost-from-lower-oil-prices.

Hamilton, J. D. (1983). Oil and the Macroeconomy since World War II. *Journal of Political Economy*, 91(2):228–248.

Hamilton, J. D. and Owyang, M. T. (2012). The Propagation of Regional Recessions. *Review of Economics and Statistics*, 94(4):935–947.

Kilian, L. (2008). Exogenous oil supply shocks: how big are they and how much do they matter for the us economy? *The Review of Economics and Statistics*, 90(2):216–240.

Kilian, L. (2009). Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market. *American Economic Review*, 99(3):1053–69.

Kilian, L. and Murphy, D. P. (2014). The Role of Inventories and Speculative Trading in the Global Market for Crude Oil. *Journal of Applied Econometrics*, 29(3):454–478.

Kilian, L. and Park, C. (2009). The Impact of Oil Price Shocks on the US Stock Market. *International Economic Review*, 50(4):1267–1287.

Lee, K. and Ni, S. (2002). On the Dynamic Effects of Oil Price Shocks: A Study Using Industry Level Data. *Journal of Monetary Economics*, 49(4):823–852.

Lee, L.-f. and Yu, J. (2014). Efficient GMM Estimation of Spatial Dynamic Panel Data Models with Fixed Effects. *Journal of Econometrics*, 180(2):174–197.

LeSage, J. P. (2008). An Introduction to Spatial Econometrics. *Revue d'économie industrielle*, 3(123):19–44.

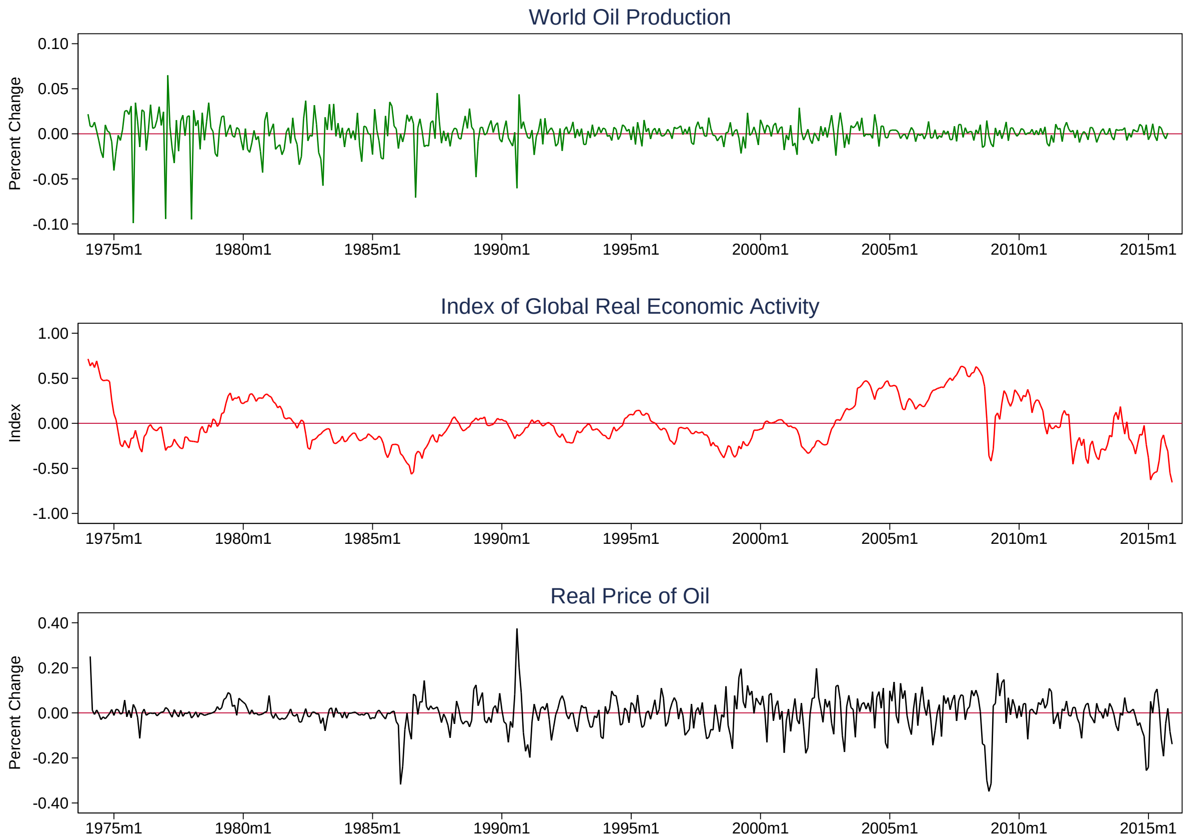
Melichar, M. (2013). Essays on the Macroeconomic Effects of Energy Price Shocks. Unpublished manuscript, Kansas State University, Manhattan, KS.

