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Brent–Dubai oil spread: Basic drivers

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ABSTRACT

This study aims to assess and quantify the effects of potential economic drivers on the Brent–Dubai price spread using the time-dependent Kalman filtering technique. To understand the pricing mechanism of crude oils, it is necessary to distinguish the driving forces of the world oil market. The Brent–Dubai price spread is selected as a global indicator representing trends in world oil trade and global economic activities. The estimates suggest that the global economic activities represented by the world trade index, world oil demand, world steel production, the number of world airline passengers and regional dynamics proxied by the growth rate of China over the US and the Euro Area have explanatory power on the Brent–Dubai spread.

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1. Introduction

The price of crude oil is one of the key factors affecting the global economy. Crude oil is consumed especially by the transportation and manufacturing sectors around the world and accounts for a large share of the world's energy consumption. It is a major cost item for oil-importing countries, whereas it has a large share in their GDPs for most of the oil-producing countries. While high oil prices provide high earnings for oil-exporting countries, they can increase the costs of energy-intensive sectors like the airline industry, transportation and manufacturing, consequently decreasing world's consumption, diminishing the growth level of oil-importing countries as well as increasing worldwide price levels and triggering inflationary pressures. On the other hand, lower oil prices mean a reduction in the revenues of oil-exporting countries, a decrease in investment spending of oil-producing companies and can even lead to bankruptcy and higher unemployment in the oil sector. Therefore, crude oil price movements are closely followed by policymakers, manufacturers, investors and researchers as they convey information about the present and future trends in global economic activities, consumption, investment opportunities and trade. In this respect, a detailed analysis of crude oil prices and their driving factors would be useful for those interested in the crude oil market. However, oil is not a homogeneous

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product and is priced differently depending on quality and physical characteristics although almost all oil types are priced relative to a set of benchmarks.

Numerous crude oil blends with particular physical properties are extracted in various regions of the world. These blends are priced against a few global benchmark crude oils: West Texas Intermediate (WTI), Brent and Dubai. These benchmarks operate as the representatives of world oil blends with different specifications and liquid financial instruments traded in the global oil market. Therefore, relevant information about the pricing process of the whole world oil market requires a detailed analysis of pricing relationships among these benchmarks and driving factors effective in these relationships, which will be discussed in the literature review in detail. However, in short, as suggested by [Wilmot \(2013\)](#), although until 2010 prices of different oil blends moved together with stable price spreads supporting the unified world oil market hypothesis, this link started to widen after 2010. This implies that there might be some drivers that can affect each crude oil price differently and lead to disparities in oil prices.

One possible explanation of diversified oil prices might be the heterogeneity of drivers affecting oil prices differently. Variables representing economic activities such as industrial production, developments in the airline and/or maritime industry, transportation, world consumption, demand for crude oil to obtain the final products, exchange rates, price levels, investor behavior and geopolitical risks can affect crude oil prices in various ways and play a major role in the price formation process ([Gyagri et al., 2017](#)). Determining these drivers and quantifying their effects will contribute to a better understanding of oil market dynamics, the behavior of oil price spreads and the price discovery process. As the effects of these drivers on the prices of different crude oil blends are not homogeneous and lead to altering oil price spreads, such a study will also provide information about how and at which level economic events affect the behavior of oil price spreads and oil contracts which might lead to arbitrage opportunities in oil markets. The main contribution of the current study is to quantify the effect of economic drivers on oil price spreads.

