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IMPACT OF FUKUSHIMA NUCLEAR DISASTER ON OIL-CONSUMING SECTORS OF JAPAN

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Abstract

The Fukushima Daiichi nuclear disaster was an accident at the Fukushima I Nuclear Power Plant in Fukushima, Japan, which resulted primarily from the tsunami following the Tohoku earthquake on 11 March 2011, and which led to year-long nuclear shutdown in the country. During the shutdown, Japan substituted fossil fuels for nuclear power and became more dependent on import and consumption of fossil fuels including oil, gas, and coal. In this paper, we try to shed light on the elasticity of oil consumption to crude oil price before and after the Fukushima disaster in Japan's various economic sectors. To do so, we apply a cointegration analysis and perform a vector error correction (VEC) variance decomposition by using quarterly data in two separate subperiods from Q1 1981 to Q4 2010 and from Q1 2011 to Q4 2015. Our findings reveal that the absolute value of elasticities of oil consumption by some economic sectors, such as the industry, non-energy, and transportation sectors to oil prices, has reduced after the disaster because of increased dependency on oil consumption, which endangered energy security in the country. To raise energy self-dependency and energy security, Japan needs to diversify its energy supply resources. For instance, the share of renewable energy in Japan's energy basket needs to increase. Because renewable energy projects are mainly considered risky and banks are reluctant to finance them, we introduce an innovative form of financing these projects: Hometown Investment Trust Funds, which has been introduced and applied in Japan and other parts of Asia.

JEL Classification: C32, O49, Q43

Contents

1. INTRODUCTION

Since the first historical oil price shock of 1973, scholars have waged an intense debate on the effects of sharp and sudden changes of oil prices on various macro variables of a nation or group of countries. In recent years, the sharp increase in oil prices that began in 2001, the sharp decline that in 2008 followed the subprime mortgage crisis, and the stunning oil price reduction in 2014–2015 have renewed interest in the effects of oil prices on the macro economy. Since crude oil has been perceived as a vital energy commodity fueling world economy, several studies (see, inter alia, Rasoulinezhad 2016; Taghizadeh-Hesary et al. 2015, 2013; Taghizadeh-Hesary and Naoyuki 2016; Yoshino and Taghizadeh-Hesary 2015a; and Yoshino and Taghizadeh-Hesary 2015) have evaluated impacts of oil price fluctuations on various macroeconomic indicators.

An issue that has not drawn sufficient attention of scholars is that of how oil price can affect the amount of oil consumed by economic sectors of a country, particularly an oil-importing one in which crude oil and its price highly determines the cost of production.

However, it should be noted that the response of all economic sectors in a country to oil price fluctuations might not be the same, especially when structural change in the country happens. A structural change, such as a new policy, a natural disaster, a new technology, etc., may alter the oil consumption pattern of economic sectors. It has always been expressed that after a serious structural change, the elasticity of oil consumption by economic sectors in relation to oil prices can change remarkably. Therefore, finding out the pattern of oil consumption by economic sectors in a country before and after a structural change can be interesting and useful.

To this end, in this research, we will empirically investigate how a disaster affects the energy consumption pattern by various economic sectors. The policy implications of this paper will help energy policy makers to protect those sectors with higher sensitivity. Furthermore, the results of our research can be used to discuss the energy security of the country.

In this survey, we consider Japan as our case study. The choice of Japan for this study is motivated by the fact that it is a country that is almost fully dependent on energy imports and has experienced an energy disaster in 2011. In March 2011, a devastating earthquake and tsunami hit eastern Japan and damaged the nuclear power plant in Fukushima. This disaster led to the shutdown of all nuclear power plants due to the lack of government safety approvals. Japan replaced this significant loss of nuclear power with energy generated from imported natural gas, low-sulfur crude oil, fuel oil, and coal. Based on the importance of oil for Japan, we chose to focus on it in this survey. In this paper, we investigate the effects of oil price on the oil-consuming economic sectors of Japan using quarterly data from the first quarter (Q1) 1981 to Q4 2015—in two separate time periods, before the Fukushima disaster (Q1 1981–Q4 2010) and after the Fukushima disaster (Q1 2011–Q4 2015)—through a cointegration test and vector error correction (VEC) variance decomposition. Our research questions are the following: (i) Considering the 2011 Fukushima nuclear breakdown as an energy structural change, do oil consumption patterns of economic sectors change before and after this disaster?, and (ii) if the answer is yes, are the responses of all economic sectors to oil price impulses of the same scale? Which sectors show higher sensitivities?

The remainder of this article is outlined as follows. The next section provides an overview of energy consumption in Japan. Section 3 provides the theoretical background. Section 4 expresses the data and econometric methodology. Section 5 discusses empirical analysis, and the final section 6 presents the concluding remarks.

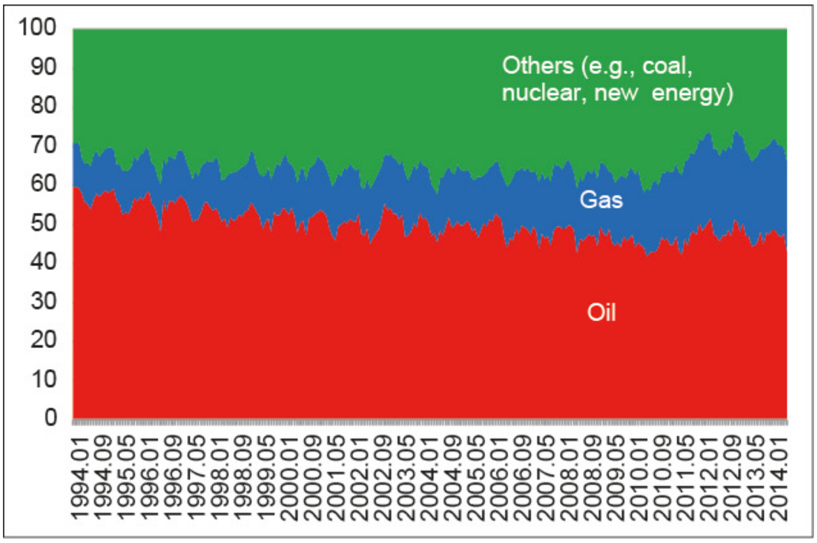
2. OVERVIEW OF ENERGY CONSUMPTION IN JAPAN

The rapid pace of Japan's industrial development after the end of World War II made Japan one of the world largest energy consumers. It is the world's largest importer of liquefied natural gas (LNG), the second-largest coal importer, and the third-largest net oil importer. Domestic energy sources in Japan meet less than 15% of its own total primary energy use.

Figure 1 shows the shares of different energy sources in Japan's energy basket during January 1994–June 2014.