Penn, D. A. et al. (2006). What do we know about oil prices and state economic performance? *Federal Reserve Bank of St. Louis, Regional Economic Development*, 2(2):131–139.

Rahman, S. and Serletis, A. (2010). The asymmetric effects of oil price and monetary policy shocks: A nonlinear var approach. *Energy Economics*, 32(6):1460–1466.

Appendices

Figure A.I: Evolution of VAR Variables, 1976-2015.



Source: World Oil Production (EIA); Index of Global Real Economic Activity (Kilian, 2009); Real Price of Oil (EIA).

Figure A.II: Evolution of VAR Residuals (Monthly), 1976-2015.

Source: World Oil Production (EIA); Index of Global Real Economic Activity (Kilian, 2009); Real Price of Oil (EIA).

Table A.I: Dependent variable: first difference in log-transformed Gross State Product (Robustness Check)

Variables	SAR (Binary Weights)									
	48 States		No CA		No NY		No TX		No CA,NY,TX	
Oil Supply	0.007**	0.008**	0.012***	0.008**	0.012***	0.008**	0.011***	0.007**	0.012***	0.008**
	(0.0025)	(0.0026)	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)
REA	0.001	0.004	-0.001	0.003	-0.001	0.003	-0.001	0.003	-0.001	0.003
	(0.0014)	(0.0024)	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)
Oil Price	-0.004*	-0.006***	-0.002	-0.004*	-0.002	-0.003*	-0.001	-0.003*	-0.002	-0.003*
	(0.0016)	(0.0016)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)
Oil Supply* Prod/Cons	-0.008***	-0.007***	-0.009***	-0.006***	-0.009***	-0.006***	-0.009***	-0.006***	-0.009***	-0.006***
	(0.0014)	(0.0016)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)
REA*Prod/Cons	-0.001	-0.003	0.000	-0.001	0.000	-0.001	-0.000	-0.002	-0.000	-0.002
	(0.0019)	(0.0025)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)
Oil Price*Prod/Cons	0.006**	0.005***	0.005**	0.003***	0.004**	0.003***	0.004**	0.004***	0.004**	0.004***
	(0.0020)	(0.0011)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Lagged GDP growth	0.148***	0.700***	0.161***	0.656**	0.173***	0.678**	0.176***	0.655**	0.171***	0.630**
	(0.0347)	(0.1112)	(0.037)	(0.200)	(0.037)	(0.217)	(0.037)	(0.202)	(0.038)	(0.197)
Spatial lag (Lambda)	0.786***	0.934***	0.751***	0.908***	0.733***	0.901***	0.752***	0.898***	0.750***	0.889***
	(0.0397)	(0.0634)	(0.040)	(0.074)	(0.042)	(0.080)	(0.042)	(0.078)	(0.042)	(0.078)
Spatial lag (t-1) (Rho)		-1.066***		-0.937*		-0.961*		-0.932*		-0.891*
		(0.2123)		(0.375)		(0.405)		(0.390)		(0.384)
Observations	1,776	1,776	1,776	1,776	1,776	1,776	1,776	1,776	1,665	1,665
Time Period (years)	37	37	37	37	37	37	37	37	37	37
No. of Panels	48	48	47	47	47	47	47	47	45	45
GMM-AIC	-0.093	-9.465	1.039	-5.908	3.306	-4.642	1.934	-5.614	-0.601	-6.372
GMM-BIC	-32.985	-36.875	-31.727	-33.214	-29.460	-31.947	-30.833	-32.919	-33.107	-33.460
Pseudo-Adj. R.sq	0.465	0.464	0.456	0.456	0.452	0.452	0.437	0.437	0.435	0.434
Hansen J-statistic	11.907	0.535	13.039	4.092	15.306	5.358	13.934	4.386	11.399	3.628
p-value of J-statistic	0.064	0.991	0.042	0.536	0.018	0.374	0.030	0.495	0.077	0.604

