Oil shocks and regional heterogeneity: The case of Japan

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Abstract

This paper addresses the question of how the effects of oil shocks on different economies are affected by their heterogeneity. We take up the Japanese regional economies as a case study and use a structural VAR model and a panel VAR model as the analytical framework. We find that the effects of oil price shocks on the Japanese regional economies are closely related to various natural and socio-economic characteristics of those regions. More specifically, in the presence of a surge in the oil price caused by an oil demand shock originated from the global real economic activity or an oil market specific demand shock, output is more negatively affected and the price level rises more in a region with colder winter, or with lower population density, or with a higher share of petroleum and coal products in total value added. In addition, the effects of oil price shocks also depend on the share of transport equipment industry, one of the key industries of Japan: The more a region is specializing in this industry the more its output and the less its price level respond to oil demand shocks.

Keywords: oil price fluctuations, Japanese regional economies, panel VAR.
JEL codes: F41, Q43, R11.

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1. Introduction

This paper studies the effects of world-market oil price fluctuations on the regional economies of Japan and analyzes how these effects are related to various types of heterogeneity across these regions.

Since 2000, the sharp rise in the world-market oil price has triggered a large number of empirical studies aiming to analyze effects of oil price shocks on the macroeconomy. Some of these studies look at the differences in the effects of oil price shocks across countries (see, e.g., Peersman and Robays (2009) and Vu and Nakata (2018)), or across regions within the same country (see our previous study Vu and Nakata (2016)).

On the other hand, very few papers investigate the factors behind these differences in the effects of oil price shocks across countries or across regions. Peersman and Robay (2009) examine the relationship between the impacts of oil price on wages, or GDP deflator and strictness of employment legislation in Euro area countries. Vu and Nakata (2018) find a negative relationship between the contributions of oil price shocks to the variances of CPI and IIP and the oil production/consumption ratio in ASEAN countries. Using regional data of Japan, Vu and Nakata (2016) analyze the relationship between the effects of oil price on CPI, IIP and the climate condition and industrial structure in these regions. However, a shortcoming of these studies is that they cannot carry out formal statistical tests due to the lack of enough observations in the sample used, and as a result, they have to rely on investigation using correlation coefficient or scatter diagram.

The present paper aims to overcome this problem by using a Japanese prefectural-level panel data set. Our data set consists of data on 47 prefectures of Japan and spans a period of over more than 30 years. We analyze the effects of oil price fluctuations on regional economies in Japan, and examine how these regional effects are related to various indicators on regional heterogeneity.

It is worth noting that Japan is suitable for an analysis of the regional differences in the effects of oil price shocks because regions in Japan are quite diverse in several dimensions. For example, the Japanese archipelago stretches over 3000 kilometers from northeast to southwest, possessing a large difference in climate and geographical conditions between regions. In addition, there is also considerable regional heterogeneity in economic structure. It is also worth noting that, for many indicators on the regional heterogeneity in Japan, the data are available to us. Therefore, using prefectural-level data of Japan with such features, our approach can analyze the regional heterogeneity in the effects of oil price shocks in much more detail and in a more rigorous way.

We employ a panel vector autoregressive (VAR) model which includes three types of oil shocks as exogenous variables, and economic variables such as the price level (CPI) and output (IIP) of each prefecture as endogenous variables. The oil shocks here are identified using the framework of Kilian (2009) before being used in the panel VAR. The use of a panel VAR model enables us to have a much larger sample size, and thus increase the precision of the estimation. In investigating the factors affecting the dynamic responses of economic variables in each prefecture to oil price shocks, we focus on climate condition such as regional winter temperature, geographical condition such as population density, and each region's specialization coefficient in transportation equipment industry, an industry which is especially important to Japanese economy, and in petroleum and coal products industry, which uses crude oil as an input in production. By introducing the interaction terms between oil price shocks and these factors, we can verify the relationship between regional factors and the effects of oil price shocks.

The rest of the paper is structured as follows. The next two sections explain the empirical methodology and data used in the study. Section 4 provides the results and analysis. The last section concludes the paper.