Figure 1: Shares of Different Energy Sources in Japan's Energy Basket, January 1994–June 2014

(%)



Notes: Shares are calculated by the calorific value of the energy sources. Oil is imported crude oil plus imported petroleum products. Gas is imported liquefied natural gas. Other energy sources include coal, nuclear power, hydropower, and new energy.

Source: Yoshino and Taghizadeh-Hesary (2015a).

In March 2011, a 9.0 magnitude earthquake struck off the coast of Sendai, Japan, triggering a large tsunami. The damage to Japan resulted in an immediate shutdown of about 10 gigawatts of nuclear electric-generating capacity. Between the 2011 Fukushima disaster and May 2012, Japan lost all of its nuclear capacity as a result of scheduled maintenance and the lack of government approvals to return to operation. Japan replaced the significant loss of nuclear power with generation from imported natural gas, low-sulfur crude oil, fuel oil, and coal. This caused the price of electricity to rise for the government, utilities, and consumers. Japan spent $250 billion on total fuel imports in 2012, a third of the country's total import charges (Taghizadeh-Hesary and Yoshino 2015). Despite strength in export markets, the yen's depreciation and soaring natural gas and oil import costs due to greater reliance on fossil fuels continued to deepen Japan's trade deficit throughout 2013. In the wake of the Fukushima nuclear incident, oil is still the main energy carrier in Japan, although the share of oil consumption in total energy consumption has reduced from about 80% in the 1970s to 43% in 2011. Japan consumed over 4.7 million barrels per day of oil in 2012 (Taghizadeh-Hesary et al. 2015).

According to the International Energy Agency,[1] strategic crude oil stocks in Japan totaled 590 million barrels at the end of December 2012, 55% of which were government stocks and 45% commercial stocks.

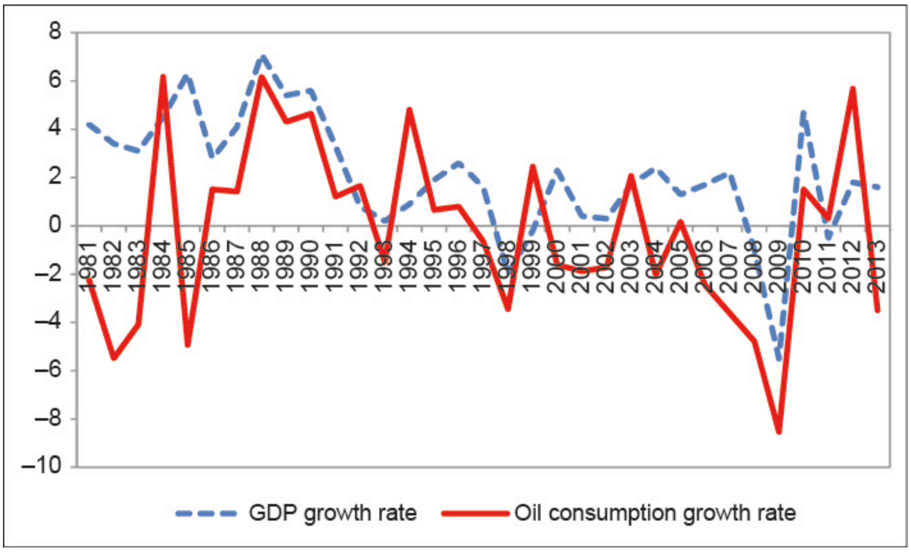
Historical analysis of crude oil consumption trends in Japan is interesting, as shown in Figure 2. Crude oil consumption peaked in 1996 at nearly 5.7 million barrels per day[2] and dropped to its lowest point of 4.3 million barrels per day in 2009 after the global financial crisis, which reduced the economic output and energy demand in the country. In late 1980 until 2006, crude oil consumption was almost 5 million barrels per day, but consumption dropped below 5 million barrels per day from 2008, following the global financial crisis.

In 2015, due to the relative improvement in Japan's economic growth, demand for energy (including oil) rose and total consumption of petroleum products reached more than 5 million barrels per day.

Besides the aforementioned trends, crude oil consumption in Japan is a procyclical variable. This means that increases in the gross domestic product (GDP) growth rate are correlated and have boosted the consumption of crude oil, while economic downturns have reduced oil consumption. Figure 2 illustrates the GDP growth rate and crude oil consumption growth rate trends during 1981–2013.

Figure 2: GDP Growth Rate and Crude Oil Consumption Growth of Japan, 1981–2013

(%)



GDP = gross domestic product.

Note: GDP is annual change in constant prices.

Source: International Energy Agency database and World Economic Outlook database of the International Monetary Fund (April 2015).

[1] U.S. Energy Information Administration. 2017. Country Analysis Brief: Japan. 2 February. http://www.eia.gov/beta/international/analysis_includes/countries_long/Japan/japan.pdf (accessed 3 February 2017).

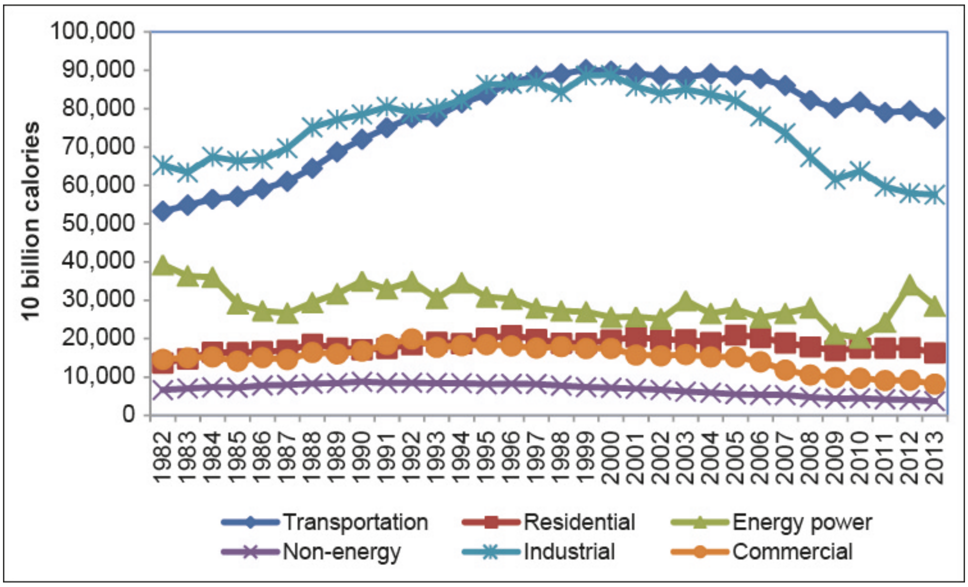
[2] Average total consumption of petroleum products in February 1996 was 6.8 million barrels per day.

