



**ADB Working Paper Series**

**EMPIRICAL ANALYSIS OF GLOBAL  
OIL PRICE DETERMINANTS AT THE  
DISAGGREGATED LEVEL OVER THE  
LAST TWO DECADES**

---

Naoyuki Yoshino and  
Victoria Alekhina

No. 982  
July 2019

**Asian Development Bank Institute**

Naoyuki Yoshino is dean and chief executive officer of the Asian Development Bank Institute. Victoriia Alekhina is a PhD candidate at Keio University, Tokyo.

The views expressed in this paper are the views of the author and do not necessarily reflect the views or policies of ADBI, ADB, its Board of Directors, or the governments they represent. ADBI does not guarantee the accuracy of the data included in this paper and accepts no responsibility for any consequences of their use. Terminology used may not necessarily be consistent with ADB official terms.

Working papers are subject to formal revision and correction before they are finalized and considered published.

The Working Paper series is a continuation of the formerly named Discussion Paper series; the numbering of the papers continued without interruption or change. ADBI's working papers reflect initial ideas on a topic and are posted online for discussion. Some working papers may develop into other forms of publication.

The Asian Development Bank recognizes "China" as the People's Republic of China.

Suggested citation:

Yoshino, N. and V. Alekhina. 2019. Empirical Analysis of Global Oil Price Determinants at the Disaggregated Level Over the Last Two Decades. ADBI Working Paper 982. Tokyo: Asian Development Bank Institute. Available: <https://www.adb.org/publications/empirical-analysis-global-oil-price-determinants-disaggregated-last-two-decades>

Please contact the authors for information about this paper.

Email: [nyoshino@adbi.org](mailto:nyoshino@adbi.org)

We sincerely thank Colin McKenzie and Masao Ogaki for their valuable suggestions in improving this paper. This research was supported by Keio University's Doctorate Student Grant-in-Aid program. The views expressed in this paper are those of the authors and do not reflect any views of the Asian Development Bank Institute or the Institute of Energy Economics, Japan. All errors remain our own.

Asian Development Bank Institute  
Kasumigaseki Building, 8th Floor  
3-2-5 Kasumigaseki, Chiyoda-ku  
Tokyo 100-6008, Japan

Tel: +81-3-3593-5500  
Fax: +81-3-3593-5571  
URL: [www.adbi.org](http://www.adbi.org)  
E-mail: [info@adbi.org](mailto:info@adbi.org)

© 2019 Asian Development Bank Institute

**Abstract**

While until the mid-1990s the Organization of the Petroleum Exporting Countries played a key role in oil pricing, during recent decades, rapid economic growth in developing economies has boosted the demand for oil, making oil prices vulnerable to a wider range of factors.

This research will provide theoretical and empirical examination on the impacts of oil supply and demand factors on Brent crude oil prices by developing an oil aggregate demand–aggregate supply model and empirically estimating using a vector autoregressive approach and monthly time series data from 1999 to 2017.

In this study, global oil demand is disaggregated into demand from the Organization for Economic Co-operation and Development (OECD), the People's Republic of China (PRC), and India to measure the scale of their contributions to global oil price movements, and the industrial production (IP) index is considered as a determinant of the oil demand side. It is found that among these three, the OECD and the PRC's IP had a positive impact on oil prices in the estimated period. Moreover, among all factors included in the model, an appreciation of the US dollar exchange rate had a significant negative impact on oil prices over the last 2 decades.

Another contribution of this paper is that it examines the equilibrium of the oil market during the estimated period and shows that oil prices were adjusting instantly, which confirms the existence of the equilibrium.

**Keywords:** oil prices, industrial production, macro-economy

**JEL Classification:** Q31, Q41, Q43

## Contents

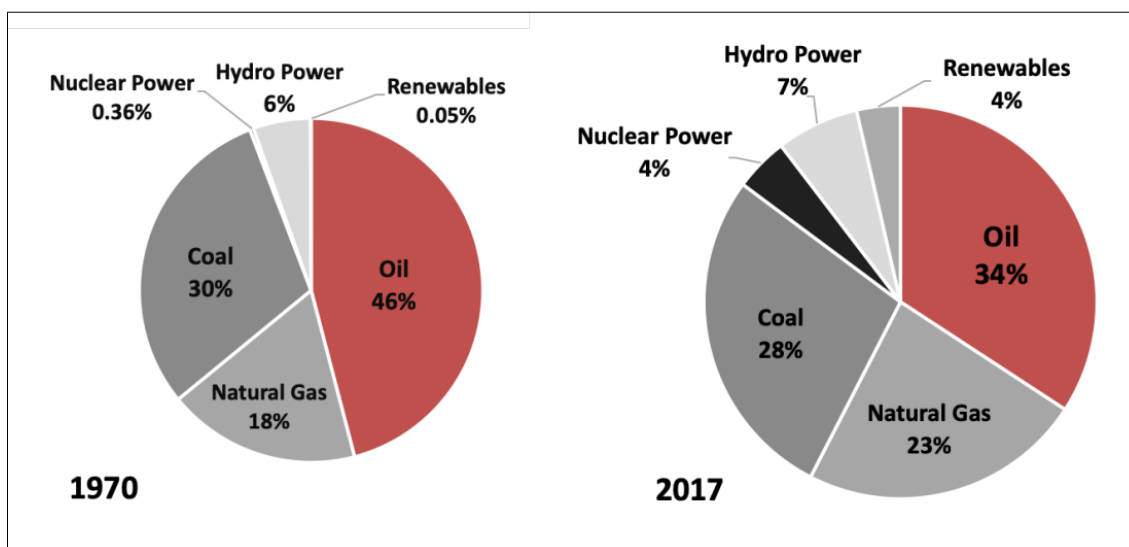
1.	INTRODUCTION .....	1
2.	LITERATURE SURVEY .....	2
3.	OVERVIEW OF THE OIL DEMAND SIDE .....	4
3.1	Organisation for Economic Co-operation and Development .....	4
3.2	People's Republic of China .....	5
3.3	India.....	5
4.	MODEL.....	7
4.1	Oil Demand .....	7
4.2	Oil Supply .....	9
5.	EMPIRICAL ANALYSIS .....	11
5.1	Data Description.....	11
5.2	Oil Market Adjustment Speed.....	11
5.3	VAR Analysis.....	13
6.	CONCLUSIONS AND FUTURE DISCUSSION.....	14
	REFERENCES .....	16

# 1. INTRODUCTION

After decades of use, oil is still the major energy source worldwide (Figure 1) due to its high energy density and relatively easy extraction, transportation, and refinery.

In the recent history of oil prices, up until the mid-1990s, the Organization of the Petroleum Exporting Countries (OPEC) played a dominating role in oil pricing. Oil price shocks in the 1970s, caused by OPEC’s oil embargo of 1973 and the Iranian revolution of 1978, were caused purely by supply changes. Hamilton (2011, 2013) defines this period as “the age of OPEC.” Since the mid-1990s, however, the power of oil pricing has moved to non-OPEC oil suppliers and notable oil consumers. Rapid economic growth in Asia, especially in India and the People’s Republic of China (PRC), has been associated with significant increases in energy consumption, particularly oil. Increased demand has caused diversification on the supply side; OPEC no longer dominates the oil market, and the pricing mechanism has become more complex.