Oil Supply, Real Economic Activity (REA) and Oil Specific Demand are structural shocks mentioned in the text. Prod/Cons is the state-level long-run ratio of energy (BTUs) produced and consumed from crude oil and petroleum form 1963-2013. The 48 states refer to 48 contiguous states in the US. Regression results are derived using GMM following Lee and Yu (2014). GMM-AIC and GMM-BIC are calculated following Andrews (1999). Clustered standard errors are in parentheses. ***, **, * denote statistical significance at 1, 5 and 10 percent respectively.

Table A.II: Effect of a unit change in *oil supply shock* on eachU.S.state GSP growth, baseline estimates.

Net Importers					Net Exporters				
State	Prod/Cons	Direct	Indirect	Total	State	Prod/Cons	Direct	Indirect	Total
CT	0.000	0.012	0.034	0.046	UT	1.019	0.003	-0.001	0.002
DE	0.000	0.012	0.032	0.044	MT	1.035	0.003	0.002	0.005
GA	0.000	0.012	0.029	0.041	CO	1.180	0.002	-0.005	-0.003
IA	0.000	0.012	0.021	0.033	KS	1.528	-0.001	0.004	0.003
ID	0.000	0.012	0.007	0.019	TX	1.732	-0.003	-0.007	-0.009
MA	0.000	0.012	0.034	0.046	ND	1.995	-0.005	0.013	0.008
ME	0.000	0.012	0.034	0.046	LA	2.445	-0.009	0.006	-0.002
MN	0.000	0.012	0.018	0.030	OK	3.274	-0.016	0.000	-0.016
NC	0.000	0.012	0.030	0.042	NM	4.797	-0.029	-0.002	-0.031
NH	0.000	0.012	0.034	0.046	WY	6.523	-0.044	0.007	-0.037
NJ	0.000	0.012	0.032	0.044					
RI	0.000	0.012	0.034	0.046					
SC	0.000	0.012	0.031	0.043					
VT	0.000	0.012	0.034	0.046					
WI	0.000	0.012	0.026	0.038					
WA	0.000	0.012	0.018	0.030					
MD	0.001	0.012	0.030	0.042					
MO	0.001	0.012	0.015	0.027					
OR	0.002	0.012	0.019	0.031					
TN	0.006	0.012	0.024	0.036					
AZ	0.006	0.012	0.003	0.015					
NY	0.011	0.012	0.033	0.045					
IN	0.024	0.012	0.029	0.041					
NV	0.027	0.012	0.014	0.025					
VA	0.049	0.012	0.029	0.040					
SD	0.054	0.012	0.007	0.018					
FL	0.062	0.012	0.028	0.040					
IL	0.075	0.011	0.026	0.038					
OH	0.080	0.011	0.029	0.040					
NE	0.139	0.011	0.005	0.016					
PA	0.144	0.011	0.031	0.042					
MI	0.156	0.011	0.029	0.040					
KY	0.193	0.010	0.027	0.038					
AL	0.358	0.009	0.026	0.035					
CA	0.504	0.008	0.018	0.025					
MS	0.611	0.007	0.015	0.022					
AR	0.652	0.006	0.007	0.014					
WV	0.751	0.006	0.030	0.036					

Note: Prod/Cons is the state-level long-run ratio of energy (BTUs) produced and consumed from crude oil and petroleum form 1963-2013. The 48 states refer to 48 contiguous states in the US. Regression results are derived using GMM following Lee and Yu (2014).

Table A.III: Effect of a unit change in *aggregate demand shock* on eachU.S.state GSP growth, baseline estimates.