2. Empirical methodology

Our study adopts a two-step approach to analyze the relationship between the effects of oil price on CPI, IIP and the regional characteristics. At the first stage, we identify oil shocks via a structural VAR. At the second stage, we use a panel VAR to estimate the effects of structural shocks on regional CPI, IIP and the regional characteristics. Below we will describe each of these VARs in details.

The VAR system in the first stage includes three variables, namely, oil production, global economic activity, and oil price. Regarding the identification scheme, we employ the contemporaneous zero restrictions of a recursive VAR following Kilian (2009). The contemporaneous zero restrictions imply the following Cholesky decomposition of the covariance matrix of the residuals of the reduced-form VAR.

$$u_t = \begin{bmatrix} u_{prod,t} \\ u_{real,t} \\ u_{poil,t} \end{bmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} \varepsilon_{oilsup,t} \\ \varepsilon_{aggdem,t} \\ \varepsilon_{ospec,t} \end{bmatrix} \tag{1}$$

This scheme has the following implications about the relationship between variables: (i) Current oil production is not affected by global economic activity and oil price in the same month; (ii) current global economic activity is affected by oil production, but not by oil price in the same month; and (iii) oil price is affected by oil production and global economic activity in the same month. With this scheme, we can decompose oil price fluctuations into three types of structural components, namely, oil supply shock, oil demand shock, and oil market specific demand shock.

The panel VAR in the second stage is represented by a system of linear equations as follows:

$$Y_{it} = Y_{it-1}A_1 + Y_{it-2}A_3 + \cdots + Y_{it-p+1}A_{p-1} + X_{it}B_1 + \cdots + X_{it-q}B_q + \eta_i + e_{it} \tag{2}$$

$$\text{for } i \in \{1,2,\cdots N\}, t \in \{1,2,\cdots,T_i\}$$

where Y_{it} is a $1 \times k$ vector of endogenous variables, X_{it} is a $1 \times l$ vector of exogenous variables, η_i and e_{it} are $1 \times k$ vectors of fixed effects and idiosyncratic errors, respectively, and p, q are the lag lengths of Y_{it} and X_{it}. About the idiosyncratic errors, we assume that $\mathrm{E}[e_{it}] = 0, E\left[e_{it}^{'}e_{it}\right] = \Sigma$, $E\left[e_{it}^{'}e_{it}\right] = 0 \ for \ all \ t > s.$

In the panel VAR in (2), endogenous variables include the two variables: Index of Industrial Production (IIP) and Consumer Price Index (CPI). Exogenous variables include the three types of shocks (oil supply shock, aggregate demand shock, and oil price specific shock) estimated in (1), the interaction terms of the structural shocks and the four variables representing the characteristics of each region, namely, the share of transportation equipment industry in total value added, the share of petroleum and coal products industry in total value added, the average temperature during winter season, and population density. Thus, there are twelve interaction terms in total. In our panel VAR analysis, the coefficients of these interaction terms are our main interest since these coefficients capture the relationship between the regional characteristics and the effects of oil price on CPI and IIP. We can judge the significance of these relationships based on the z-value results obtained for the coefficients of interaction terms. In this regard, we believe that our approach is superior to the approach used by previous studies in the literature which is merely splitting the sample into sub-samples.

Our estimation strategy is as follows. In order to remove the fixed effects, we adopt forward orthogonal deviation (FOD) transformation. With FOD transformation, deviations from the average of all available future observations are subtracted from each variable. We then estimate the transformed the panel VAR model with System GMM estimation as proposed by Arellano and Bover (1995). This method enables us to improve efficiency in estimation.

About the lag length in the panel VAR, we set p=12 taking into the fact that the data we use are monthly. We set a lag length of three month for the exogenous variables.

To avoid estimating too many parameters, we do not include all variables on the regional characteristics at once, but instead, we include each of them one by one in the estimation of the panel VAR. Thus, there are a total of twelve regression equations being estimated.