**Figure 1: World Primary Energy Consumption by Source, 1970 and 2017**



Note: original data unit is million tons of oil equivalent (toe).

Source: Institute of Energy Economics, Japan (IEEJ) and British Petroleum (BP).

Petroleum prices are highly volatile compared to the prices of other commodities due to the fact that oil supply and demand have a low price elasticity (Askari and Krichene 2010). Oil supply is almost inelastic in the short run and can be increased only up to its full capacity. On the other hand, demand is also rigid, as it has little adjustment potential in the short run in response to an oil price increase (Adams and Marquez 1984; Hamilton 2009).

Global oil prices took a steep plunge in the second half of 2014, once again highlighting the importance of demand, supply, and other factors on oil price determination. The objective of this research is to examine the contributions of various factors to oil prices by developing an oil aggregate demand–aggregate supply (AD-AS) model and empirically estimating it using a vector autoregressive (VAR) approach and monthly time series data from 1999 to 2017. The novelty of this study is that the industrial production (IP) index is used as a determinant of oil demand, since IP is proved to be highly

associated with oil demand and prices (Ratti and Vespignani 2016; Herrera, Lagalo, and Wada 2011).

In addition, to compare the role of advanced and developing economies in recent oil price formations, this analysis uses oil demand at the country-specific and country-group levels. Moreover, we include factors such as world oil reserves, gas prices, and the US dollar exchange rate in the model in order to fulfill the objectives of this research. Finally, we test the hypothesis of an oil market equilibrium and find that oil prices were adjusting instantly between 1999 and 2017, which confirms the existence of the equilibrium (in line with Taghizadeh-Hesary and Yoshino [2014] and Yoshino and Taghizadeh-Hesary [2016]).

The empirical evidence obtained shows the scale of the contributions of the abovementioned factors to global oil prices and suggests that over the last two decades, oil prices were mostly driven by oil demand from large energy consumers. Since crude oil is a crucially important production input, understanding the sources of oil price movements and improving the accuracy of energy price forecasts will eventually contribute to developing energy policy implications and help to strategically deal with unexpected oil price shocks.

This research provides the theoretical and empirical framework on the impacts of oil supply and demand factors on the over the last 2 decades, disaggregating the oil demand side into three components and testing for the equilibrium of the oil market. Crude oil is proved to be the most important production input in the economy and is critical to economic growth. Thus, it is crucial to understand the factors that affect global prices, not only for economic policy making but also for the private sector. Among the variables affecting international oil prices, we differentiate between the physical (oil supply, demand, and reserves) and financial (the US dollar exchange rate and the price of gas) variables. Also, we disaggregate oil demand into demand from the Organization for Economic Co-operation and Development (OECD), the PRC, and India to identify the contributions of the most significant oil consumers to oil price movements and compare the role of advanced and developing countries in global oil price determination.

The rest of this paper is organized as follows. In the second section we provide a literature review. In the third section, we review the oil demand side. In the fourth section, we develop a theoretical model, followed by statistical tests and econometric work in the fifth section. Section 6 discuss the results and concludes the paper.

## 2. LITERATURE SURVEY

As discussed in Alekhina and Yoshino (2018a), the literature on oil price movements and their sources and effects was pioneered by Hamilton (1983) and followed by wide number of studies. Among others, Kilian (2009) first differentiated between different types of oil shocks; Hamilton (2009) explained the oil shock of 2007–2008; Kilian and Hicks (2013) showed the contribution of an economic boom in emerging economies to the real price of oil; Askari and Krichene (2010) estimated the impacts of monetary policy, the exchange rate, and the prices of gas on the oil market; Peersman and Van Robays (2012) confirmed the cross-country differences in responses to oil price shocks; and Ratti and Vespignani (2014) assessed the impact of the oil supply sector on oil prices.

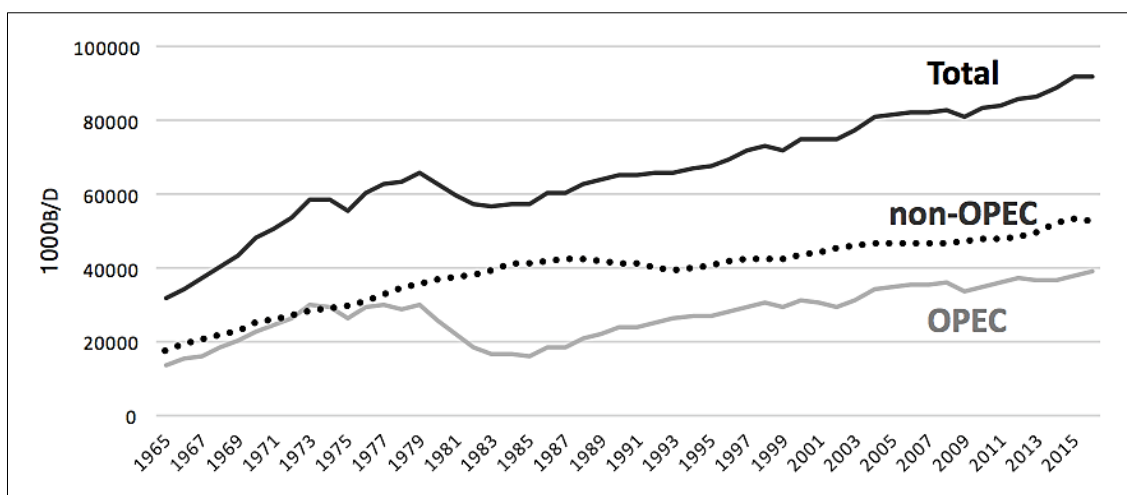
Recently, the strong relationship between oil price fluctuations and monetary policy, the business cycle, and real economic activity has been discussed extensively. For example,

Kormilitsina (2011) provides a dynamic stochastic general equilibrium model for oil market and explains the optimal monetary policy measures in response to an oil price shock. Finn (2000) explains the effects of oil price shocks on real economic activity, assuming perfect market competition. Huynh (2015) provides an estimation of the impacts of energy prices on the business cycle, while Taghizadeh-Hesary and Yoshino (2014) develop an oil demand and supply model considering a monetary policy variable. Alekhina and Yoshino (2018a) and Alekhina and Yoshino (2018b) show that oil price fluctuations have a significant impact on the macroeconomic variables and monetary policy of an energy exporting economy. Thus, it is of paramount importance to understand the sources of oil price volatility for policy makers, the private sector, and individuals.

As mentioned in Ratti and Vespignani (2014), Hamilton (2013) identifies two most recent periods in the history of oil prices that are associated with significant shifts in the energy market:

1. “The age of OPEC” (1973–1996), when the focus of the global oil market shifted to the Middle East from North America; the average real oil price increased; and oil pricing was dominated by OPEC supply.
2. “A new industrial age” (1997–2010), when economic growth in developing economies, such as the PRC and India, boosted the demand for oil, which increased the supply of oil from non-OPEC countries, decreasing the market power of OPEC.