Net Importers					Net Exporters				
State	Prod/Cons	Direct	Indirect	Total	State	Prod/Cons	Direct	Indirect	Total
CT	0.000	-0.001	-0.002	-0.003	UT	1.019	-0.001	-0.002	-0.002
DE	0.000	-0.001	-0.002	-0.003	MT	1.035	-0.001	-0.002	-0.002
GA	0.000	-0.001	-0.002	-0.003	CO	1.180	-0.001	-0.002	-0.002
IA	0.000	-0.001	-0.002	-0.003	KS	1.528	-0.001	-0.002	-0.002
ID	0.000	-0.001	-0.002	-0.003	TX	1.732	-0.001	-0.002	-0.002
MA	0.000	-0.001	-0.002	-0.003	ND	1.995	0.000	-0.002	-0.002
ME	0.000	-0.001	-0.002	-0.003	LA	2.445	0.000	-0.002	-0.002
MN	0.000	-0.001	-0.002	-0.003	OK	3.274	0.000	-0.002	-0.002
NC	0.000	-0.001	-0.002	-0.003	NM	4.797	0.000	-0.002	-0.002
NH	0.000	-0.001	-0.002	-0.003	WY	6.523	0.000	-0.002	-0.002
NJ	0.000	-0.001	-0.002	-0.003					
RI	0.000	-0.001	-0.002	-0.003					
SC	0.000	-0.001	-0.002	-0.003					
VT	0.000	-0.001	-0.002	-0.003					
WI	0.000	-0.001	-0.002	-0.003					
WA	0.000	-0.001	-0.002	-0.003					
MD	0.001	-0.001	-0.002	-0.003					
MO	0.001	-0.001	-0.002	-0.003					
OR	0.002	-0.001	-0.002	-0.003					
TN	0.006	-0.001	-0.002	-0.003					
AZ	0.006	-0.001	-0.002	-0.002					
NY	0.011	-0.001	-0.002	-0.003					
IN	0.024	-0.001	-0.002	-0.003					
NV	0.027	-0.001	-0.002	-0.003					
VA	0.049	-0.001	-0.002	-0.003					
SD	0.054	-0.001	-0.002	-0.003					
FL	0.062	-0.001	-0.002	-0.003					
IL	0.075	-0.001	-0.002	-0.003					
OH	0.080	-0.001	-0.002	-0.003					
NE	0.139	-0.001	-0.002	-0.003					
PA	0.144	-0.001	-0.002	-0.003					
MI	0.156	-0.001	-0.002	-0.003					
KY	0.193	-0.001	-0.002	-0.003					
AL	0.358	-0.001	-0.002	-0.003					
CA	0.504	-0.001	-0.002	-0.003					
MS	0.611	-0.001	-0.002	-0.003					
AR	0.652	-0.001	-0.002	-0.002					
WV	0.751	-0.001	-0.002	-0.003					

Note: Prod/Cons is the state-level long-run ratio of energy (BTUs) produced and consumed from crude oil and petroleum form 1963-2013. The 48 states refer to 48 contiguous states in the US. Regression results are derived using GMM following Lee and Yu (2014).

Table A.IV: Effect of a unit change in *oil-specific demand shock* on eachU.S.state GSP growth, baseline estimates.

Net Importers					Net Exporters				
State	Prod/Cons	Direct	Indirect	Total	State	Prod/Cons	Direct	Indirect	Total
CT	0.000	-0.001	-0.002	-0.003	UT	1.019	-0.001	-0.002	-0.002
DE	0.000	-0.001	-0.002	-0.003	MT	1.035	-0.001	-0.002	-0.002
GA	0.000	-0.001	-0.002	-0.003	CO	1.180	-0.001	-0.002	-0.002
IA	0.000	-0.001	-0.002	-0.003	KS	1.528	-0.001	-0.002	-0.002
ID	0.000	-0.001	-0.002	-0.003	TX	1.732	-0.001	-0.002	-0.002
MA	0.000	-0.001	-0.002	-0.003	ND	1.995	0.000	-0.002	-0.002
ME	0.000	-0.001	-0.002	-0.003	LA	2.445	0.000	-0.002	-0.002
MN	0.000	-0.001	-0.002	-0.003	OK	3.274	0.000	-0.002	-0.002
NC	0.000	-0.001	-0.002	-0.003	NM	4.797	0.000	-0.002	-0.002
NH	0.000	-0.001	-0.002	-0.003	WY	6.523	0.000	-0.002	-0.002
NJ	0.000	-0.001	-0.002	-0.003					
RI	0.000	-0.001	-0.002	-0.003					
SC	0.000	-0.001	-0.002	-0.003					
VT	0.000	-0.001	-0.002	-0.003					
WI	0.000	-0.001	-0.002	-0.003					
WA	0.000	-0.001	-0.002	-0.003					
MD	0.001	-0.001	-0.002	-0.003					
MO	0.001	-0.001	-0.002	-0.003					
OR	0.002	-0.001	-0.002	-0.003					
TN	0.006	-0.001	-0.002	-0.003					
AZ	0.006	-0.001	-0.002	-0.002					
NY	0.011	-0.001	-0.002	-0.003					
IN	0.024	-0.001	-0.002	-0.003					
NV	0.027	-0.001	-0.002	-0.003					
VA	0.049	-0.001	-0.002	-0.003					
SD	0.054	-0.001	-0.002	-0.003					
FL	0.062	-0.001	-0.002	-0.003					
IL	0.075	-0.001	-0.002	-0.003					
OH	0.080	-0.001	-0.002	-0.003					
NE	0.139	-0.001	-0.002	-0.003					
PA	0.144	-0.001	-0.002	-0.003					
MI	0.156	-0.001	-0.002	-0.003					
KY	0.193	-0.001	-0.002	-0.003					
AL	0.358	-0.001	-0.002	-0.003					
CA	0.504	-0.001	-0.002	-0.003					
MS	0.611	-0.001	-0.002	-0.003					
AR	0.652	-0.001	-0.002	-0.002					
WV	0.751	-0.001	-0.002	-0.003					