3. Data

In this study, we use monthly data of the period 1976:1-2016:12, except for the regional characteristic variables for which we use annual, or sample period average data in same period. For the oil production, we obtain world oil production data from website of U.S. Energy Information Administration (EIA). As for a measure of global real economic activity, we use the index constructed by Lutz Kilian which we downloaded from his website. Oil price data is also taken from EIA website, and is the crude oil acquisition cost by refiner in the US (dollars per barrel).

For the panel VAR analysis, we use prefectural level data in Japan with 47 prefectures in total. Data of index of industrial production (IIP), and consumer price index (CPI) are taken from Nikkei-NEEDS-CDCIs database. Annual data of the share of transportation equipment industry in value added, and share of petroleum and coal products industry in value added are from census of manufactures. As for temperature of winter, we use the 1980-2011 average temperature data in prefectural capitals during winter season (from December to February) which is downloaded from website of Japan Meteorological Agency. Annual data of population density are calculated from total population and total area (km^2), among which the former data is taken from website of Ministry of Internal Affairs and Communications.

4. Estimation results and analysis

This section provides the estimation results obtained using the panel VAR. Here, to save space, we report only results about exogenous variables, i.e., oil shocks and regional characteristics. These results are shown in Tables 1-4.

We start by looking at the coefficients of structural shocks. In the case of the oil supply shock (SY_t), a positive shock increases IIP and decreases CPI significantly. These signs are consistent with conventional economic theory because oil is used as an input in production and here the positive oil supply shock raises the supply of oil reducing its price. In the case of the oil demand shock (DE_t), a positive shock also increases IIP and CPI significantly and this result is also consistent with theory. As for the oil market specific demand shock (OIL_t), a positive shock increases IIP and CPI significantly. Conventional economic theory predicts that (positive) oil market specific demand shocks increase CPI, meanwhile the effects of these shocks on IIP depend on economic structure. Our results here are consistent with previous studies, e.g., Vu and Nakata (2018), Iwaisako and Nakata (2017), Fukunaga, Hirakata and Sugo (2009). One interpretation of these results is that oil market specific demand shocks are news shocks reflecting changes in the expectations about the future growth of the world economy. On the other hand, Vu and Nakata (2018) propose an alternative interpretation which is that oil market specific demand shocks are demand shocks that occur at first in the oil industry or a small number of related industries, and then over time spread to other industries.

Next, we look at the coefficients of the interaction terms. These coefficients are the main interest of our study because the show how the regional heterogeneity in various characteristics affects the differences in the effects of oil price shocks across regions.

Table 1 shows the results for the share of transport equipment industry ($ShareTrans_t$). In Panel A of this table, which displays the effects on IIP, we can see that the coefficients of the interaction terms of DE_t and $ShareTrans_t$ take on significantly positive values at the lag lengths of one, two, and three, while the coefficients of the interaction terms of OIL_t and $ShareTrans_t$ take on significantly positive values at two and three lags. These results imply that, other things equal, the more a region is specializing in the transport equipment industry, the more its output will increase in response to a shock that raises global real economic activity and thus the demand for oil in the world market.

In Panel B of Table 1, which displays the effects on CPI, we observe that the coefficient of the interaction terms of DE_t and $ShareTrans_t$ is significantly negative at one lag, implying that, ceteris paribus, the more a region is specializing in the transport equipment industry, the less its price level is affected by oil demand shocks. Regarding this result, our interpretation is that $ShareTrans_t$ is highly positively correlated with the development of industry in a region, so the higher is $ShareTrans_t$ in a region, the more goods (including consumption goods) the region can produce, the less it is dependent on goods produced from other regions, and thus the smaller transportation costs it needs to bear in importing goods from other regions, and therefore the less its CPI are affected by oil shocks.

Table 2 shows the results for the share of petroleum and coal products in total value added ($SharePetroCoal_t$). In panel A of this table, the coefficients of the interaction terms of OIL_t and $SharePetroCoal_t$ at one and three lags are negative, implying that in a region with a higher share of petroleum and coal products in total value added, output will be more negatively affected by an oil price surge caused by an oil market specific demand shock. This result is easy to understand because crude oil is an input in the production of petroleum and coal products.