2.1 Oil Consumption in Japan by Sector

Generally, there are six oil-consuming sectors in an economy: commercial, energy power generation, industry, non-energy, residential, and transportation.

Figure 3 shows the oil consumption in each of these six sectors in Japan during 1982–2013. Clearly, the transportation and industry sectors have had the highest consumption during this period and, importantly, until early 1990, the industry sector had used more crude oil than the transportation sector. However, after the burst of Japan's asset price bubble in the 1990s, the Japanese economy suffered from sluggish economic growth and recessions (Japan's so-called "lost decade") and the industry sector's oil demand started to shrink (Taghizadeh-Hesary and Naoyuki 2016). Another reason for the reduced demand for oil in the industry sector was the huge foreign direct investment from Japan to other Asian countries—including the People's Republic of China, Thailand, and Malaysia—which moved a significant part of industrial production to other countries. Since then, the transportation sector has remained the major consumer of oil in the country, and consumption in the sector has been almost constant. However, in recent years, mainly because of the increased share of hybrid cars and higher energy efficiency in Japanese automobiles, demand for oil in the sector has started to decrease. Industry sector demand has a negative slope and demand for oil for energy power generation has also been decreasing because of the substitution to LNG.

Figure 3: Crude Oil Consumption by Sector in Japan, 1982–2013



Source: Energy Data and Modelling Center database of the Institute of Energy Economics, Japan.

In 1982, shares of the transportation, residential, energy power, non-energy, industry, and commercial sectors in total oil consumption were 28%, 7%, 20%, 3%, 33%, and 9%, respectively. However, it is interesting to mention that by 2013, these ratios had changed and the shares of the transportation, residential, energy power, non-energy, industry, and commercial sectors were measured at 40%, 8%, 15%, 2%, 30%, and 5%, respectively.

3. THEORETICAL BACKGROUND

3.1 Background

Consider a simple production (Q) function (Eq. 1) with three various inputs, labor (L), capital (K), and energy (G) with (A) as the total factory productivity.

$$Q_{t'} = A_{t'} L_{t'}^{\phi'} G_{t'}^{\varpi} \overline{K} \qquad (1)$$

Suppose energy input in the above production function comprises two components: oil demand and non-oil demand. Before the 2011 Fukushima disaster in Japan, global oil price fluctuations notably affected these two components and reduced oil demand and increased non-oil demand in Japan. Because other types of energy (nuclear) had plenty of supply, rather than crude oil, this allowed the Government of Japan to replace crude oil with other types of energy.

The following figures represent the oil demand and non-oil demand curves in Japan before and after the Fukushima disaster.

Figure 4: Crude Oil Demand Curve

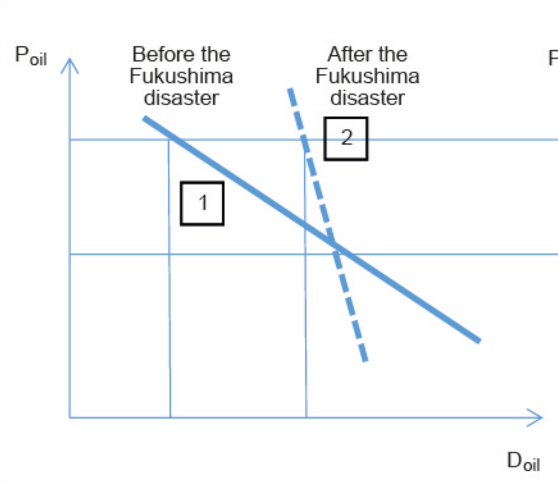
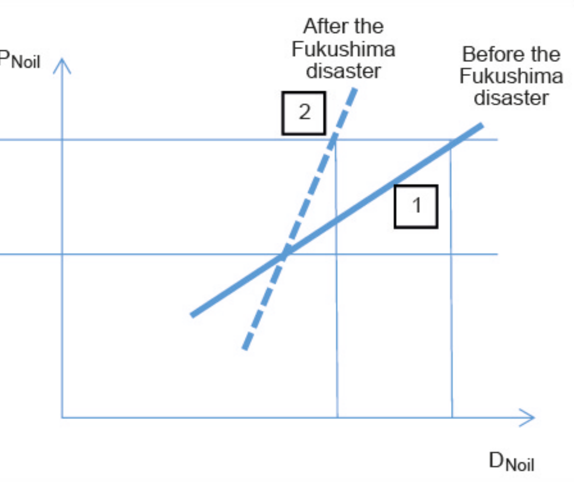


Figure 5: Non-Oil (Noil) Demand Curve



Source: Authors' compilation.

As seen in Figures 4 and 5, the oil demand curve is quite flat or elastic (an elastic demand curve means that a small change in price typically results in a greater response in the demanded quantity) before the disaster. Before the Fukushima disaster, oil price changes led to the oil demand reduction and non-oil demand (i.e., nuclear) increase. After the disaster in Japan, the non-oil supply has been very limited. Hence, the demand curve could not increase remarkably, even after the oil price increase. Therefore, companies could not highly reduce oil demand, as shown in Figure 4, number 2. This shows that after the Fukushima disaster, since non-oil energy resources were no longer as diversified as before, resources were few. Therefore, the elasticity of oil demand to oil prices was reduced as shown in Figure 4. Furthermore, if the non-oil energy supply (including renewable energy supply) is increased, the demand curve in Figure 4 will return to its previous place. Hence, the development of alternative energy is highly important for Japan, in order to raise energy security.

3.2 Necessity for Development of Renewable Energy Projects by Using Hometown Investment Trust Funds

It is important to note that in order to avoid this situation Japan needs to develop green energy or other alternative types of energy. In Japan, the Hometown Investment Trust (HIT) Funds as a new source of financing was created to support solar and wind power. The basic objective of the HIT funds was to connect local investors with projects in their own locality, in which they had personal knowledge and interest. Individual investors would choose their preferred projects and make investments through the internet (Yoshino and Kaji 2013). One of the major applications of HITS in Japan related to wind power and solar power projects, which started to raise money from individuals (about $100 to $5,000 per investor) who were interested in promoting green energy. By means of these funds, many Japanese put a small amount of money in the construction of wind power and solar power. The advertisement of each project related to wind power and solar power through the internet plays an important role in pushing people to invest in these projects. Internet marketing companies that can guarantee these renewable projects will be completed with minimal problems and mistakes can do marketing for these projects. Local banks have started to make use of the information provided by HIT funds. If these projects are done properly and are received well by individual investors, banks can then start to make loans to those projects. In this way, renewable projects (wind and solar,) which are mainly considered risky, can be supported by HIT funds until they are able to borrow from banks. Therefore, the use of alternative financing vehicles, such as HIT funds, has assisted the growth of solar and wind projects in Japan, where the finance sector is still dominated by banks.