Note: Prod/Cons is the state-level long-run ratio of energy (BTUs) produced and consumed from crude oil and petroleum form 1963-2013. The 48 states refer to 48 contiguous states in the US. Regression results are derived using GMM following Lee and Yu (2014).

Table A.V: Effect of a unit change in *oil supply shock* on eachU.S.state GSP growth under different production-consumption ratios.

State	Assumed Production - Consumption Ratio						State	Assumed Production - Consumption Ratio					
	Baseline	x 2.00	x 1.50	x 0.90	x 0.75	x 0.50		Baseline	x 2.00	x 1.50	x 0.90	x 0.75	x 0.50
AL	0.035	0.023	0.029	0.036	0.038	0.041	NC	0.042	0.037	0.039	0.042	0.043	0.044
AR	0.014	-0.019	-0.003	0.017	0.022	0.030	ND	0.008	-0.030	-0.011	0.012	0.018	0.027
AZ	0.015	-0.017	-0.001	0.018	0.023	0.031	NE	0.016	-0.014	0.001	0.019	0.024	0.031
CA	0.025	0.004	0.015	0.027	0.031	0.036	NH	0.046	0.046	0.046	0.046	0.046	0.046
CO	-0.003	-0.053	-0.028	0.002	0.009	0.022	NJ	0.044	0.042	0.043	0.045	0.045	0.046
CT	0.046	0.046	0.046	0.046	0.046	0.046	NM	-0.031	-0.108	-0.069	-0.023	-0.011	0.008
DE	0.044	0.041	0.042	0.044	0.044	0.045	NV	0.025	0.004	0.015	0.028	0.031	0.036
FL	0.040	0.032	0.036	0.040	0.041	0.043	NY	0.045	0.044	0.045	0.045	0.046	0.046
GA	0.041	0.035	0.038	0.041	0.042	0.044	OH	0.040	0.034	0.037	0.041	0.042	0.044
IA	0.033	0.019	0.026	0.034	0.036	0.040	OK	-0.016	-0.078	-0.047	-0.010	0.000	0.015
ID	0.019	-0.008	0.005	0.022	0.026	0.033	OR	0.031	0.015	0.023	0.032	0.035	0.039
IL	0.038	0.028	0.033	0.038	0.040	0.042	PA	0.042	0.037	0.040	0.042	0.043	0.044
IN	0.041	0.035	0.038	0.041	0.042	0.044	RI	0.046	0.046	0.046	0.046	0.046	0.046
KS	0.003	-0.040	-0.018	0.008	0.014	0.025	SC	0.043	0.039	0.041	0.043	0.044	0.045
KY	0.038	0.029	0.033	0.039	0.040	0.042	SD	0.018	-0.010	0.004	0.021	0.025	0.033
LA	-0.002	-0.051	-0.027	0.003	0.010	0.022	TN	0.036	0.025	0.031	0.037	0.039	0.041
MA	0.046	0.046	0.046	0.046	0.046	0.046	TX	-0.009	-0.065	-0.037	-0.004	0.005	0.019
MD	0.042	0.037	0.040	0.042	0.043	0.044	UT	0.002	-0.043	-0.020	0.006	0.013	0.024
ME	0.046	0.046	0.046	0.046	0.046	0.046	VA	0.040	0.034	0.037	0.041	0.042	0.043
MI	0.040	0.034	0.037	0.041	0.042	0.043	VT	0.046	0.046	0.046	0.046	0.046	0.046
MN	0.030	0.014	0.022	0.032	0.034	0.038	WA	0.030	0.014	0.022	0.032	0.035	0.039
MO	0.027	0.007	0.017	0.029	0.032	0.037	WI	0.038	0.030	0.034	0.039	0.040	0.042
MS	0.022	-0.003	0.010	0.024	0.028	0.034	WV	0.036	0.025	0.030	0.037	0.038	0.041
MT	0.005	-0.037	-0.016	0.009	0.015	0.026	WY	-0.037	-0.120	-0.078	-0.028	-0.016	0.005