**Figure 2: World Crude Oil Production, 1965–2015**



B/D = barrels per day, OPEC = Organization of the Petroleum Exporting Countries.

Sources: BP Statistical Review of World Energy; IEEJ.

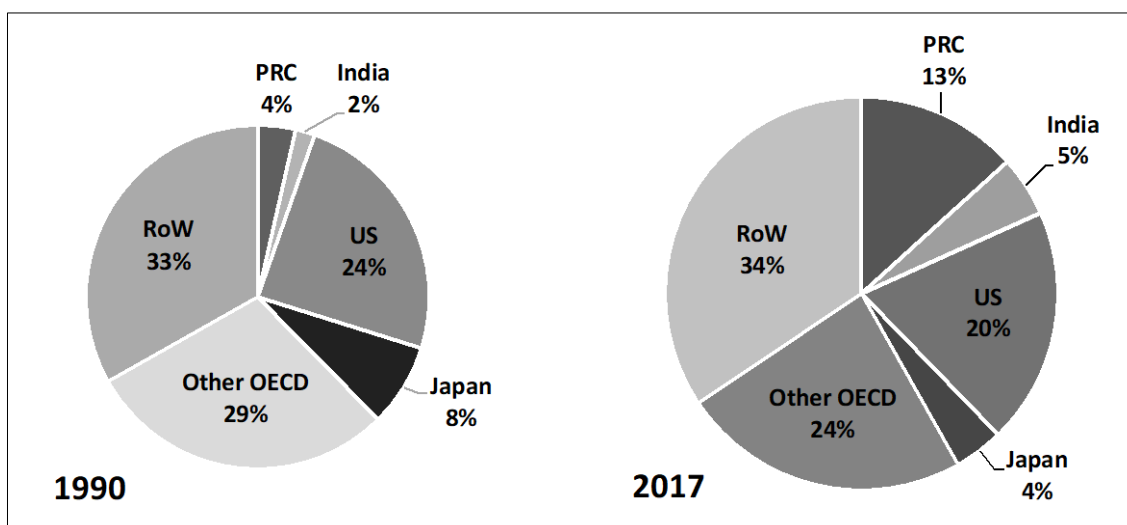
Understanding the sources of oil prices movements is of importance since they affect various industries and sectors in the macroeconomy. Hence, oil price inflation may have a harmful effect on economic growth. Historically, OPEC had control over oil prices through the supply volume (Figure 2) since demand for oil was almost price inelastic. However, due to increased oil supply from other countries and also the rapid development of new technologies, which allow for energy extraction from alternative sources as well as for relatively easier substitution between different energy products, the price of oil became more sensitive to a number of different factors.

This research complements existing studies in several aspects. Firstly, the demand side of oil market is disaggregated into the demand from the OECD (an average of 36 economies), the PRC, and India to estimate the scale and difference in the impacts of these main oil consumers. Secondly, industrial production (IP) is considered as a determinant for oil demand (following Ratti and Vespignani [2016]) as it is highly associated with oil consumption. Finally, global oil reserves, the US dollar exchange rate, and gas prices are considered as they have been proved to play important roles in oil price determination (Hamilton and Herrera 2004; Askari and Krichene 2010).

### 3. OVERVIEW OF THE OIL DEMAND SIDE

Figure 3 shows the total world oil consumption, which has grown by around 40% (1.3% average annual growth) from 3,154 megatons (Mt) to 4,470 Mt between 1990 and 2017.<sup>1</sup> While OECD countries have experienced a decline in the percentage share in total oil consumption, the PRC and India have significantly expanded their oil consumption.

**Figure 3: Total Oil Consumption, 1990 and 2017**



OECD = Organisation for Economic Co-operation and Development, PRC = People's Republic of China, RoW = rest of world, US = United States.

Sources: BP Statistical Review of World Energy; Institute of Energy Economics, Japan (IEEJ).

#### 3.1 Organisation for Economic Co-operation and Development

Established in 1961, the OECD consists of advanced economies, including the United States, much of Europe, Japan, and other countries. The OECD's total oil consumption grew from 1,455 Mt in 1990 to 2,115 Mt in 2017.<sup>2</sup> In 2017, around half of world's total oil was consumed by a total of 36 OECD countries (Figure 3). However, recent consumption growth has been much lower than that of non-OECD countries. In recent decades, oil consumption in the OECD has significantly declined due to an economic downturn in some member countries and more mature transportation sectors in others. Although developed economies tend to have higher vehicle ownership per capita, they

<sup>1</sup> IEEJ EDMC, BP Statistical Review of World Energy.

<sup>2</sup> BP Statistical Review of World Energy June 2018.



also have higher fuel taxes and policies to improve energy efficiency and speed up the development of alternative energy sources. Furthermore, the service sector is usually larger than the energy-intensive manufacturing sector in advanced countries, which also contributes to slower oil consumption growth even in times of economic growth. In contrast, developing countries have larger manufacturing and less-developed transportation sectors with high potential for growth, which is associated with larger growth in oil consumption.<sup>3</sup>

### 3.2 People's Republic of China

Among non-OECD countries, the PRC's oil consumption during the last two decades has seen the fastest growth (from 113 Mt in 1990 to 596 Mt in 2017)<sup>4</sup> due to rapid economic development. Crude oil consumption shares in the world's total increased from 4% for the PRC in 1990 to 13% in 2017, making the PRC the top oil importer by volume.<sup>5</sup> As the most populous country with a rapidly growing economy, the PRC was a net oil exporter until the early 1990s and became the world's largest net importer of crude oil and petroleum products by volume in 2013.<sup>6</sup> The PRC's oil consumption growth accounted for about 43% of the world's oil consumption growth in 2014. The country's total petroleum and other production, the fourth-largest in the world, has risen about 50% over the past two decades and serves only its domestic market. However, production growth has not kept pace with demand growth during this period. Total net oil imports, driven primarily by crude oil imports, now outweigh domestic supply, and oil import dependency rose from 30% in 2000 to about 57% in 2014 by EIA estimates. Besides crude oil, the PRC is the world's top coal producer, consumer, and importer and accounts for almost half of global coal consumption, and coal supplies the majority of the PRC's total energy consumption (66% in 2012). Furthermore, the use of natural gas has been rapidly increasing over the past decade.<sup>7</sup>

### 3.3 India

India, the world's second most populated country, has been becoming crucially dependent on energy imports as a result of its rapid economic development. India has also had one of the fastest growths in oil consumption during the last two decades due to the economic growth. Crude oil consumption shares in the world's total increased from 2% for India in 1990 to 5% in 2017, making India the top oil importer behind the PRC and the US by volume.<sup>8</sup> As the largest petroleum consumer after the US and the PRC, India has rapidly growing energy needs. Primary energy consumption in India more than doubled between 1990 and 2013, reaching an estimated 775 million tons of oil equivalent.<sup>9</sup> Oil consumption increased from 58 Mt in 1990 to 222 Mt in 2017.<sup>10</sup> At the same time, India's per capita energy consumption is one-third of the global average, according to the International Energy Agency (IEA), indicating room for higher

---

<sup>3</sup> According to the EIA (<https://www.eia.gov/finance/markets/crudeoil/demand-oecd.php>).