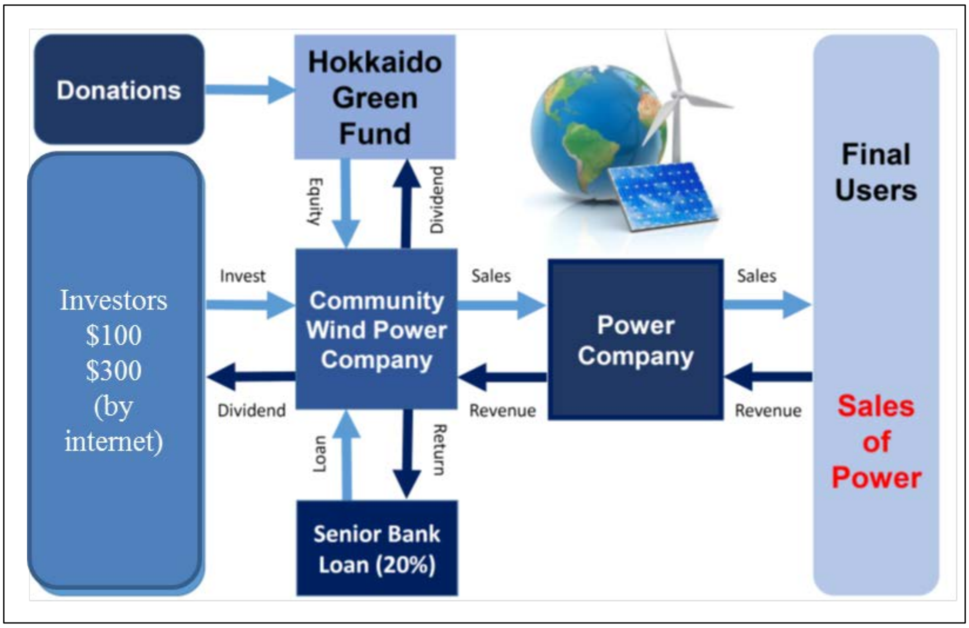
HIT funds have expanded from Japan to Cambodia, Viet Nam, Peru, and Mongolia. They are also attracting attention from the Government of Thailand and Malaysia's central bank.

Asia's finance sectors are still dominated by banks and the venture capital market is generally not well developed. However, internet sales are gradually expanding, and the use of alternative financing vehicles, such as HIT funds, will assist the growth of risky sectors in Asia.

Figure 5 provides an example of a financing scheme for renewable projects using HIT funds in Japan. The Hokkaido Green Fund, established in 2000 to finance wind power projects in northern Japan, was generated by donations. It was very difficult to raise money from banks. Only 20% of total investment is financed by banks and the other 80% comes from individual investors' money and donation (Hokkaido Green Fund). The community wind power corporation runs wind power and sells electricity to the power company that supplies power to the region. In many cases, the price of the power produced by wind power is 5% more than that of other forms of electricity. However, users are willing to pay 5% extra user charges to save the environment. More than 19 wind power projects were constructed using a similar method. In the case of solar power, the local government put money in the community fund.

Another example is the revitalization of an old hydropower plant in Nara prefecture in Japan. The old hydropower plant was constructed in 1914, however, it was abolished. Local community and individual investors raised money (1 unit of investment at $300) and 274 individuals invested in the revitalization through HIT funds. Total cost was $500,000 and 184 households received electricity from the revitalized dam and the extra electricity sold to the power supply company in the region.

Figure 6: Financing Scheme for Renewable Energy Projects Using Hometown Investment Trust Funds



HIT = Hometown Investment Trust Fund.

Source: Authors.

3.3 Theoretical Remarks

Based on the above theoretical issue, it would be useful to empirically investigate the effects of oil price shocks on the oil demand of Japan's various sectors before and after the Fukushima disaster. Following the theoretical new Keynesian-based model introduced by Yoshino and Taghizadeh-Hesary (2015a), an energy-consuming economy like Japan consists of two distinct sectors of households and firms. The total demand of a representative household for energy can be considered as follows:

$$C_t^G = \left(\frac{1-A}{A}\right)^A \frac{\alpha_o\left[\Omega(E_t\pi_{t+1}-\pi_t)\right]^{\frac{\sigma}{\eta}}(W_t)^{\frac{1}{\eta}}}{\left(P_t^{NG}\right)^{\frac{A(1-\eta)}{\eta}}\left(P_t^G\right)^{\frac{1-A(1-\eta)}{\eta}}(L_t)^{\frac{\kappa}{\eta}}(M_t)^{\frac{\sigma}{\eta}}} \tag{2}$$

C_t^G represents total consumption of energy goods (oil, gas, coal), A is the elasticity of substitution between two groups of commodities (energy goods and non-energy goods), $E_t\pi_{t+1}$, and π_t are the expected values of the inflation rate in the next period and the present inflation rate, respectively. W_t denotes the household's nominal wage per working hour, P_t^{NG} and P_t^G are the prices of non-energy commodities, and energy (aggregated price of all energy carriers: oil, gas, coal, etc.), respectively. L_t is the labor supply by the representative household, and M_t denotes the representative household's real money holding.

In the case of a firm, they assume a representative firm whose output depends on the employment of labor, energy input, and capital. This firm's production function may be written as

$$Q_t = A_t L_t^{\phi} G_t^{\varpi} \bar{K} \tag{3}$$

where Q_t is output, L_t is labor measured in man-hours, G_t is the flow of energy in barrels of crude oil, $\bar{K}$ is capital in dollars, which is a fixed amount, and t is time. A_t is a time-varying exogenous technology parameter, and ϕ, ϖ are the output elasticities of labor and energy inputs, respectively.

Yoshino and Taghizadeh-Hesary (2015a) finally showed that, since there is a state of equilibrium in their model, they have $Y_t = C_t^G + C_t^{NG}$ (they assumed that GDP (Y) is equal to consumption of energy and non-energy commodities and that except for the manufacturing sector, there is also a service sector in this economy, which is exogenously determined), then they finally obtained an energy-incorporated investment-saving (IS) curve, which is Eq. 4. This equation shows how prices (energy and non-energy prices) affect the output level.

$$Y_t = \left(\frac{1-A}{A}\right)^A \frac{\alpha_o \left(\frac{\Omega}{\psi}\left[\left(\Delta\pi_t\right) - \xi\left(\Delta\vartheta_t\right)\right]\right)^{\frac{\sigma}{\eta}} \left(W_t\right)^{\frac{1}{\eta}}}{\left(P_t^{NG}\right)^{\frac{A(1-\eta)}{\eta}} \left(P_t^G\right)^{\frac{1-A(1-\eta)}{\eta}} \left(L_t\right)^{\frac{\kappa}{\eta}} \left(M_t\right)^{\frac{\sigma}{\eta}}} + C_t^{NG} \tag{4}$$