In Panel B of Table 2, which shows the effects on CPI, the coefficient of the interaction terms of SY_t and $SharePetroCoal_t$ is significantly negative at one lag, and the coefficients of the interaction terms of DE_t and $SharePetroCoal_t$ take on significant negative values contemporaneously and at two lags. This result can be interpreted similarly as was the result observed in Panel B of Table 1.

Table 3 shows the results for population density (PD_t). In Panel A of this table, the coefficients of the interaction terms of structural shocks and PD_t are insignificant at all lags. In Panel B, the coefficients of the interaction terms of $DE_t \times PD_t$ and $OIL_t \times PD_t$ at one lag take on significantly negative values, implying that, other things the same, the price level in a region with higher population density will be less affected by oil price surges caused by shocks to global real economic activity or oil market specific demand shocks. This result is intuitive because urban regions with high population density in Japan usually have well established public transportation systems (especially railways), therefore have relatively lower dependency on motor vehicles and gasoline consumption per se.

Table 4 shows the results for temperature of winter ($TempWinter_t$). In Panel A, the coefficient of the interaction term of OIL_t and $TempWinter_t$ takes on a significantly negative value at three lags, implying that, ceteris paribus, regions with lower temperatures during winter will have output to be more negatively affected by oil price surges resulted from oil market specific demand shocks. In Japan, regions with colder winter (i.e. those located the north or northeast of Japan, such as Hokkaido, Aomori, Iwate and so on) consume more oil for heating and snowplowing during winter. For this reason, an oil market specific demand shock, which raises the price of oil, may push up production costs more in these regions than in those with warmer winter. In Panel B of Table 4, the coefficients of the interaction terms of SY_t and $TempWinter_t$ at the one and three lags, as well as those on the interaction terms of OIL_t and $TempWinter_t$ at the two and three lags are significantly negative. These imply that a region with colder winter will have the price level to be more affected by oil supply shocks and oil market specific demand shocks. Our interpretation for this is the same as that for result on output noted right above.

5. Concluding remarks

In this paper we address the question of how the effects of oil shocks on different economies are affected by their heterogeneity. We take up the Japanese regional economies as a case study and use a structural VAR model and a panel VAR model as the analytical framework.

Our main conclusion is that the effects of oil price shocks on the Japanese regional economies are closely related to various natural and socio-economic characteristics of those regions. More specifically, in the presence of a surge in the oil price caused by an oil demand shock originated from the global real economic activity or an oil market specific demand shock, output is more negatively affected and the price level rises more in a region with colder winter, or with lower population density, or with a higher share of petroleum and coal products in total value added. In addition, the effects of oil shocks also depend on the share in total value added of transport equipment industry, one of the key industries of Japan: The more a region is specializing in this industry the more its output and the *less* its price level respond to oil demand shocks. Interestingly, the last result, though appears counterintuitive, can be explained based on the relationships between this the share of industry and the general level of development of industries in a region, the dependency on goods imported from other regions and transportation costs.

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Table 1: The relationship between the effects of oil shocks and regional share of transportation equipment in total value added