Note: Production-consumption ratios are the *actual* state-level ratio of energy (BTUs) produced and consumed from crude oil and petroleum. The 48 states refer to 48 contiguous states in the US. Regression results are derived using GMM following Lee and Yu (2014).

Table A.VI: Effect of a unit change in *aggregate demand shock* on eachU.S.state GSP growth under different production-consumption ratios.

State	Assumed Production - Consumption Ratio						State	Assumed Production - Consumption Ratio					
	Baseline	x 2.00	x 1.50	x 0.90	x 0.75	x 0.50		Baseline	x 2.00	x 1.50	x 0.90	x 0.75	x 0.50
AL	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	NC	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
AR	-0.002	-0.002	-0.002	-0.003	-0.003	-0.003	ND	-0.002	-0.002	-0.002	-0.002	-0.003	-0.003
AZ	-0.002	-0.002	-0.002	-0.003	-0.003	-0.003	NE	-0.003	-0.002	-0.002	-0.003	-0.003	-0.003
CA	-0.003	-0.002	-0.002	-0.003	-0.003	-0.003	NH	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
CO	-0.002	-0.001	-0.002	-0.002	-0.002	-0.003	NJ	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
CT	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	NM	-0.002	0.000	-0.001	-0.002	-0.002	-0.002
DE	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	NV	-0.003	-0.002	-0.002	-0.003	-0.003	-0.003
FL	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	NY	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
GA	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	OH	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
IA	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	OK	-0.002	-0.001	-0.001	-0.002	-0.002	-0.002
ID	-0.003	-0.002	-0.002	-0.003	-0.003	-0.003	OR	-0.003	-0.002	-0.003	-0.003	-0.003	-0.003
IL	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	PA	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
IN	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	RI	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
KS	-0.002	-0.002	-0.002	-0.002	-0.002	-0.003	SC	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
KY	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	SD	-0.003	-0.002	-0.002	-0.003	-0.003	-0.003
LA	-0.002	-0.001	-0.002	-0.002	-0.002	-0.003	TN	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
MA	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	TX	-0.002	-0.001	-0.002	-0.002	-0.002	-0.003
MD	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	UT	-0.002	-0.001	-0.002	-0.002	-0.002	-0.003
ME	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	VA	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
MI	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	VT	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
MN	-0.003	-0.002	-0.003	-0.003	-0.003	-0.003	WA	-0.003	-0.002	-0.003	-0.003	-0.003	-0.003
MO	-0.003	-0.002	-0.003	-0.003	-0.003	-0.003	WI	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
MS	-0.003	-0.002	-0.002	-0.003	-0.003	-0.003	WV	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
MT	-0.002	-0.002	-0.002	-0.002	-0.002	-0.003	WY	-0.002	0.000	-0.001	-0.002	-0.002	-0.002