The total energy demand is equal to the summation of the representative household's energy consumption and the energy input of the firm, which is shown as q_t^D, so $q_t^D = C_t^G + G_t$. Now, by substituting the household energy consumption and firm's energy input in this equation, and by assuming equilibrium in the labor market, the total energy demand obtained is as follows:

$$q_t^D = \left(\frac{1-A}{A}\right)^A \frac{\alpha_o \left(\frac{\Omega}{\psi}\left[\left(\Delta\pi_t\right) - \xi\left(\Delta\vartheta_t\right)\right]\right)^{\frac{\sigma}{\eta}} \left(W_t\right)^{\frac{1}{\eta}}}{\left(P_t^{NG}\right)^{\frac{A(1-\eta)}{\eta}} \left(P_t^G\right)^{\frac{1-A(1-\eta)}{\eta}} \left(L_t\right)^{\frac{\kappa}{\eta}} \left(M_t\right)^{\frac{\sigma}{\eta}}} + \varpi Q_t \left(\frac{P_t^C}{P_t^G}\right) \tag{5}$$

The above theoretical background, which shows how an oil price fluctuation could affect the households' demand and the supply side demand for oil, helps us to construct our econometric model and imply a logical and reliable estimation.

Many earlier studies on the oil price shocks suffered from the omitted variable bias. In other words, a number of studies considered bivariate models (Taghizadeh-Hesary et al. 2015), which might be biased due to the omission of other relevant variables that can have an influence on the effect oil price shocks have on the oil consumption of Japan's sectors. Thus, to avoid this problem, we investigated the effects of oil price fluctuations on oil-consuming sectors in Japan separately within the multivariate framework by including several control variables.

Following Taghizadeh-Hesary and Yoshino (2016) who show that oil demand (consumption) is a function of several variables including GDP, wage rates, interest rate, and consumer price index (CPI). In this paper, for simplicity, we assume that wage rates are constant throughout our survey and do not have significant impact on oil consumption. Moreover, interest rate is endogenous to money amount, which is why we included GDP and CPI to our econometric model. Therefore, our final econometric model can be written as follows:

$$S_t = \propto_t + \beta_1 Oilp_t + \beta_2 GDP_t + \beta_3 CPI_t + \beta_4 Interest\ rate_t + \varepsilon_t \quad (6)$$

where t = Q1 1981, Q2 1990, …, Q4 2015 refer to the time period. *S* denotes the oil-consuming sector in Japan (since we consider a variety of six sectors, we will have six estimations in our study). *Oilp* is global oil prices; and GDP and CPI are GDP of Japan in real terms and CPI of Japan, respectively. *Interest rate* indicates the short-term interest rate of the United States (US) Federal Reserve as monetary variable in our estimates. We included a US monetary variable because US monetary policy is dominant globally and affects commodity prices (see Taghizadeh-Hesary and Yoshino [2014] and Yoshino and Taghizadeh-Hesary [2014]). B_1, B_2, B_3, and B_4 represent the long-run elasticity estimates of oil consumption by Japan's sectors with respect to oil prices, GDP, CPI, and interest rate.

It should be mentioned that we have three control variables (GDP, CPI, and interest rate) in our econometric model that help us achieve better estimates.

4. DATA AND ECONOMETRIC METHODOLOGY

4.1 Data

Our empirical research uses quarterly time series of crude oil demand by sectors (commercial, industry, non-energy, transportation, power energy, and residential) in Japan for Q1 1981Q4 2015. Data are obtained from the Energy Data and Modelling Center (EDMC) database of the Institute of Energy Economics, Japan (IEEJ), Nikkei Needs Database, Bank of Japan Time Series database, and the Organisation for Economic Co-operation and Development (OECD) database. Table 1 describes the symbols and definitions of these variables.

Table 1: Variables and Definitions

Variable	Definition
LOILP	Logarithm of CIF price of imported crude oil to Japan (yen)
LCOMMER	Logarithm of crude oil demand by the commercial sector in Japan
LINDUS	Logarithm of crude oil demand by the industry sector in Japan
LNONEN	Logarithm of crude oil demand by the non-energy sector in Japan
LTRANSPO	Logarithm of crude oil demand by the transportation sector in Japan
LPOGEN	Logarithm of crude oil demand by the power energy sector in Japan
LRESIDEN	Logarithm of crude oil demand by the residential sector in Japan
LGDP	Logarithm of GDP of Japan in real term
LCPI	Logarithm of CPI of Japan
LINTER	Logarithm of short- term interest rate of US Federal Reserve

CIF = cost, insurance, and freight; CPI = consumer price index; GDP = gross domestic product.

Source: Authors' compilation.

4.2 Econometric Methodology

The empirical estimation of our model has two separate objectives. The first is to examine how the oil price and oil consumption of Japan's sectors are related in the long run before and after the Fukushima disaster. The second is to investigate the portion of oil prices in the oil consumption changes of Japan's economic sectors during the two periods before and after the disaster. We start our empirical estimation by considering the assumption that the logarithmic form of the model in Eq. (7) can be approximated by a levels vector autoregressive (VAR) model. This approach serves our estimation goal well since it avoids the endogeneity problem by treating all variables to be endogenous (Ang 2007, Sims 1980).

Accordingly, the levels VAR model can be written as follows:

$$y_t = a_0 + \sum_{j=1}^{p} A_j y_{t-j} + \varepsilon_t \tag{7}$$

where y_t = [Loilp, Lcommer, Lindus, Lnonen, Ltranspo, Lpogen, Lresiden, Lgdp, Lcpi, Linter]. These variables can be either I(0) or I(1). a_0 indicates a vector of constant terms and A_j represents a matrix of VAR parameters for lag *j*. Besides, ε_t is the vector of error terms.

The testing and estimation procedure consists of three steps. First, we start by applying an integration analysis to perform three unit root tests: the Augmented Dickey-Fuller (ADF), the Phillips-Perron (PP), and the Elliott-Rothenbergy-Stock (ERS) tests. The first two tests are so popular in econometric studies, but the choice of the ERS unit root test to complement the widely performed ADF and PP tests is motivated by the argument that when a linear trend is in the series, the performance of the ERS test can substantially enhance the power of the unit root test over the traditional tests (Elliott et al. 1996).