Panel A

	Dependent Variable: IIP		
	Coef.	Std. Err..	z-value
SY_t	0.036	0.035	1.01
$SY_t * ShareTrans_t$	0.664*	0.385	1.72
SY_{t-1}	0.139***	0.033	4.15
$SY_{t-1} * ShareTrans_{t-1}$	0.131	0.360	0.36
SY_{t-2}	0.016	0.035	0.46
$SY_{t-2} * ShareTrans_{t-2}$	-0.154	0.388	-0.4
SY_{t-3}	0.044	0.034	1.29
$SY_{t-3} * ShareTrans_{t-3}$	-0.130	0.369	-0.35
DE_t	0.123**	0.047	2.61
$DE_t * ShareTrans_t$	-0.315	0.444	-0.71
DE_{t-1}	0.042	0.045	0.94
$DE_{t-1} * ShareTrans_{t-1}$	0.880**	0.393	2.24
DE_{t-2}	0.174***	0.050	3.46
$DE_{t-2} * ShareTrans_{t-2}$	1.001**	0.441	2.27
DE_{t-3}	0.217***	0.050	4.35
$DE_{t-3} * ShareTrans_{t-3}$	1.810***	0.482	3.75
OIL_t	0.150***	0.042	3.61
$OIL_t * ShareTrans_t$	-0.314	0.456	-0.69
OIL_{t-1}	0.148***	0.040	3.74
$OIL_{t-1} * ShareTrans_{t-1}$	0.509	0.422	1.21
OIL_{t-2}	0.143***	0.042	3.42
$OIL_{t-2} * ShareTrans_{t-2}$	1.015**	0.461	2.2
OIL_{t-3}	0.113***	0.041	2.78
$OIL_{t-3} * ShareTrans_{t-3}$	0.898**	0.444	2.02

Note: ***, **, * indicate statistical significance at the 1%, 5%, 10% level, respectively. Notation: SY_t is oil supply shock; DE_t is oil demand shock; OIL_t is oil market specific demand shock; $ShareTrans_t$ is share of transportation equipment industry in total value added.

Table 1: The relationship between the effects of oil shocks and regional share of transportation equipment in total value added

Panel B

	Dependent Variable: CPI		
	Coef.	Std. Err..	z-value
SY_t	-0.016***	0.005	-2.95
$SY_t * ShareTrans_t$	0.026	0.047	0.55
SY_{t-1}	-0.031***	0.005	-5.88
$SY_{t-1} * ShareTrans_{t-1}$	0.040	0.047	0.85
SY_{t-2}	-0.021***	0.005	-3.91
$SY_{t-2} * ShareTrans_{t-2}$	0.002	0.048	0.04
SY_{t-3}	-0.015**	0.006	-2.49
$SY_{t-3} * ShareTrans_{t-3}$	-0.024	0.050	-0.48
DE_t	0.022**	0.005	4.6
$DE_t * ShareTrans_t$	-0.067	0.034	-1.96
DE_{t-1}	0.039**	0.005	8.06
$DE_{t-1} * ShareTrans_{t-1}$	-0.066**	0.033	-1.99
DE_{t-2}	-0.002	0.004	-0.51
$DE_{t-2} * ShareTrans_{t-2}$	0.055*	0.030	1.81
DE_{t-3}	-0.002	0.005	-0.33
$DE_{t-3} * ShareTrans_{t-3}$	-0.014	0.032	-0.45
OIL_t	0.018***	0.004	4.15
$OIL_t * ShareTrans_t$	0.042	0.033	1.25
OIL_{t-1}	0.039***	0.004	9.22
$OIL_{t-1} * ShareTrans_{t-1}$	-0.027	0.033	-0.81
OIL_{t-2}	0.021***	0.005	4.46
$OIL_{t-2} * ShareTrans_{t-2}$	0.010	0.039	0.27
OIL_{t-3}	0.026***	0.004	6.26
$OIL_{t-3} * ShareTrans_{t-3}$	0.038	0.033	1.16

Note: ***, **, * indicate statistical significance at the 1%, 5%, 10% level, respectively. Notation: SY_t is oil supply shock; DE_t is oil demand shock; OIL_t is oil market specific demand shock; $ShareTrans_t$ is share of transportation equipment industry in total value added.

Table 2: The relationship between the effects of oil shocks and regional share of petroleum and coal products in total value added