One of the important spreads closely followed by oil market investors is Brent–Dubai, which is also a financial instrument of the world oil market. Brent and Dubai are significant benchmarks to follow in the world oil market for different reasons. Although WTI and Brent are accepted as global benchmarks, Brent has been the dominant benchmark crude oil in the global oil market since 2007. Dubai, an emerging international benchmark especially since 2009, is highly traded in Asian markets ([Kim et al., 2013](#)). The Brent–Dubai relationship attracts special attention as a key instrument for evaluating the relative price of Brent related light-sweet crudes over Dubai related medium-sour crudes since the rising world demand for medium/heavy-sour crudes has placed more importance on Dubai as a benchmark. Due to Asia's increasing share in the world's oil consumption and energy demand, the Dubai benchmark has gained importance in global oil pricing strategies ([Hammoudeh et al., 2008](#); [Gyagri et al., 2017](#)). If the Brent–Dubai price spread is wide (i.e., the price difference curve is high), this might suggest low demand for crude oil in Asia and/or a supply-side risk in the Brent curve. In contrast, a narrow Brent–Dubai spread indicates a lower price differential, signaling a decrease in the gap between light and medium crude oils. Thus, it can be said that the pricing mechanism of the Brent–Dubai spread conveys information about the current and future actions of oil market players as well as trends in global oil trade, which requires the analysis of drivers affecting the Brent–Dubai price relationship. This study aims to assess and quantify the effects of potential economic drivers on the Brent–Dubai price spread.

A number of drivers that affect the Brent–Dubai spread were introduced by [Imsirovic and Pryor \(2018\)](#). These are demand for oil refinery products, OPEC (Organization of Petroleum Exporting Countries) decisions, transportation costs and arbitrage opportunities, geopolitical incidents, global trends and international policy sanctions like the cap on sulfur content in marine fuels required by the IMO (International Maritime Organization). However, the effect of these drivers on the Brent–Dubai spread has not been quantified through an econometric model.

The main contribution of our study is to identify the main economic drivers for the Brent–Dubai price spread based on a dynamic time series model. Thus, it would be possible to understand how various economic activities of countries affect demands for different oil blends and their prices, which might bring about an opportunity to foresee trends in the oil trade. In our attempt to do this, unlike the review study by [Gyagri et al. \(2017\)](#), the cointegration analysis of [Hammoudeh et al. \(2008\)](#), or the policy analysis of [Imsirovic and Pryor \(2018\)](#), we quantify the effect of economic drivers on the Brent–Dubai spread using a time-varying Kalman filter approach. Following the empirical literature, a set of economic drivers are considered for the present study; e.g. the relative growth of China and India to that of the US or the Euro Area, global PMI (Purchasing Managers' Index), OPEC spare oil capacity, global oil production, global oil exports, global rig count, the Baltic dry index, the Kilian index, the world trade index, world steel production, the number of world airline passengers and world oil demands. Our empirical findings suggest that the world trade index, world oil demands, world steel production, the number of world airline passengers, the China–US growth differential, and the China–Euro Area growth differential are some economic drivers that affect Dubai oil price differently from Brent.

The next section will describe the crude oil types and their yields. The review of the literature will be presented in section three. Section four explains the empirical framework. The methodology will be presented in section five; the data will be introduced in section six and empirical evidence is presented in section seven. The last section is for the conclusion.

2. Crude oil types and their yields

Various factors can affect prices in the global oil markets: diversity of oil types, physical properties of oil brands, geographical locations of oil production areas, yield rates of end products extracted from different oil brands and

investment strategies of oil market players. In particular, the physical properties of oils and refinery yield rates are the two basic factors that affect price of oil.

Crude oil is a non-uniform commodity in the sense that the quality and physical characteristics of crude oil extracted in one region are different from oils extracted in other regions of the world due to their diverse physical conditions. Specifically, two basic characteristics of crude oil are assessed according to their API (American Petroleum Institute) gravities and sulfur contents.

Different oil types are classified as light, medium, and heavy according to their API gravity, while sweet and sour indicate their sulfur level. Oils with high API gravity and low sulfur content are called light-sweet oils, while low API gravity and high sulfur content oils are regarded as medium/heavy-sour oils. Thus, according to their physical properties, Brent and WTI are global benchmarks for light-sweet crude oils, whereas Dubai is used as the benchmark for medium-sour blends.