<sup>4</sup> IEEJ EDMC, BP Statistical Review of World Energy.

<sup>5</sup> IEEJ EDMC, Energy Statistics Yearbook 2016 (United Nations).

<sup>6</sup> According to the EIA (<https://www.eia.gov/todayinenergy/detail.php?id=1553>).

<sup>7</sup> According to EIA (2015). *Country Report: China*. Washington, DC. US Energy Information Administration (<https://www.eia.gov/beta/international/analysis.cfm?iso=CHN>).

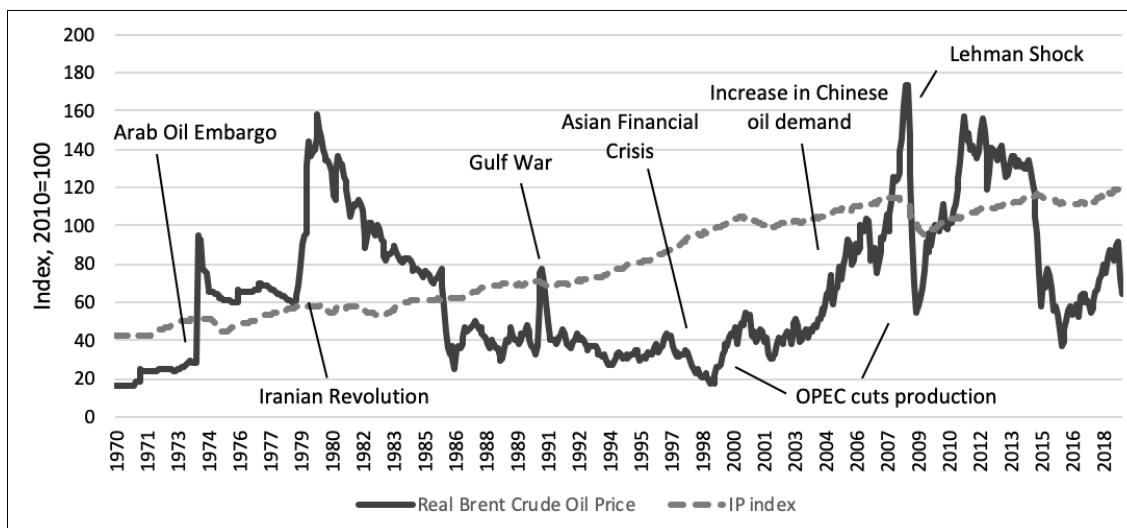
<sup>8</sup> IEEJ EDMC, Energy Statistics Yearbook 2016 (United Nations).

<sup>9</sup> International Energy Agency. India: Balances for 2013.

<sup>10</sup> IEEJ EDMC, BP Statistical Review of World Energy.

energy demand in the long term as the country continues its economic development.<sup>11</sup> According to the IEA, in 2013, India's largest energy source was coal (44%), followed by traditional biomass and waste (24%) and petroleum and other liquids (23%). Other renewable fuel sources make up a small portion of primary energy consumption, although the capacity potential is significant for several of these resources, such as solar, wind, and hydroelectricity.<sup>12</sup>

**Figure 4: Real Brent Crude Oil Price Index and US Industrial Production Index (2010=100)**



OPEC = Organization of the Petroleum Exporting Countries.

Note: Monthly average oil prices are adjusted for the US monthly consumer price index, 2010=100.

Source: Federal Reserve Bank of St. Louis; Swiss National Bank.

Currently, besides the physical volume of oil produced and consumed through demand and supply channels, oil prices are affected by a number of factors (Figure 4), such as but not limited to:

1. The US dollar exchange rate. Oil prices are denominated in US dollars; therefore, a depreciation of the US dollar must push oil prices up since it will increase demand from countries using non-US dollar currencies.
2. Natural gas and coal prices. Increasing substitutability with oil and its large expansion allow these prices to influence the oil supply and prices.
3. Oil reserves. Reserves affect oil prices through the supply side since new discoveries positively contribute to oil output.
4. Monetary policy. Easy monetary policy with low interest rates stimulate demand for goods, and therefore lead to an increase in the demand for oil, pushing up oil prices.
5. Renewable energy development, market speculations, and other factors.

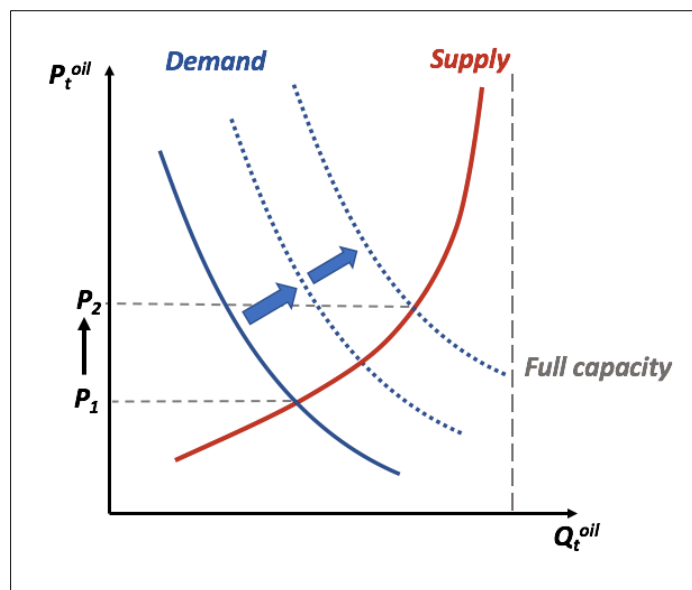
Besides the abovementioned factors, there are also geopolitical events and other trends affecting global oil prices, as summarized and presented in Figure 4. Oil demand, supply,

<sup>11</sup> International Energy Agency. World Energy Outlook 2015, pp. 428.

<sup>12</sup> According to EIA (2016). *Country Report: India*. Washington, DC. US Energy Information Administration (<https://www.eia.gov/beta/international/analysis.cfm?iso=IND>).

and the price relationship with the demand side pushing oil prices up are summarized in Figure 5.

**Figure 5: Oil Demand, Supply, and Price**



Source: Authors.