After performing unit root tests, we have to determine the optimal lag. In this research, the Schwartz information criterion (SIC) is selected to show the optimal lag of our models. The function of this criterion can be written as

$$SIC_{(p)} = -2\left(\frac{LL}{T}\right) + \frac{\ln(T)}{T} t_p \tag{8}$$

where *LL* represents the log likelihood for a VAR(p), *T* stands for the number of observations, and *p* indicates the number of lags. It should be noted that to check whether the Fukushima disaster in 2011 is a structural point in our models, we performed the Chow test, which has a null hypothesis of no break point. The test equation is

$$Chow\ Test = \frac{(RSS_p - (RSS_1 + RSS_2))/k}{(RSS_1 + RSS_2)/(N_1 + N_2 - 2k)} \tag{9}$$

where RSS_p indicates pooled regression line, RSS_1 represents regression line before break, and RSS_2 is regression line after break.

After finding the optimal lag length of each model, the next step is to test for cointegration vector implying the Johansen approach for each of the VARs constructed in levels (since we have six Japanese sectors, the total VARs will be 12 equations before and after the Fukushima disaster in Japan). Moreover, it is not possible that given the big sample size in this research (136 quarterly observations), the Johansen cointegration test statistics may not be biased. Therefore, there is no need to follow improved approaches such as Reinsel and Ahn (1992).

If the Johansen test shows us the existence of cointegrated vector, we can check the normalized cointegration equations to find the long-run elasticity of oil consumption of economic sectors in relation to oil prices.

In the next step, the VEC variance decomposition is performed for our 12 equations before and after the Fukushima disaster. Generally, variance decomposition provides information about the relative importance of oil prices in affecting the oil consumption by economic sectors in our models. In the case of cointegration vectors between variables, we have to run variance decomposition based on the vector error correction (VEC) model, which is specified as follows:

$$x = \phi(L)x_1 + x_t'\sigma + \varepsilon_t \tag{10}$$

where x = (Oil consumption, oil prices, GDP, CPI, and interest rate), $\Phi(L)$ is the coefficient matrix for lag operators L, and δ are the cointegrating vectors capturing the long-run relation among the variables in the system.

5. ESTIMATION AND SPECIFICATION TESTS

To evaluate the stationarity of all series, we performed three unit root tests on all variables at levels and first differences. The tests used are the augmented ADF test, the PP test, and the ERS test. It should be noted that for ADF test, the Akaike Information Criterion (AIC) is used to choose the lag length. The maximum number of lags is set to five. For the PP test, Barlett Kernal is applied as the spectral estimation method. Moreover, the bandwidth is selected using the Newey West method. For the ERS test, Auto Regressive (AR) spectral Ordinary Least Squares (OLS) is used as the spectral estimation method and the optimal lag length is selected using AIC.

The results summarized in Table 2 depict that all unit root tests yield remarkably similar results, i.e., all the series are nonstationary in their levels but become stationary after taking the first difference. Therefore, it can be concluded from the unit root test results that all series are I(1) at the 5% level of significance.

Given that the variables share common integration properties, we can proceed to investigate the existence of a common trend, or equivalently, a long-run cointegrating relationship between the series.

To perform the cointegration test, we first have to check the structural changes caused by the Fukushima disaster, which can take two periods of research time for us. To find the presence of structural changes throughout the period of our survey, we tested a significant point after the March 2011 Great East Japan earthquake and tsunami, which shut down all nuclear power generation capacity in Japan due to a lack of technical approval, thus requiring substitution by oil and other fossil fuels. We used the Chow test to check the availability of structural breaks at these points. The results confirm a structural break at Q1 2011 and, as a result, we can determine two subperiods for our analysis: Q1 1981–Q3 2010 and Q1 2011–Q4 2015.

Table 2: Unit Root Tests (ADF, PP, ERS)

Variables	ADF Test Statistic Level	ADF Test Statistic First Difference	PP Test Statistic Level	PP Test Statistic First Difference	ERS Test Statistic Level	ERS Test Statistic First Difference
LOILP	–0.37	–11.04	–0.77	–10.04	30.56	0.17
LCOMMER	–0.06	–9.34	–0.17	–24.75	58.74	0.23
LINDUS	–0.70	–5.82	–0.52	–6.11	30.64	0.09
LNONEN	1.60	–6.30	1.31	–5.88	71.70	2.99
LTRANSPO	–1.57	–7.07	–2.49	–14.45	21.49	0.19
LPOGEN	–2.93	–4.97	–1.34	–9.74	32.63	0.13
LRESIDEN	–2.31	–7.94	–1.37	–6.21	15.57	1.34
LGDP	–1.24	–6.83	–1.93	–5.29	52.53	1.29
LCPI	0.74	4.48	1.11	7.46	33.81	0.10
LINTER	–0.15	–7.76	–0.07	–7.76	24.35	0.98
1% Critical value	–3.48	–3.48	–3.47	–3.47	1.93	1.93
5% Critical value	–2.88	–2.88	–2.88	–2.88	3.13	3.13
10% Critical value	–2.57	–2.57	–2.57	–2.57	4.22	4.22

ADF = Augmented Dickey-Fuller, ERS = Elliott-Rothenbergy-Stock, PP = Philips-Perron.

Source: Authors' compilation.

Table 3: Chow Test for Structural Break in Q1 2011

F-statistic	**3.47**	**Prob. F (7,83)**	**0.001**
Log likelihood ratio	24.07	**Prob. Chi-square (7)**	0.003
Wald statistic	23.94	**Prob. Chi-square (7)**	0.003

Prob. = probability.

Source: Authors' compilation.

As shown in Table 3, since the p-value is lower than 5%, the null hypothesis can be rejected and, hence, we can confirm the structural break in Q1 2011.

Another main issue before applying the cointegration test is lag order selection. Normally, six main criteria are available for lag order selection: the Schwarz information criterion (SIC), the Hannan-Quinn criterion (HQC), the Akaike information criterion (AIC), the general-to-specific sequential likelihood ratio (LR) test, a small sample correction to that test (SLR), and the Lagrange multiplier (LM) test. In this research, we selected optimal lag numbers using the Schwarz information criterion (SC), which suggests different lags for our variables in different models as shown below:

(i) Period of Q1 1981–Q4 2010

Before the Fukushima disaster in Japan, the SIC represents four lags for Lcommer, Lnonen, and Lresiden, and suggests three lags for Lindus and Ltranspo. The criterion shows one lag for Lpogen for this time period. The results are shown in Table 4.

Table 4: Lag Length Selection

Eq.		Eq. (1)	Eq. (2)	Eq. (3)	Eq. (4)	Eq. (5)	Eq. (6)
Dependent Variable		**Lcommer**	**Lindus**	**Lnonen**	**Ltranspo**	**Lpogen**	**Lresiden**
SC	0	–3.00	–4.84	–4.32	–6.29	–4.10	–1.51
	1	–14.94	–17.07	–16.63	–18.42	–16.09	–13.31
	2	–15.88	–17.54	–16.87	–18.56	**–16.28***	–17.26
	3	–16.06	**–18.22***	–16.89	**–19.13***	–15.84	–17.46
	4	**–16.63***	–17.99	**–17.45***	–19.15	–15.43	**–17.94***
	5	–16.41	–17.73	–17.16	–18.89	–15.08	–17.88

* indicates lag order selected by the criterion.