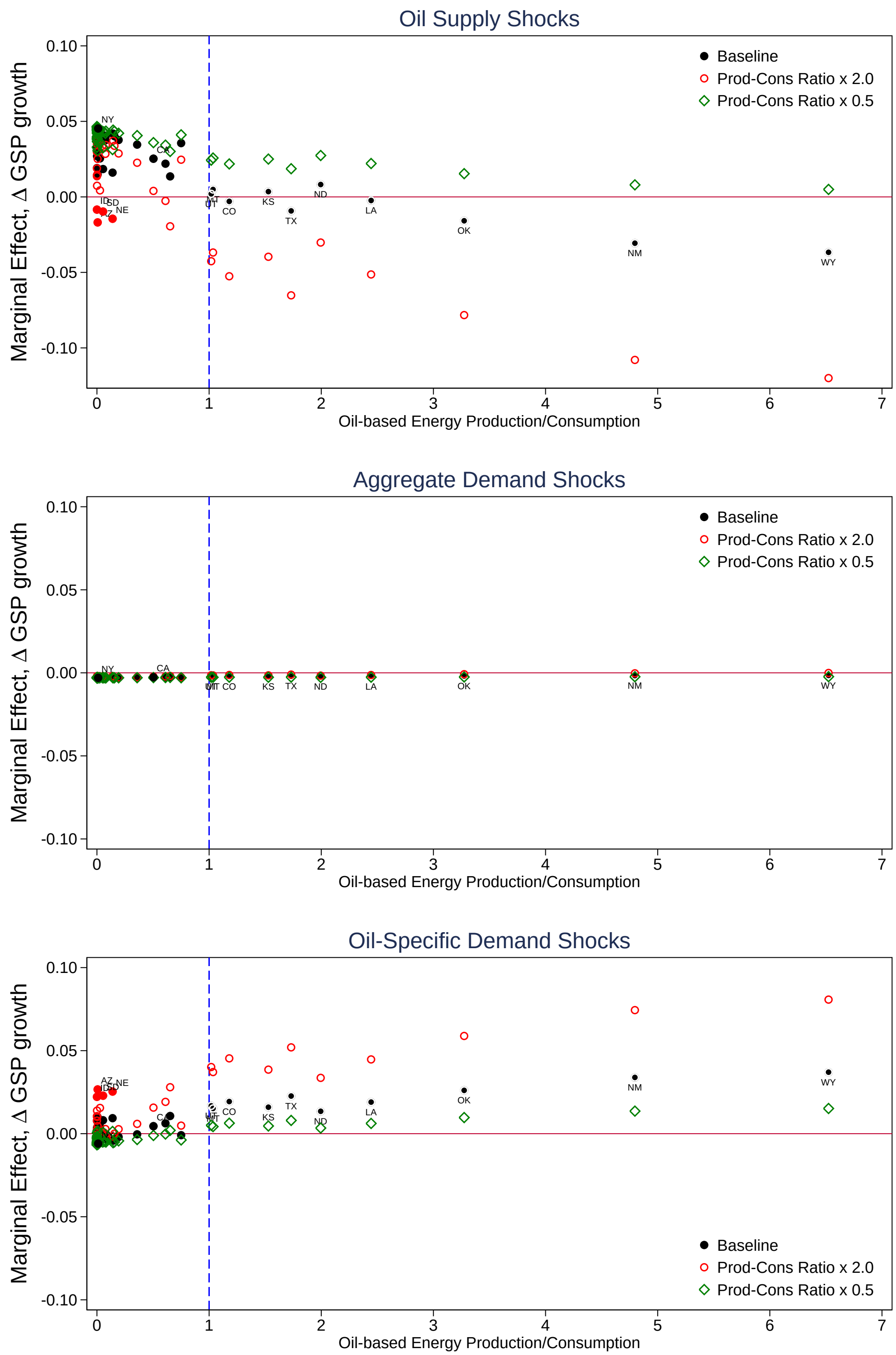
Note: Production-consumption ratios are the *actual* state-level ratio of energy (BTUs) produced and consumed from crude oil and petroleum. The 48 states refer to 48 contiguous states in the US. Regression results are derived using GMM following Lee and Yu (2014).

Table A.VII: Effect of a unit change in *oil-specific demand shock* on eachU.S.state GSP growth under different production-consumption ratios.