## 4. MODEL

### 4.1 Oil Demand

Following Taghizadeh-Hesary and Yoshino's (2014) methodology of a two-country (oil exporter and oil importer) model, we can assume a simplified multi-input production function for an oil importing country:

$$Y_t^d = f(K_t^d, N_t^d, E_t^d) \quad (1)$$

Where  $Y_t^d$  is total production,  $K_t^d$  is the capital input,  $N_t^d$  is the labor input or the total number of man-hours worked in a year, and  $E_t^d$  is the energy input. Assuming that in (1) all variables are in per capita form, we can omit the labor wage in our model:

$$\frac{Y_t^d}{N_t^d} = f\left(\frac{K_t^d}{N_t^d}, \frac{E_t^d}{N_t^d}\right) \quad (2)$$

Assuming the above production function:

$$y_t^d = f(k_t^d, q_t^e) \quad (3)$$

$q_t^e$  is the energy input, which can be disaggregated as follows:

$$q_t^e = v(q_t^o + q_t^g) \quad (4)$$

where  $q_t^o$  is the crude oil input (in barrels) and  $q_t^g$  is the natural gas input (in cubic feet) as natural gas is the main substitute to crude oil (due to existing technologies). Since oil

and gas are the main substitutes not oil and coal, we omit coal in our model. The Cobb-Douglas production function will be:

$$y_t^d = f(k_t^d)^\alpha (q_t^e)^\beta \quad (5)$$

$$\text{s.t. } \alpha + \beta = 1 \quad (6)$$

$$\frac{\partial f}{\partial k_t^d} = \frac{\alpha y_t^d}{k_t^d} \quad (7)$$

$$\frac{\partial f}{\partial q_t^e} = \frac{\beta y_t^d}{q_t^e} \quad (8)$$

An oil importer's profit equation can then be expressed as:

$$\text{Max } \pi_t^d = p_t^y y_t^d - i_t k_t^d - e_t p_t^e q_t^e \quad (9)$$

$$\text{s.t. } \alpha + \beta = 1 \quad (10)$$

where  $p_t^y$  is the output price level,  $i_t$  is the borrowed capital rent, and  $p_t^e$  is the energy price in US dollars.  $e_t$  is the exchange rate since all oil and gas are denominated in US dollars. We can obtain using the Lagrange function:

$$\mathcal{L} = (p_t^y y_t^d - i_t k_t^d - e_t p_t^e q_t^e) - \lambda [y_t^d - (k_t^d)^\alpha (q_t^e)^\beta] \quad (11)$$

$$\frac{\partial \mathcal{L}}{\partial k_t^d} = -i_t + \lambda \left( \frac{\alpha y_t^d}{k_t^d} \right) = 0 \quad (12)$$

$$\frac{\partial \mathcal{L}}{\partial q_t^e} = -e_t p_t^e + \lambda \left( \frac{\beta y_t^d}{q_t^e} \right) = 0 \quad (13)$$

$$\frac{\partial \mathcal{L}}{\partial y_t^d} = p_t^y - \lambda = 0 \quad (14)$$

$$-i_t + p_t^y \left( \frac{\alpha y_t^d}{k_t^d} \right) = 0 \quad (15)$$

$$k_t^d = \frac{\alpha p_t^y y_t^d}{i_t} \quad (16)$$

$$-e_t p_t^e + p_t^y \frac{\beta y_t^d}{q_t^e} = 0 \quad (17)$$

$$q_t^e = \frac{\beta p_t^y y_t^d}{e p_t^e} \quad (18)$$

The simplified log linear form of the oil demand side, therefore, will be:

$$\log q_t^e = \log \beta + \log p_t^y + \log y_t^d - \log e_t - \log p_t^o - \log p_t^g \quad (19)$$

$$q_t^d = d_0 + d_1 p_t^o + d_2 p_t^g + d_3 y_t^d + d_4 e_t + u_{dt} \quad (20)$$

where all variables are in logarithmic forms (in nominal terms) and the  $d$  coefficients are the elasticities of global demand. Disaggregating the demand side  $y_t^d$  into demand from OECD (advanced economies' demand) and the PRC and India (developing economies' demand) and assuming industrial production is a key determinant of oil demand, we can finally obtain the structural demand equation (21):

$$q_t^d = d_0 + d_1 p_t^o + d_2 p_t^g + d_3 i p_t^o + d_4 i p_t^c + d_5 i p_t^i + d_6 e_t + u_{dt} \quad (21)$$

## 4.2 Oil Supply

For the oil exporter, we assume the production function consists of capital  $K_t^s$ ;  $N_t^s$  is the labor input; and energy reserves are  $R_{t-1}$ ; as described in the previous subsection for the oil demand side (oil-importing country):

$$q_t^s = f(K_t^s, N_t^s, R_{t-1}) \quad (22)$$

Assuming that in (22) all variables in per capita form:

$$\frac{Y_t^s}{N_t^s} = f\left(\frac{K_t^s}{N_t^s}, \frac{R_{t-1}}{N_t^s}\right)$$

(23)

Thus, we can obtain:

$$y_t^s = (k_t^s, r_{t-1}^o)$$

(24)

Following Taghizadeh-Hesary and Yoshino (2014), we also assume that the total oil supply is equal to the total oil production described by the following equation:

$$Q_t^s = \sum_{t=0}^T q_t^s \quad (25)$$

where  $Q_t^s$  is the total extraction at the end of period  $t$ ,  $q_t^s$  is the oil output (extraction), and  $r_t^o$  is the amount of crude oil reserves at period  $t$ . Equation (26) shows the diminishing amount of proven reserves every period by  $q_t^s$ . No new discovery of oil is assumed.  $r_{t-1}^o$  is the amount of proven oil reserves.

$$r_t^o = r_{t-1}^o - q_t^s \quad (26)$$

The extraction cost is represented as in Favero, Pesaran, and Sharma (1994), where  $\alpha(q_t^s)$  is the extraction cost and  $\frac{1}{2}\beta(r_t^o - r_{t-1}^o)$  is the scarcity cost:

$$C_t(q_t^s, r_t^o) = \alpha(q_t^s) + \frac{1}{2}\beta(r_t^o - r_{t-1}^o)^2 > 0, \alpha > 0, \beta > 0 \quad (27)$$

Similarly, the maximization problem can be specified for the oil supply side, and producers of crude oil will maximize their profits as below:

$$\pi_t^s = e_t p_t^e q_t^s - [\alpha(q_t^s) + \frac{1}{2}\beta(r_t^o - r_{t-1}^o)^2] \quad (28)$$

Where  $p_t^e$  is the expected price of oil. The maximization problem can be expressed as follows:

$$\text{Max } \pi_t^s = e_t p_t^e q_t^s - [\alpha(q_t^s) + \frac{1}{2}\beta(r_t^o)^2] \quad (29)$$

$$\text{s.t. } (r_t^o - r_{t-1}^o) = -q_t^s \quad (30)$$

Therefore, from the above we can obtain:

$$\frac{\partial \pi_t^s}{\partial q_t^s} = e_t p_t^e - [\alpha(q_t^s) + \beta(r_{t-1}^o - q_t^s)] = e_t p_t^e - \alpha(q_t^s) + \beta(r_{t-1}^o - q_t^s) \quad (31)$$

$$e_t p_t^e - (\alpha + \beta)q_t^s + \beta(r_{t-1}^o) = 0 \quad (32)$$

$$q_t^s = (e_t p_t^e + \beta r_{t-1}^o) / (\alpha + \beta) \quad (33)$$

Finally, simplifying the above into the log-linear form gives the following equation for the oil supply side:

$$q_t^s = s_0 + s_1 p_t^e + s_2 e_t + s_3 r_{t-1}^o + u_{st} \quad (34)$$

Furthermore, we assume that supply is equal to demand (market clearing condition) and equate (21) to (34):

$$\begin{aligned} d_0 + d_1 p_t^o + d_2 p_t^g + d_3 i p_t^o + d_4 i p_t^c + d_5 i p_t^i + d_6 e_t + u_{dt} \\ = s_0 + s_1 p_t^e + s_2 e_t + s_3 r_{t-1}^o + u_{st} \end{aligned} \quad (35)$$

From which we can obtain the final oil price equation,<sup>13</sup> which is as follows:

$$p_t^o = \frac{[(d_0 - s_0) + d_2 p_t^g + d_3 i p_t^o + d_4 i p_t^c + d_5 i p_t^i + e_t (d_6 - s_2) - s_3 r_{t-1}^o + (u_{dt} - u_{st})]}{(s_1 - d_1)} \quad (36)$$

The empirical analysis of the developed model follows in the next section.