SC: Schwarz information criterion.

Source: Authors' compilation.

(ii) Period of Q1 2011–Q4 2015

In the case of the second time period, which contains data after the 2011 Fukushima nuclear breakdown in Japan, the SIC criterion suggests one lag for Lindus, Lnonen, and Lpogen, while it shows two lags for Ltranspo and Lresiden. Moreover, for Lcommer, three lags are suggested by the criterion (See Table 5.).

Table 5: Lag Length Selection

Eq.		Eq. (1)	Eq. (2)	Eq. (3)	Eq. (4)	Eq. (5)	Eq. (6)
Dependent Variable		**Lcommer**	**Lindus**	**Lnonen**	**Ltranspo**	**Lpogen**	**Lresiden**
SC	0	–8.76	–10.43	–9.73	–11.92	–9.13	–6.28
	1	–11.5	**–14.30***	**–13.81***	–15.63	**–12.62***	–10.35
	2	–13.03	–14.18	–13.29	**–16.13***	–11.24	**–11.46***
	3	**–17.09***	–	–	–	–	–

* indicates lag order selected by the criterion.

SC: Schwarz information criterion.

Source: Authors' compilation.

After detecting the optimal lags, we conducted a cointegration analysis using Johansen's technique for our six econometric equations before and after the 2011 Fukushima disaster (our equations will be 12) by assuming a linear deterministic trend. This approach proposes two likelihood ratio test statistics: the trace and the maximum eigenvalue statistics. Based on the results, the series are cointegrated and there is a long-run relationship between variables. According to the existence of cointegration between variables, the normalized cointegrating coefficients of oil prices, which indicate the elasticity of this variable (because our models are in the log-log form), can be estimated. Table 6 reports the elasticity of oil prices before and after the Fukushima disaster in Japan.

Table 6: Elasticity of Oil-Consuming Sectors with Respect to Oil Prices

Oil Consuming Sector	Before the Fukushima Disaster (Q1 1981–Q4 2010)	After the Fukushima Disaster (Q1 2011–Q4 2015)
Commercial	+0.312	–1.191
Industry	–0.458	+0.358
Non-energy sector	–0.354	+0.247
Transportation	–0.355	–0.051
Power generation	–0.005	–3.168
Residential	+0.101	–1.624

Note: all elasticities in this table are statistically significant.

Source: Authors' compilation.

It can be seen from Table 6, that the negative elasticity of the industry and non-energy sectors to oil prices before Fukushima became positive after Fukushima because of more reliance on oil. For the same reason, the absolute value of the elasticity of the transportation sector reduced, which is in accordance with Figure 1 in the theoretical section of this paper. For commercial and residential sectors, the elasticities were positive during the first period (Q1 1981–Q4 2010) because usage of kerosene was popular for residential and commercial heating. However, most recently, fuel substitution is occurring in these sectors as high prices have decreased demand for kerosene for heating purposes. In power generation, the reason that the absolute value of the elasticity of the consumption to oil prices increase in the second period, is that power generation plants are shifting from oil to LNG because of environmental issues. Initially, coal was the dominant fuel for thermal power generation in Japan, but it later lost that place to oil. More recently, in response to global environmental concerns, electric power companies are promoting the introduction of LNG-fired plants, as they emit less carbon dioxide and other pollutants.

For further analysis, we perform the variance decomposition based on the VECM approach (the VEC models are used due to the existence of cointegration between variables) in two time periods as B.F. (Before the Fukushima disaster) and A.F. (After the Fukushima disaster).

Table 7: VEC Variance Decomposition

Variance Period		2	4	6	8	10
Lcommer	B.F.	0.356	15.920	16.194	18.891	19.495
	A.F.	1.474	18.351	24.247	54.693	40.837
Lindus	B.F.	2.658	13.048	22.977	26.604	29.236
	A.F.	1.623	2.721	18.889	35.610	35.531
Lnonen	B.F.	0.004	6.247	12.878	16.535	19.112
	A.F.	1.076	5.145	15.342	11.161	13.562
Ltranspo	B.F.	0.485	9.017	19.173	22.301	23.802
	A.F.	8.641	12.158	23.291	27.937	37.281
Lpogen	B.F.	1.863	3..617	7.410	9.290	10.095
	A.F.	13.747	17.350	16.245	20.668	22.501
Lresiden	B.F.	0.705	1.083	0.993	1.113	1.047
	A.F.	0.145	2.575	2.952	15.286	15.080

Source: Authors' compilation.

The results of variance decompositions stated in Table 7 show that before the Fukushima disaster, oil consumption by the commercial sector in Japan was less explained by oil prices than after the nuclear disaster. For instance, 19.4% of variance in Lcommer in 10 steps was explained by oil prices before the disaster, while over 40% of variance was explained by this variable after 2011. In the case of other sectors in Japan, a similar pattern is seen as oil price explains the variance of oil consumption by sectors after the Fukushima disaster more than before this disaster. It expresses the larger portion of oil prices in changes of oil consumption by Japan's sectors after the 2011 disaster. In other words, after the disaster in 2011, the role of oil and its prices in oil consumption fluctuation has improved, which is a negative sign for Japan's energy security.

6. CONCLUDING REMARKS

Based on the importance of crude oil, typically for industrialized nations that are generally oil importers, this paper has attempted to investigate empirically the effects of the 2011 Fukushima disaster on oil consumption patterns in the various sectors of Japan's economy. We used vector autoregressive analysis of quarterly data collected from several databases such as the EDMC of the IEEJ. Following evidence of a structural break in the data, the fluctuation analysis in our model was performed for two different periods, Q1 1981–Q4 2010 and Q1 2011–Q4 2015.

The data trend shows that oil is still the main energy carrier in Japan, although the share of oil consumption in total energy consumption in Japan declined from about 80% in the 1970s to 43% in 2011. Following Vivoda (2012), after the Fukushima disaster in 2011 as a structural point, when considering relative cost, feasibility of increased production and availability of fuels, Japan increased consumption of fossil fuels to make up for the loss of nuclear power. Furthermore, crude oil consumption in Japan is a procyclical variable. This means that increases in the GDP growth rate have boosted the consumption of crude oil, and economic downturns have had the effect of reducing oil consumption. The data trend of oil consumption in various economic sectors in Japan indicates that the transportation and industry sectors recorded the highest consumption during the period. Importantly, until early 1990, the industry sector was consuming more crude oil than the transportation sector. But after the bursting of Japan's asset price bubble in the 1990s, the Japanese economy suffered from sluggish economic growth and recession—Japan's so-called "lost decade"—and oil demand of the industry sector started to shrink.