Panel A

	Dependent Variable: IIP		
	Coef.	Std. Err..	z-value
SY_t	0.090***	0.028	3.18
$SY_t * SharePetroCoal_t$	-0.573	0.907	-0.63
SY_{t-1}	0.136***	0.028	4.84
$SY_{t-1} * SharePetroCoal_{t-1}$	0.207	0.916	0.23
SY_{t-2}	0.009	0.030	0.32
$SY_{t-2} * SharePetroCoal_{t-2}$	0.206	1.029	0.2
SY_{t-3}	0.043	0.028	1.55
$SY_{t-3} * SharePetroCoal_{t-3}$	-0.377	1.055	-0.36
DE_t	0.102***	0.039	2.63
$DE_t * SharePetroCoal_t$	1.110	1.296	0.86
DE_{t-1}	0.136***	0.038	3.58
$DE_{t-1} * SharePetroCoal_{t-1}$	0.189	1.333	0.14
DE_{t-2}	0.246***	0.043	5.74
$DE_{t-2} * SharePetroCoal_{t-2}$	-0.621	1.633	-0.38
DE_{t-3}	0.357***	0.040	8.96
$DE_{t-3} * SharePetroCoal_{t-3}$	-1.507	1.629	-0.93
OIL_t	0.134***	0.034	3.95
$OIL_t * SharePetroCoal_t$	-0.993	1.338	-0.74
OIL_{t-1}	0.210***	0.032	6.48
$OIL_{t-1} * SharePetroCoal_{t-1}$	-2.235*	1.238	-1.8
OIL_{t-2}	0.215***	0.032	6.66
$OIL_{t-2} * SharePetroCoal_{t-2}$	-0.631	1.360	-0.46
OIL_{t-3}	0.196***	0.033	5.97
$OIL_{t-3} * SharePetroCoal_{t-3}$	-2.574***	1.464	-1.76

Note: ***, **, * indicate statistical significance at the 1%, 5%, 10% level, respectively. Notation: SY_t is oil supply shock; DE_t is oil demand shock; OIL_t is oil market specific demand shock; $SharePetroCoal_t$ is share of petroleum and coal products industry in total value added.

Table 2: The relationship between the effects of oil shocks and regional share of petroleum and coal products in total value added

Panel B

	Dependent Variable: CPI		
	Coef.	Std. Err..	z-value
SY_t	-0.015***	0.005	-3.27
$SY_t * SharePetroCoal_t$	0.049	0.180	0.27
SY_{t-1}	-0.025***	0.004	-5.72
$SY_{t-1} * SharePetroCoal_{t-1}$	-0.383**	0.154	-2.49
SY_{t-2}	-0.022***	0.004	-4.97
$SY_{t-2} * SharePetroCoal_{t-2}$	0.116	0.158	0.74
SY_{t-3}	-0.019***	0.005	-3.81
$SY_{t-3} * SharePetroCoal_{t-3}$	0.148	0.164	0.91
DE_t	0.012***	0.004	2.86
$DE_t * SharePetroCoal_t$	0.506***	0.172	2.94
DE_{t-1}	0.031***	0.004	7.8
$DE_{t-1} * SharePetroCoal_{t-1}$	0.209	0.175	1.19
DE_{t-2}	0.004	0.004	1.03
$DE_{t-2} * SharePetroCoal_{t-2}$	-0.353**	0.175	-2.01
DE_{t-3}	-0.002	0.004	-0.54
$DE_{t-3} * SharePetroCoal_{t-3}$	-0.159	0.172	-0.93
OIL_t	0.017***	0.004	4.62
$OIL_t * SharePetroCoal_t$	0.205	0.174	1.18
OIL_{t-1}	0.037***	0.004	10.56
$OIL_{t-1} * SharePetroCoal_{t-1}$	-0.012	0.159	-0.07
OIL_{t-2}	0.017***	0.004	4.31
$OIL_{t-2} * SharePetroCoal_{t-2}$	0.172	0.177	0.97
OIL_{t-3}	0.029***	0.004	8.32
$OIL_{t-3} * SharePetroCoal_{t-3}$	-0.208	0.157	-1.32

Note: ***, **, * indicate statistical significance at the 1%, 5%, 10% level, respectively. Notation: SY_t is oil supply shock; DE_t is oil demand shock; OIL_t is oil market specific demand shock; $SharePetroCoal_t$ is share of petroleum and coal products industry in total value added.