The physical properties of oils affect their market prices since physical properties affect oil processing procedures, necessary refinery specifications, refinery technology and, consequently, refining costs. Light-sweet oils are traded at higher prices compared to medium/heavy-sour crudes since they can easily be processed in refineries without necessitating further upgrading (MathPro, 2011).

Refinery yield rate is another criterion for assessing the value of crude oils. After refining, crudes with different physical properties yield different amounts of end products: gasoline, diesel, jet fuel, kerosene, home heating oil, asphalt, etc. Among these, transportation fuels [gasoline (land transportation), diesel (land transportation), jet fuel (air transportation), and heavy fuel oil (maritime transportation)] are the most valuable refined products. Refineries are designed to achieve maximum gain for the most highly demanded products by trading off the other outputs. This way, it becomes possible to meet changing demands for various refined products (MathPro, 2011). Brent, as a global benchmark for light-sweet oil blends, is mostly refined to produce light end petroleum products such as gasoline and naphtha. However, Dubai is the benchmark for the world's largest regional source of medium-sour crude oil basket. This makes the Dubai price an indicator for the medium grade crude oil market; thus, medium-sour blends like Dubai are the major sources of middle distillate oil products like diesel/gasoil and jet fuel/kerosene. Therefore, the Brent–Dubai spread moves with the market conditions that differentiates between light-sweet and medium-sour crude oils.

3. Review of literature

In the literature, different aspects have been studied regarding the multivariate analyses of crude oil prices. One group of studies aims to determine the main drivers affecting the prices of different types of crude oil and examines the relationship between crude oil prices and several financial and economic drivers. Another group of researchers focused on the interaction among different crude oil prices. The purpose of this article is to identify a set of drivers for the interactions between the prices of two benchmark oils: Brent and Dubai.

In the first group, various models were employed to estimate the relationships between oil prices and their drivers. The findings of empirical literature suggest a number of factors: industrial production; developments in the airline industry, maritime industry and transportation; and exchange rates (see, for example, Ratti and Vespignani, 2016; Liu et al., 2019).

Li et al. (2019b) discussed the connection between investor behavior and major crude oil markets and observed that investor behavior weakly Granger causes WTI, Dubai, Daqing spot prices and Brent futures while bidirectional causality exists between WTI future returns and investor behavior. Furthermore, their results suggested that investors mostly refer to the WTI market as the benchmark rather than other crude oils. Li et al. (2019a) examined the relationships between geopolitical risks and the prices of WTI, Brent, Dubai and Nigerian Forcados crude oils.

In addition to the drivers of crude oil prices, the relationship among a set of oil prices is a well-studied area in the literature within the unified world oil market or the law of one price hypothesis. They suggest the existence of an integrated international crude oil market so that price differentials among crude oil prices should not be high and there exists a long-run co-movement among them. Moreover, the prices of oils having similar physical properties should align closely after adjusting for quality, extraction and transportation cost allowances so that price spreads for those oils remain stable. Proponents of the unified world oil market hypothesis include Adelman (1984), Gulen (1997, 1999), Silvapulle and Moosa (1999), Ewing and Harter (2000), Hammoudeh et al. (2008), Bekiros and Diks (2008), Fattouh (2010), Wilmot (2013), Kim et al. (2013), Kuck and Schweikert (2017) and Luo et al. (2018). Starting in 2010, it seems that the world oil market is facing a transformation from being one global market to becoming regional markets. The findings of Weiner (1991), Milonas and Henker (2001), Kaufmann and Ullman (2009), Chang et al. (2010), Liu et al. (2013), Lu et al. (2014), Kaufmann and Banerjee (2014) and Xiao and Huang (2018) do not support the unified world oil market hypothesis, suggesting that long-run co-movement may not exist among oil prices.