State	Assumed Production - Consumption Ratio						State	Assumed Production - Consumption Ratio					
	Baseline	x 2.00	x 1.50	x 0.90	x 0.75	x 0.50		Baseline	x 2.00	x 1.50	x 0.90	x 0.75	x 0.50
AL	0.000	0.006	0.003	-0.001	-0.002	-0.004	NC	-0.004	-0.001	-0.003	-0.004	-0.005	-0.005
AR	0.011	0.028	0.019	0.009	0.006	0.002	ND	0.013	0.034	0.024	0.011	0.008	0.003
AZ	0.010	0.027	0.018	0.008	0.006	0.002	NE	0.009	0.025	0.017	0.008	0.005	0.001
CA	0.005	0.016	0.010	0.003	0.002	-0.001	NH	-0.007	-0.006	-0.006	-0.007	-0.007	-0.007
CO	0.019	0.045	0.032	0.017	0.013	0.006	NJ	-0.006	-0.004	-0.005	-0.006	-0.006	-0.006
CT	-0.006	-0.006	-0.006	-0.006	-0.006	-0.007	NM	0.034	0.074	0.054	0.030	0.024	0.014
DE	-0.005	-0.004	-0.004	-0.005	-0.006	-0.006	NV	0.004	0.016	0.010	0.003	0.002	-0.001
FL	-0.003	0.001	-0.001	-0.003	-0.004	-0.005	NY	-0.006	-0.005	-0.006	-0.006	-0.006	-0.006
GA	-0.004	-0.001	-0.002	-0.004	-0.004	-0.005	OH	-0.003	0.000	-0.002	-0.004	-0.004	-0.005
IA	0.001	0.008	0.004	0.000	-0.001	-0.003	OK	0.026	0.059	0.042	0.023	0.018	0.010
ID	0.008	0.022	0.015	0.006	0.004	0.001	OR	0.002	0.010	0.006	0.001	0.000	-0.002
IL	-0.002	0.003	0.000	-0.002	-0.003	-0.004	PA	-0.004	-0.002	-0.003	-0.004	-0.005	-0.005
IN	-0.004	-0.001	-0.002	-0.004	-0.004	-0.005	RI	-0.006	-0.006	-0.006	-0.006	-0.007	-0.007
KS	0.016	0.039	0.027	0.014	0.010	0.005	SC	-0.005	-0.002	-0.004	-0.005	-0.005	-0.006
KY	-0.002	0.003	0.000	-0.002	-0.003	-0.004	SD	0.008	0.023	0.016	0.007	0.004	0.001
LA	0.019	0.045	0.032	0.016	0.013	0.006	TN	-0.001	0.005	0.002	-0.002	-0.002	-0.004
MA	-0.006	-0.006	-0.006	-0.006	-0.006	-0.007	TX	0.023	0.052	0.037	0.020	0.015	0.008
MD	-0.004	-0.002	-0.003	-0.004	-0.005	-0.005	UT	0.017	0.040	0.028	0.014	0.011	0.005
ME	-0.007	-0.006	-0.006	-0.007	-0.007	-0.007	VA	-0.003	0.000	-0.002	-0.004	-0.004	-0.005
MI	-0.003	0.000	-0.002	-0.004	-0.004	-0.005	VT	-0.006	-0.006	-0.006	-0.006	-0.006	-0.007
MN	0.002	0.011	0.006	0.001	0.000	-0.002	WA	0.002	0.010	0.006	0.001	0.000	-0.002
MO	0.004	0.014	0.009	0.003	0.001	-0.002	WI	-0.002	0.002	0.000	-0.003	-0.003	-0.004
MS	0.006	0.019	0.013	0.005	0.003	0.000	WV	-0.001	0.005	0.002	-0.001	-0.002	-0.004
MT	0.015	0.037	0.026	0.013	0.010	0.004	WY	0.037	0.081	0.059	0.033	0.026	0.015

Note: Production-consumption ratios are the *actual* state-level ratio of energy (BTUs) produced and consumed from crude oil and petroleum. The 48 states refer to 48 contiguous states in the US. Regression results are derived using GMM following Lee and Yu (2014).

Figure A.III: Aggregate short-run growth effects stemming from different kinds of shocks in each year, depending on realized production-consumption ratios



Each figure illustrates the marginal effect of a unit increase in each underlying oil price shock given each state long-run average energy production/consumption from crude oil and petroleum. The vertical spikes represent 95 percent confidence interval. States to the right of the vertical dash blue line are net exporters.