## 5. EMPIRICAL ANALYSIS

### 5.1 Data Description

For the analysis, we consider the period of growing oil demand from developing economies in the 1990s and use monthly data starting from January 1999 to December 2017, given the data availability.

**Table 1: Description of Variables**

Notation	Variable	Data
$p_t^o$	Brent crude oil price	Index, base year 2010
$i p_t^o$	OECD industry production	Index, base year 2010
$i p_t^c$	PRC industry production	Index, base year 2010
$i p_t^i$	India industry production	Index, base year 2010
$r_{t-1}^o$	World proved reserve of crude oil	Million barrels
$e_t$	Nominal effective exchange rate	Index, base year 2010
$p_t^g$	Henry Hub natural gas price	US dollars per million British thermal units

OECD = Organisation for Economic Co-operation and Development, PRC = People's Republic of China.

Sources: Institute of Energy Economics, Japan (IEEJ); Federal Reserve Economic Data (FRED); OECD; Swiss National Bank; BP Statistical Data; IMF; World Bank.

The monthly data is in nominal terms and is seasonally adjusted using the technique Census X-13. The original data for oil reserves were interpolated to monthly data using a linear interpolation method. The PRC's industry production data excludes construction, and all variables are in logarithmic form. We perform the augmented Dickey-Fuller (ADF) test for all variables in logarithmic forms in levels and first differences for both intercept as well as trend and intercept. All variables are stationary (do not contain unit roots) at first differences. A structural break was identified in July 2008 using the Chow test.<sup>14</sup>

### 5.2 Oil Market Adjustment Speed

In this section, we test equilibrium versus disequilibrium in the oil market between 1997 and 2017 to confirm whether (35) holds. There is rich literature on equilibrium models using a number of methods (Goldfeld and Quandt 1981; Bowden 1978). Moreover,

<sup>13</sup> Following Taghizadeh and Yoshino (2014), the expected oil price is assumed to form rationally as  $\tilde{p}_t^e = E(\tilde{p}_t^o | I_{t-1})$ , where  $E$  is the expectations and  $I_{t-1}$  is the information set in  $t-1$ . According to McCallum (1976), the actual and expected prices can be expressed as  $\tilde{p}_t^o = \tilde{p}_t^e + \eta_{st}$ , where  $\eta_{st}$  is the forecast error uncorrelated with  $I_{t-1}$ .

<sup>14</sup> Tests results are available upon request.

Taghizadeh-Hesary and Yoshino (2014) examined the equilibrium in the oil market between 1960 and 2011, incorporating a monetary policy factor. The version of the disequilibrium oil model developed in Taghizadeh-Hesary and Yoshino (2014) based on their findings is further developed in our analysis by disaggregating oil demand into demand from the OECD, the PRC, and India and including a dummy variable for the oil price drop in 2008 following the global financial crisis. It can be rewritten as follows:

$$\begin{cases} \widetilde{q}_t^d = d_0 + d_1\widetilde{p}_t^o + d_2\widetilde{p}_t^g + d_3\widetilde{ip}_t^o + d_4\widetilde{ip}_t^c + d_5\widetilde{ip}_t^l + d_6\widetilde{e}_t + d_7Z_t + u_{dt} \\ \widetilde{q}_t^s = s_0 + s_1\widetilde{p}_t^o + s_2\widetilde{e}_t + s_3\widetilde{r}_{t-1}^o + s_4\widetilde{u}_{dt} + u'_{st} \\ \widetilde{q}_t^* = \min(\widetilde{q}_t^d, \widetilde{q}_t^s) \end{cases} \quad (37)$$

$$u'_{st} = u_{st} - \eta_{st} \quad (38)$$

$$\Delta\widetilde{p}_t^o = \lambda(\widetilde{q}_t^d - \widetilde{q}_t^s) \quad (39)$$

Where  $\widetilde{q}_t^*$  is the equilibrium quantity, and the price equation is non-stochastic.  $\lambda$  represents the adjustment speed. The equilibrium is assumed to be close to disequilibrium if the oil prices adjust instantly (when  $\lambda$  is large). Solving the latter using oil price equation (35), we derive:

$$\widetilde{p}_t^o = \frac{1}{\frac{1}{\lambda} + (s_1 - d_1) \left[ \frac{(d_0 - s_0) + (d_6 - s_2)\widetilde{e}_t + d_2\widetilde{p}_t^g}{+ d_3\widetilde{ip}_t^o + d_4\widetilde{ip}_t^c + d_5\widetilde{ip}_t^l - s_3\widetilde{r}_{t-1}^o} \right] + \frac{\widetilde{p}_{t-1}^o}{1 - \lambda(d_1 - s_1)} + d_7Z_t + s_4\widetilde{u}_{dt} + (u_{dt} - u'_{st})} \quad (40)$$

Equation (36) can, therefore, be rewritten with  $p_t^{o*}$  denoting the market clearing oil price as follows:

$$\begin{cases} \widetilde{q}_t^d = d_0 + d_1\widetilde{p}_t^{o*} + d_2\widetilde{p}_t^g + d_3\widetilde{ip}_t^o + d_4\widetilde{ip}_t^c + d_5\widetilde{ip}_t^l + d_6\widetilde{e}_t + d_7Z_t + u_{dt} \\ \widetilde{q}_t^s = s_0 + s_1\widetilde{p}_t^{o*} + s_2\widetilde{e}_t + s_3\widetilde{r}_{t-1}^o + s_4\widetilde{u}_{dt} + u'_{st} \\ \widetilde{q}_t^* = \widetilde{q}_t^d = \widetilde{q}_t^s \end{cases} \quad (41)$$

$\widetilde{p}_t^{o*}$  can be derived from (38) and following Bowden (1978) as proposed in Taghizadeh-Hesary and Yoshino (2014)<sup>15</sup>:

$$\widetilde{p}_t^o = \delta\widetilde{p}_{t-1}^o + (1 - \delta)\widetilde{p}_t^{o*} \quad (42)$$

We can input  $p_t^{o*}$  derived from (40), which gives us  $\delta = \frac{1}{1 - \lambda(d_1 - s_1)}$ . Finally, we can assess equilibrium by testing the null hypothesis of  $\delta = 0$ . The estimation results for the final reduced form equation are presented in Table 2. The coefficient for  $\widetilde{p}_{t-1}^o$  is not significant, which means that  $\delta = 0$  or  $\lambda = \infty$ , or that there is immediate adjustment of the oil market, hence, indicating equilibrium, which confirms our model specification as assumed in (35).