As for the dominance of benchmark oils, although Chang et al. (2010), Lu et al. (2014) and Xiao and Huang (2018) found that WTI and Brent are dominant in the oil market, Zhang (2013), Aruga (2015) and Ji and Fan (2015) and more recently Zhang et al. (2019) showed that WTI is losing its power as a benchmark while Brent and Dubai are becoming dominant in the global market.

China being a fast-growing economy, the integration of the Chinese oil market with global oil markets has attracted the attention of some researchers. Among them, Jia et al. (2015), Chan and Woo (2015) and Song et al. (2019) explored dynamic correlations among the prices of Chinese Daqing crude oil and global benchmark oils. Particularly, Song et al.

(2019) found that Dubai has the highest impact on Daqing, indicating the rising effect of Dubai as a benchmark in international oil markets. It was also suggested that while the WTI-Brent relationship is strong, the WTI-Dubai and Brent-Dubai pairs have relatively low correlations, implying that Asian and Middle East crude oil markets are moving closer while European and American crude oil markets are in convergence.

4. Empirical framework

Demand for petroleum products is mostly a function of human activities. These could range from industrial activities to personal activities like holidays or leisure. Each of these activities requires energy consumption, and crude oil products are the main source of energy in today's world. Therefore, it can be argued that economic activities have a direct impact on crude oil prices through consumption of and demand for refined oil products in various industrial activities. Moreover, different regions of the world have different scales and cycles of economic activities. This also results in different demand patterns for different petroleum products in each region. Owing to the fact that each type of crude oil has its own physical properties, demand for crude oil in different parts of the world varies such that certain crude oil blends are not demanded in some regions at all. This fact, combined with freight and refinery economics, shapes the demand pattern for petroleum products.

If there is an increase in economic activities that require the consumption of more middle distillate oil products, then it is expected that the demand for Dubai will go up, leading to a shift in the Brent-Dubai spread and vice versa. This pattern forces Dubai and Brent to diverge parallel to the divergence between middle distillate and light petroleum final products. Thus, it can be concluded that economic drivers, as representative of economic activities, have certain effects on crude oil price spreads through the growing/diminishing demand for petroleum products.

Within this framework, in addition to physical properties and refinery yield rates, demand for oil end products is the third most important element in the pricing mechanism of crude oils. The economic activities of countries (such as transportation, electricity consumption and manufacturing) require energy generation and specific inputs for production, which in turn increase demand for oil products. For instance, a rise in land transportation elevates gasoline consumption, which increases the demand for light-sweet crude oils (like Brent) with higher yields of gasoline. Such a macroeconomic trend is highly likely to affect the prices of oil benchmarks in different directions.

While light end products such as gasoline used to be the most demanded refined products, light-sweet crude oils like WTI and Brent were preferred and priced higher compared to medium/heavy-sour crude oils like Dubai since typical yields of light-sweet oils contain higher volumes of valuable light end products. However, this has altered as a result of changing market conditions, economic factors and varying demands for refined oil products. As consumption of oil end products changes in different parts of the world due to various economic activities, the demand structure for light-sweet and medium/heavy-sour crude oils and their pricing dynamics are also changing. As [Imsirovic and Pryor \(2018\)](#) and [Rushforth and Blei \(2020\)](#) discussed, yield specifications of oils and demands for refined crude oil products are becoming significant drivers of benchmark oil prices. Although Brent maintains its place as the major global benchmark, Middle East crudes, mainly Dubai, are critical for Asian countries since the physical properties and end products of Middle East oils match the demand of regional economies, especially in China.

Since East Asian refineries are more suitable for processing sourer and heavier crude oils, Dubai oil is demanded more in East Asia as Dubai is sourer and heavier than Brent oil. This feature of East Asian refineries leads to higher yields of diesel, fuel oil and jet fuel ([Imsirovic and Pryor, 2018](#); [Rushforth and Blei, 2020](#); [MathPro, 2011](#)). Therefore, as world trade and worldwide production levels increase (mostly driven by Asian growth), consumption of oil products such as diesel, fuel oil and jet fuel will increase, resulting in a higher demand for sour crude. This is captured with a higher Dubai crude price. Hence, it can be argued that the Brent-Dubai spread is subject to change over time depending on the course of various influential drivers that might be critical to determining the nature of the link between the Dubai and Brent prices.