Apart from the data trend, the normalized cointegrating estimations indicate the elasticities of oil consumption by six separate economic sectors in Japan to oil prices in two subperiods before and after the 2011 Fukushima disaster. To sum up the normalized cointegrating results, we can conclude the following:

For industry and non-energy sectors, the negative elasticity to oil prices before Fukushima became positive after Fukushima because of more reliance on oil. In addition, for the same reason, the absolute value of the elasticity of the transportation sector reduced.

For commercial and residential sectors, the elasticities were positive during the first period (Q1 1981–Q4 2010) because usage of kerosene was popular for residential and commercial heating. However, most recently, fuel substitution is occurring in these sectors as high prices have decreased demand for kerosene for heating purposes.

In power generation, the reason that the absolute value of the elasticity of the consumption to oil prices increase in the second period, is that power generation plants are shifting from oil to LNG because of environmental issues. Initially, coal was the dominant fuel for thermal power generation in Japan, but it later lost that place to oil. More recently, in response to global environmental concerns, electric power companies are promoting the introduction of LNG-fired plants, as they emit less carbon dioxide and other pollutants.

The reduction of elasticity in some of Japan's economic sectors after the Fukushima disaster in 2011 is in line with our hypothesis in this research. However, the VEC variance decomposition analysis showed that after the Fukushima disaster in 2011, the role of oil and its price in fluctuations of oil consumption amounts are higher than before the disaster. It means that after the 2011 Fukushima disaster, crude oil has remained the most significant energy source in Japan.

Based on the conclusions of this research, the authors want to recommend the importance of energy diversification for Japan. Since the results of our research reveal the dependency of oil-consuming sectors to oil prices, the energy security of Japan should be drawn attention by scholars more than before. It can be noted that it is a significant challenge to realize a multilayer diversified supply–demand structure capable of ensuring energy security not only in normal times, but also in times of crisis. Improvement of the energy self-sufficiency rate has been a major goal of Japan's energy policy over the years. On the other hand, Japan's energy self-sufficiency rate has dropped to a mere 6% due to the shutdown of nuclear power plants, which is the second-lowest figure among 34 OECD countries and an extremely low level compared with non-resource-producing countries such as Spain (26.7%), Italy (20.1%), and the Republic of Korea (17.5%).

Therefore, the recommended goal would be to diversify energy-supplying countries and develop domestic resources, reduce procurement risks, and improve self-sufficiency rate to the level higher than before the Great East Japan Earthquake (approx. 25%).

However, the Government of Japan has started to use good policies to boost energy diversification in the country, which could contribute to raising energy security and one of the important issues for securing the economic growth in the country (Yoshino and Taghizadeh-Hesary 2015b and 2016). For instance, because of the full liberalization of the Japanese power-retailing industry introduced in 2016, all consumers, including ordinary households and stores, are able to easily and freely select power suppliers and electric rate systems. Another useful policy is the expansion of a well-balanced introduction of renewable energy such as solar power, wind power, and geothermal power; and the introduction of a new way of financing renewable projects to make their development possible (HITs). In addition, using the policies suggested in the Long-Term Energy Supply and Demand Outlook in Japan by fiscal year 2030 can help the country to lower the share of oil in its economic sectors. These include policies such as development and utilization of innovative storage batteries, technologies for realizing a hydrogen-based society, next generation renewable energy, and new technologies including those related to carbon capture and storage.

REFERENCES

Ang, J. B. 2007. CO2 emissions, energy consumption, and output in France. *Energy Policy* 35: 4772–4778. doi:10.1016/j.enpol.2007.03.032

Elliott, G., R. Thomas, and S. James. 1996. Efficient tests for an autoregressive unit root. *Econometrica* 64: 813–836.

Rasoulinezhad, E. 2016. Investigation of Sanctions and Oil Price Effects on the Iran-Russia Trade by Using the Gravity Model. *Vestn. St Petersbg. Univ. Ser*. 5(2): 68–84.

Reinsel, G. C. and S. K. Ahn. 1992. Vector autoregressive models with unit roots and reduced rank structure: estimation, likelihood ratio test, and forecasting. *J. Time Ser. Anal.* 13: 353–375.

Sims, C. A. 1980. Macroeconomic and reality. *Econometrica* 48: 1–48.

Taghizadeh-Hesary, F., E. Rasoulinezhad, and Y. Kobayashi. 2015. Oil price fluctations and oil consuming sectors: An empirical analysis of Japan (No. 539).

Taghizadeh-Hesary, F., N. Yoshino, G. Abdoli, and A. Farzinvash. 2013. An estimation of the impact of oil shocks on crude oil exporting economies and their trade partners. *Front. Econ. China* 8: 571–591.

Taghizadeh-Hesary, F. and N. Yoshino. 2014. Monetary Policies and Oil Price Determination: An Empirical Analysis. *OPEC Energy Review* 38 (1): 1–20. doi: 10.1111/opec.1202

———. 2015. Macroeconomic effects of oil price fluctuations on emerging and developed economies in a model incorporating monetary variables. *Economics and Policy of Energy and the Environment* 2: 51–75. doi: 10.3280/EFE2015-002005

Taghizadeh-Hesary, F. and Y. Naoyuki. 2016. Monetary Policy, Oil Prices and the Real Macroeconomic Variables: An Empirical Survey on China, Japan and the United States. *China An Int. J.* 14: 46–69.

Vivoda, V. 2012. Japan’s energy security predicament post-Fukushima. *Energy Policy* 46: 135–143.

Yoshino, N. and S. Kaji, eds. 2013. *Hometown Investment Trust Funds*. Tokyo: Springer.

Yoshino, N. and F. Taghizadeh-Hesary. 2014. Monetary Policies and Oil Price Fluctuations Following the Subprime Mortgage Crisis. *Int. J. Monetary Economics and Finance* 7(3): 157–174. doi: 10.1504/IJMEF.2014.066482

———. 2015a. Effectiveness of the Easing of Monetary Policy in the Japanese Economy, incorporating Energy Prices. *J. Comp. Asian Dev.* 14: 227–248. doi:10.1080/15339114.2015.1059059

———. 2015b. An Analysis of Challenges Faced by Japan’s Economy and Abenomics. *The Japanese Political Economy* 40: 1–26. doi: 10.1080/2329194X.2014.998591

———. 2015. Effectiveness of the Easing of Monetary Policy in the Japanese Economy, Incorporating Energy Prices. *J. Comp. Asian Dev.* 14: 227–248.

———. 2016. Causes and Remedies of the Japan's Long-lasting Recession: Lessons for China. *China & World Economy* 24: 23–47. doi: 10.1111/cwe.12149