Table 3: The relationship between the effects of oil shocks and regional population density

Panel A

	Dependent Variable: IIP		
	Coef.	Std. Err..	z-value
SY_t	0.095***	0.029	3.23
$SY_t * PD_t$	-0.019	0.020	-0.94
SY_{t-1}	0.135***	0.027	4.96
$SY_{t-1} * PD_{t-1}$	0.022	0.019	1.15
SY_{t-2}	0.005	0.029	0.18
$SY_{t-2} * PD_{t-2}$	-0.001	0.021	-0.03
SY_{t-3}	0.050*	0.028	1.8
$SY_{t-3} * PD_{t-3}$	-0.025	0.019	-1.36
DE_t	0.087**	0.037	2.33
$DE_t * PD_t$	0.008	0.020	0.4
DE_{t-1}	0.113***	0.037	3.1
$DE_{t-1} * PD_{t-1}$	0.012	0.022	0.52
DE_{t-2}	0.273***	0.042	6.55
$DE_{t-2} * PD_{t-2}$	-0.011	0.024	-0.44
DE_{t-3}	0.387***	0.038	10.29
$DE_{t-3} * PD_{t-3}$	-0.005	0.023	-0.22
OIL_t	0.133***	0.034	3.92
$OIL_t * PD_t$	-0.013	0.021	-0.61
OIL_{t-1}	0.183***	0.032	5.67
$OIL_{t-1} * PD_{t-1}$	0.010	0.021	0.5
OIL_{t-2}	0.224***	0.031	7.13
$OIL_{t-2} * PD_{t-2}$	-0.002	0.021	-0.12
OIL_{t-3}	0.198***	0.032	6.18
$OIL_{t-3} * PD_{t-3}$	-0.018	0.021	-0.87

Note: ***, **, * indicate statistical significance at the 1%, 5%, 10% level, respectively. Notation: SY_t is oil supply shock; DE_t is oil demand shock; OIL_t is oil market specific demand shock; PD_t is population density.

Table 3: The relationship between the effects of oil shocks and regional population density

Panel B

	Dependent Variable: CPI		
	Coef.	Std. Err..	z-value
SY_t	-0.014***	0.004	-3.08
$SY_t * PD_t$	-0.001	0.003	-0.19
SY_{t-1}	-0.030***	0.004	-6.73
$SY_{t-1} * PD_{t-1}$	0.002	0.003	0.66
SY_{t-2}	-0.021***	0.005	-4.72
$SY_{t-2} * PD_{t-2}$	0.000	0.003	0.05
SY_{t-3}	-0.015***	0.005	-3.06
$SY_{t-3} * PD_{t-3}$	-0.002	0.003	-0.69
DE_t	0.018***	0.004	4.51
$DE_t * PD_t$	-0.002	0.002	-1.02
DE_{t-1}	0.035***	0.004	9.39
$DE_{t-1} * PD_{t-1}$	-0.004**	0.002	-1.98
DE_{t-2}	0.005	0.003	1.38
$DE_{t-2} * PD_{t-2}$	-0.003	0.002	-1.39
DE_{t-3}	-0.003	0.004	-0.69
$DE_{t-3} * PD_{t-3}$	-0.001	0.002	-0.24
OIL_t	0.022***	0.004	6.2
$OIL_t * PD_t$	-0.001	0.002	-0.39
OIL_{t-1}	0.041***	0.003	11.92
$OIL_{t-1} * PD_{t-1}$	-0.006***	0.002	-3.12
OIL_{t-2}	0.024***	0.004	6.11
$OIL_{t-2} * PD_{t-2}$	-0.003	0.002	-1.13
OIL_{t-3}	0.030***	0.003	8.81
$OIL_{t-3} * PD_{t-3}$	-0.001	0.002	-0.74

Note: ***, **, * indicate statistical significance at the 1%, 5%, 10% level, respectively. Notation: SY_t is oil supply shock; DE_t is oil demand shock; OIL_t is oil market specific demand shock; PD_t is population density.