Moreover, [BP \(2020\)](#) reports that world oil consumption growth was driven by China and other emerging economies, thus indicating the importance of China in the world's oil demand. As long as China and the Asia-Pacific countries are the biggest buyers of Middle East oils, the economic structure and growth of China and the Asia-Pacific countries stand to be one of the major drivers of oil price relationship, particularly the Brent-Dubai spread.

Overall, it can be argued that global and regional economic drivers affect the nature of oil prices as much as their physical properties and yield rates. A close look at these economic drivers and global economic activities will reveal the underlying dynamics of world oil demand and the drivers of oil prices. For this, in order to capture the effects of changes in global and regional economic conditions, eight drivers have been selected and these are explained in sections six and seven.

5. Methodology

The Kalman filter method was employed to explore the effects of the various drivers that affect the Brent-Dubai oil price relationship – world trade, the number of world air passengers, world oil demand, world steel production, the China-US growth differential, the China-Euro Area growth differential, the India-US growth differential and the India-Euro Area growth differential. The Kalman filter methodology is an iterative algorithm that employs a sequence

of equations and observed data over time to estimate unobserved state variables. The state-space representation of the Kalman filter is given by:

$$\xi_{t+1} = \mu + F\xi_t + Bz_{t+1} + v_{t+1} \tag{1}$$

$$y_t = A'x_t + H'\xi_t + w_t \tag{2}$$

Eq. (1) is known as the state equation that ξ_t changes over time, and Eq. (2) is known as the signal equation, which captures the evolution of observed values of y_t through time. The covariance matrices of the noise terms can be given as follows:

$$E(v_t v'_k) = \begin{cases} Q, & \text{if } t = k \\ 0, & \text{otherwise} \end{cases}$$

where Q is a positive definite matrix,

$$E(w_t w'_k) = \begin{cases} D, & \text{if } t = k \\ 0, & \text{otherwise} \end{cases}$$

where D is a positive definite matrix.

The general forms of system matrices are given by F, B, A, H, Q and D . Q and D represent the Gaussian zero mean and non-zero covariance matrices of disturbance terms of v_t and w_t , respectively. The change in the coefficients of the observation equation is modeled by the state equation.

A set of initial values is needed for the Kalman filter estimates. The initial values are taken as $\xi_{1|0} \sim N(\hat{\xi}_{1|0}, P_{1|0})$, where $\hat{\xi}_{1|0} = 0$ and $vec(P_{1|0}) = [I - (F \otimes F)]^{-1} vec(Q)$ by following Hamilton (1994). As in Harvey (1990) and Hamilton (1994), the iterative estimation starts by calculating the Kalman Gain matrix given by

$$K_t = P_{t|t-1} H (H' P_{t|t-1} H + D)^{-1}$$

The next step is to update the covariance of ξ_t stated as

$$P_{t|t} = [I - K_t H'] P_{t|t-1}$$

With the new covariance, the updated ξ_t can be calculated by

$$\begin{aligned} \hat{\xi}_{t|t-1} &= F \hat{\xi}_{t-1|t-1} \\ P_{t|t-1} &= F P_{t-1|t-1} F' + Q, \end{aligned}$$

then, the new estimation can be obtained by

$$\hat{\xi}_{t|t} = \hat{\xi}_{t|t-1} + K_t (y_t - A'x_t - H'\hat{\xi}_{t|t-1})$$