<sup>15</sup> See Taghizadeh-Hesary and Yoshino (2014) for more details,  $E(\widetilde{p}_t^o | I_{t-1})$  and  $\widetilde{p}_t^o = \widetilde{p}_t^e + \eta_{st}$ . Therefore, the random error term  $\widetilde{u}_{dt}$  can be obtained entering the oil price equation from the supply side.



**Table 2: Reduced Form Equation with Substituted Coefficient, 1999– 2017**

$\widetilde{p}^o = 0.15 \widetilde{p}^o(-1)$ (1.16)	$-3.88 \widetilde{\varepsilon}$ (-5.34)***	$+2.25 \widetilde{ip}^o$ (1.98)*	$+1.02 \widetilde{ip}^c$ (0.43)	$-0.16 \widetilde{ip}^i$ (-0.40)	$-0.09 \widetilde{p}^g$ (-0.65)*	$-0.56 \widetilde{r}_{t-1}^o$ (-0.69)	$-0.52 \widetilde{u}_{dt}$ (-0.12)
$R^2 = 0.97$							

Note: Yearly data is used to estimate the equation. t-statistics are in parentheses. \* indicates significance at 10 %; \*\* indicates significance at 5 %; \*\*\* indicates significance at 1 %.

### 5.3 VAR Analysis

The previous section derived the oil price equation and confirmed the existence of the equilibrium in the oil market. Finally, we can analyze the oil price determinants specified in equation (36). To estimate the equation empirically, we can rely on a structural vector auto-regressive (SVAR) model, which is a popular technique in oil price modeling. Pioneered by Sims (1980), the VAR model has become a useful econometric technique for estimating the macroeconomic impacts of oil prices (Hamilton 1983; Du, He, and Wei 2010; Peersman and Van Robays 2012; Yoshino and Taghizadeh-Hesary 2016; Alekhina and Yoshino 2018a and 2018b; Taghizadeh-Hesary et al 2019; and others) as well as for analyzing the determinants of oil prices (Kilian 2009; Askari and Krichene 2010; Ratti and Vespignani 2014 and 2016; Taghizadeh-Hesary and Yoshino 2014; Yoshino and Taghizadeh-Hesary 2014; and others).

To analyze equation (36), we consider a SVAR model, which can be expressed as:

$$B_0 X_t = \beta + \sum_{i=1}^j B_i X_{t-i} + \varepsilon_t \quad (43)$$

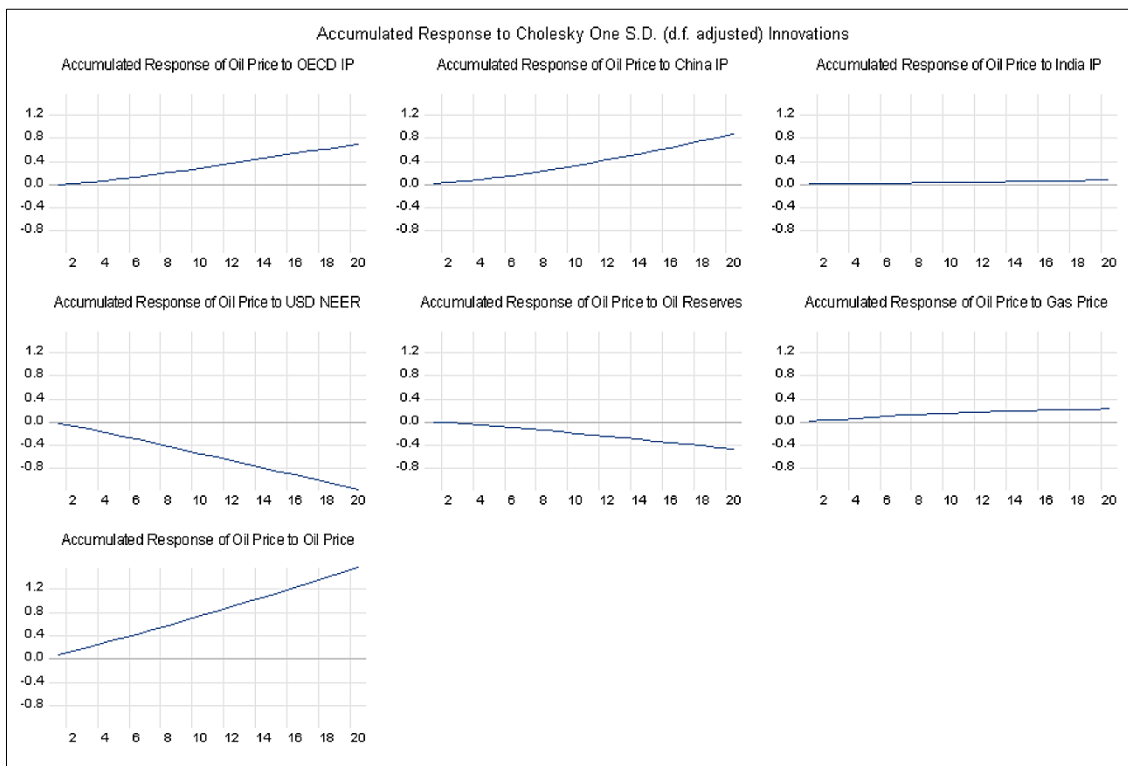
where  $j$  is the optimal lag length (determined as 2 by the Akaike Information Criterion (AIC)),  $\varepsilon_t$  is a vector of uncorrelated structural innovations with zero mean (shocks),  $B_0$  is the matrix of parameters on the contemporaneous endogenous variables, and  $B_i$  is the matrix of parameters on the lagged endogenous variables and  $n \times 1$  vector of endogenous variables  $X_t$ , which can be expressed as follows:

$$X_t = [\Delta \log(ip_t^o), \Delta \log(ip_t^c), \Delta \log(ip_t^i), \Delta \log(e_t), \Delta \log(r_{t-1}^o), \Delta \log(p_t^g), \Delta \log(p_t^o)] \quad (44)$$

We can estimate the model using monthly data from January 1999 to December 2017, which is described in Table 1.

Considering the above, we perform a co-integration test and after confirming the presence of the co-integrated equation we estimate the vector error correction (VEC) model and perform impulse response functions (IRF) analysis using recursive identification or Cholesky decomposition (zero short-run restrictions) for solving the system of linear equations, finally obtaining the impulse responses in Figure 6.

**Figure 6: Impulse Response Functions**



Note: The responses of oil prices to positive one-unit shocks. Data is for the period January 1999–December 2017, monthly seasonally adjusted in logarithmic form. Impulses for 20 months are presented.

Source: Authors' calculations.

The IRF analysis results suggest that on the oil demand side, major oil importers' industrial production (OECD countries and the PRC) significantly and positively affected oil prices between January 1999 and December 2017. The impact of the rapidly growing Chinese economy and that of the OECD group on oil prices was larger than that of India, the impact of which was almost insignificant. The US dollar exchange rate negatively affected Brent oil prices, which is in line with our assumptions. Oil reserves and gas prices have shown, respectively, slightly negative and positive associations with oil prices during the estimated period.