Table 4: The relationship between the effects of oil shocks and regional temperature of winter

Panel A

	Dependent Variable: IIP		
	Coef.	Std. Err..	z-value
SY_t	0.129***	0.049	2.64
$SY_t * TempWinter_t$	-0.009	0.009	-1.02
SY_{t-1}	0.128***	0.048	2.69
$SY_{t-1} * TempWinter_{t-1}$	0.004	0.008	0.46
SY_{t-2}	0.055	0.052	1.07
$SY_{t-2} * TempWinter_{t-2}$	-0.010	0.009	-1.08
SY_{t-3}	0.018	0.049	0.37
$SY_{t-3} * TempWinter_{t-3}$	0.003	0.009	0.34
DE_t	0.082	0.065	1.27
$DE_t * TempWinter_t$	0.002	0.011	0.17
DE_{t-1}	0.162***	0.061	2.67
$DE_{t-1} * TempWinter_{t-1}$	-0.008	0.010	-0.78
DE_{t-2}	0.373***	0.075	4.98
$DE_{t-2} * TempWinter_{t-2}$	-0.020	0.013	-1.59
DE_{t-3}	0.369***	0.064	5.77
$DE_{t-3} * TempWinter_{t-3}$	0.003	0.011	0.24
OIL_t	0.071	0.062	1.14
$OIL_t * TempWinter_t$	0.010	0.010	0.97
OIL_{t-1}	0.151***	0.054	2.79
$OIL_{t-1} * TempWinter_{t-1}$	0.007	0.009	0.78
OIL_{t-2}	0.247***	0.056	4.42
$OIL_{t-2} * TempWinter_{t-2}$	-0.005	0.010	-0.46
OIL_{t-3}	0.306***	0.055	5.52
$OIL_{t-3} * TempWinter_{t-3}$	-0.023**	0.009	-2.43

Note: ***, **, * indicate statistical significance at the 1%, 5%, 10% level, respectively. Notation: SY_t is oil supply shock; DE_t is oil demand shock; OIL_t is oil market specific demand shock; $TempWinter_t$ is temperature of winter.

Table 4: The relationship between the effects of oil shocks and regional temperature of winter

Panel B

	Dependent Variable: CPI		
	Coef.	Std. Err..	z-value
SY_t	-0.018**	0.007	-2.47
$SY_t * TempWinter_t$	0.001	0.001	0.65
SY_{t-1}	-0.018**	0.007	-2.4
$SY_{t-1} * TempWinter_{t-1}$	-0.002*	0.001	-1.8
SY_{t-2}	-0.013*	0.008	-1.69
$SY_{t-2} * TempWinter_{t-2}$	-0.002	0.001	-1.35
SY_{t-3}	0.008	0.008	0.96
$SY_{t-3} * TempWinter_{t-3}$	-0.005***	0.001	-3.55
DE_t	0.018**	0.007	2.52
$DE_t * TempWinter_t$	0.000	0.001	-0.31
DE_{t-1}	0.040***	0.007	5.87
$DE_{t-1} * TempWinter_{t-1}$	-0.001	0.001	-1.37
DE_{t-2}	0.004	0.006	0.65
$DE_{t-2} * TempWinter_{t-2}$	0.000	0.001	-0.21
DE_{t-3}	-0.008	0.007	-1.26
$DE_{t-3} * TempWinter_{t-3}$	0.001	0.001	0.98
OIL_t	0.011*	0.006	1.82
$OIL_t * TempWinter_t$	0.002*	0.001	1.86
OIL_{t-1}	0.053***	0.006	8.65
$OIL_{t-1} * TempWinter_{t-1}$	-0.003***	0.001	-3.11
OIL_{t-2}	0.022***	0.007	3.23
$OIL_{t-2} * TempWinter_{t-2}$	0.000	0.001	-0.01
OIL_{t-3}	0.039***	0.006	6.56
$OIL_{t-3} * TempWinter_{t-3}$	-0.002**	0.001	-2.04

Note: ***, **, * indicate statistical significance at the 1%, 5%, 10% level, respectively. Notation: SY_t is oil supply shock; DE_t is oil demand shock; OIL_t is oil market specific demand shock; $TempWinter_t$ is temperature of winter.