## 6. CONCLUSIONS AND FUTURE DISCUSSION

In this study, we estimated oil supply and demand model at the disaggregated country/region level over the last two decades. The empirical data analysis led us to the conclusion that the paradigm of the oil market has shifted during the last 20 years: recently, the oil demand side has affected oil prices more than the supply side. The results show that large oil consumers, such as the group of OECD countries and the PRC (see Figure 6) now have more of an impact on oil price change rather than oil suppliers such as OPEC, the Russian Federation, or others. This is in accordance with our initial assumptions, as stated at the beginning of this paper, and also consistent with Kilian and Hicks (2013). Rapidly growing demand for oil and changes in consumer structure has led to a more diversified supply together with an increased rate of substitution between oil and other energy products due to technological progress making the demand for oil more elastic on price than ever.

We find that the appreciation of the US dollar has had a negative impact on oil prices (in line with Yoshino and Taghizadeh-Hesary [2014]). Also, the impact of the volume of world oil reserves on oil prices was slightly negative between 1999 and 2017 (Askari and Krichene (2010) found that the short-run supply is not influenced by oil reserves). Large oil importers' industrial production (OECD and the PRC) positively affected oil prices, while India's IP did not show a significant impact on oil prices since India still highly relies on coal and biomass in its energy mix. Finally, while reviewing the oil price determinants, we tested whether the oil market was in equilibrium/disequilibrium over the last 2 decades and confirmed the existence of the equilibrium and, hence, the correctness of our theoretical aggregate demand–aggregate supply model (in line with Taghizadeh-Hesary and Yoshino 2014).

## REFERENCES

- Adams, F., and J. Marquez. 1984. Petroleum Price Elasticity, Income Effects, and OPEC's Pricing Policy. *The Energy Journal*, 5(1): 115–128.
- Alekhina, V. and N. Yoshino. 2018a. Exogeneity of World Oil Prices to the Russian Federation's Economy and Monetary Policy. *Eurasian Economic Review*. <https://doi.org/10.1007/s40822-018-0115-3>.
- Alekhina, V. and N. Yoshino. 2018b. Impact of World Oil Prices on an Energy Exporting Economy Including Monetary Policy. ADBI Working Paper 828. Tokyo: Asian Development Bank Institute.
- Askari, H. and Krichene, N. 2010. An Oil Demand and Supply Model Incorporating Monetary Policy. *Energy*, 35: 2013–2021.
- Bowden, R.J. 1978. *The Econometrics of Disequilibrium*. Amsterdam: North-Holland Publishing Company.
- Du, L., He, Y. and Wei, C. 2010. The Relationship between Oil Price Shocks and China's Macro-economy: An Empirical Analysis. *Energy Policy*, 38(8): 4142–4151.
- Favero, C.A., M.H. Pesaran, S. and Sharma. 1994. A Duration Model of Irreversible Oil Investment: Theory and Empirical Evidence. *Journal of Applied Econometrics* 9: S95–S112.
- Finn, M. G. 2000. Perfect Competition and the Effects of Energy Price Increases on Economic Activity. *Journal of Money, Credit, and Banking*, 32(3): 400–416.
- Goldfeld, S.M., and R.E. Quandt. 1981. Single-Market Disequilibrium Models: Estimating and Testing. *Journal of Econometrics* 16(1): 157–157.
- Hamilton, J.D. 1983. Oil and the Macroeconomy since World War II. *The Journal of Political Economy*, 91(2): 228–248.
- . 2009. Understanding Crude Oil Prices. *The Energy Journal*, International Association for Energy Economics, 30(2): 179–206.
- . 2013. "Historical Oil Shocks" in *Routledge Handbook of Major Events in Economic History*, pp. 239–265, edited by Randall E. Parker and Robert Whaples, New York: Routledge Taylor and Francis Group.
- Hamilton, J.D. and Herrera, A.M. 2004. Oil Shocks and Aggregate Macroeconomic Behavior: The Role of Monetary Policy: A Comment. *Journal of Money, Credit, and Banking*, 36(2): 265–286.
- Herrera, A. M., L.G. Lagalo, and T. Wada. 2011. Oil Price Shocks and Industrial Production: Is the Relationship Linear?" *Macroeconomic Dynamics*, 15 (3): 472–497. <https://doi.org/10.1017/S1365100511000290>.
- 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): 1053–1069.
- Kilian, L. and B. Hicks. 2013. Did Unexpectedly Strong Economic Growth Cause the Oil Price Shock of 2003–2008? *Journal of Forecasting* 32(5): 385–394.
- Kormilitsina, A. 2011. Oil Price Shocks and the Optimality of Monetary Policy. *Review of Economic Dynamics*, 14(1): 199–223.

- McCallum, B.T. 1976. Rational Expectations and the Natural Rate Hypothesis: Some Consistent Estimates. *Econometrica* 44(1): 43–52.
- Peersman, G. and I. Van Robays. 2012. Cross-Country Differences in the Effects of Oil Shocks. *Energy Economics*, 34(5): 1532–1547.
- Ratti, R.A. and J.L. Vespignani. 2014. OPEC and Non-OPEC Oil Production and the Global Economy. *Energy Economics*, 50: 364–378.
- . 2016. Oil Prices and Global Factor Macroeconomic Variables. *Energy Economics*, 59: 198–212.
- Sims, C. A. 1980. Macroeconomics and Reality. *Econometrica* 48(1): 1–48.
- Taghizadeh-Hesary, F., E. Rasoulinezhad, and N. Yoshino. 2019. Energy and Food Security: Linkages through Price Volatility. *Energy Policy*, 128: 796–806.
- Taghizadeh-Hesary, F. and N. Yoshino. 2013. Which Side of the Economy Is Affected More by Oil Prices: Supply or Demand? Working Paper No. 13-139, United States Association for Energy Economics (USAEE), Cleveland, OH.
- . 2014. Monetary Policies and Oil Price Determination: An Empirical Analysis. *OPEC Energy Review*, 38(1): 1–20.
- 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. *Frontiers of Economics in China*, 8(4): 571–591.
- Taghizadeh-Hesary, F., N. Yoshino, M. Mohammadi Hossein Abadi, and R. Farboudmanesh. 2016. Response of Macro Variables of Emerging and Developed Oil Importers to Oil Price Movements. *Journal of the Asia Pacific Economy*, 21(1): 91–102.
- Yoshino, N., and V. Alekhina. 2016. Impact of Oil Price Fluctuations on an Energy Exporting Economy: Evidence from Russia. *Journal of Administrative and Business Studies*, 2(4): 156–166.
- Yoshino, N. and F. Taghizadeh-Hesary. 2014. Monetary Policy and Oil Price Fluctuations Following Subprime Mortgage Crisis. *International Journal of Monetary Economics and Finance*, 7(3), 157–173.
- . 2016. *Monetary Policy and the Oil Market*. Tokyo: Springer.
- . 2017. *Japan's Lost Decade: Lessons for Asian Economies*. Singapore: Springer.