This paper aims to capture the time-varying relationship between Brent and Dubai crude oil prices by considering the effect of a set of economic drivers. To this end, the baseline state-space model is built as follows:

$$\alpha_{c,t} = \beta_0 + \beta_1 \alpha_{c,t-1} + \beta_m driver_{t-1} + v_t \quad v_t \sim N(0, Q) \tag{3}$$

$$dubai_t = \alpha_0 + \alpha_{c,t} brent_t + w_t \quad w_t \sim N(0, D) \tag{4}$$

In the above model, Eqs. (3) and (4) represent the state equation and the signal equation, respectively. These equations explain the co-movement among the Brent and Dubai crudes and a driving factor. To rewrite Eqs. (3) and (4) similar to the state-space model given in Eqs. (1) and (2), the matrices are defined as $x_t = [1]'$, $A' = [\alpha_0]$, $\xi_t = [\alpha_{c,t}]$, $H' = [brent_t]$, $B = [driver_{t-1}]$, $Q = [\sigma_v^2]$ and $D = [\sigma_w^2]$. Here, $dubai_t$ and $brent_t$ are the prices of Dubai and Brent crude oils, respectively at time t , $driver_{t-1}$ is the value of an economic driver at time $t - 1$, and $\alpha_{c,t}$ is the time-dependent parameter. Here, if β_m is found to be statistically significant for any driver, then it can be said that the time-dependent relationship between the crude oil prices is affected by the economic driver in question.

6. Data

The data set of the study includes the world trade index, the number of world airline passengers, world oil demand, world steel production, the China–US growth differential, the China–Euro Area growth differential, the India–US growth differential and the India–Euro Area growth differential. Here, these drivers are selected to represent the changes in global and regional oil market dynamics. Accordingly, the number of world airline passengers is related to the global demand for the aviation industry and jet fuel, while the world trade index and world steel production are associated with global industrial activities. As regional economic development indicators, China–US, China–Euro Area, India–US and India–Euro Area growth differentials are selected to capture the relative growth of Eastern and Southeastern Asian economies over the US and the Euro Area. The monthly price series of Brent and Dubai are taken from Refinitiv Eikon, country growth rates are

calculated from the International Financial Statistics database of the IMF, while the number of world airline passengers is retrieved from the Worldbank database. The world trade index is taken from the World Trade Monitor, world oil demand from www.jodidb.org, and world steel production from www.worldsteel.org. Since crude oil price series are monthly and the analyses are performed with monthly data, all quarterly and annual series are converted to the monthly frequency with data interpolation. All the series employed are in natural logarithms, except for the country growth rates, which are seasonally adjusted growth rates.

7. Empirical findings

To explore the effects of the various drivers on the Brent–Dubai oil price spread, the Kalman filter method was employed. The empirical evidence is reported in Table 1, where Panel A and Panel B report the estimated coefficients of the signal and state specifications, respectively. The columns give the effects of various economic drivers on the Brent–Dubai crude oil price spread. Here, the intercept term (α_0) in the model indicates that there is a fixed drift parameter between the prices of Brent and Dubai oils independent from the effects of economic drivers. In other words, whether the level of the economic driver changes or not, the spread between the prices of oils is accounted for. The time-varying slope term ($\alpha_{c,t}$) stands for a possible long-run relationship that moves Brent differently from Dubai. A significant slope term supports the argument that there is a set of drivers that affects Dubai oil prices differently from Brent oil prices. In the first model, we assume that drivers affect only the slope term. The last value of $\alpha_{c,t}$ for the world trade index column is 0.942 and this is statistically significant.² In other words, a 1% change in Brent price generates a 0.942% change in Dubai price, which is close to a full pass through. In Panel B of this column, it is seen that the coefficient of the lagged variable, $\alpha_{c,t-1}$, is positive and statistically significant (0.887), indicating strong autocorrelation. Notably, the coefficient for the world trade index, β_m , is positive and statistically significant, suggesting that as world trade increases the Brent price will affect the Dubai price more. In other words, a positive value for β_m suggests that any driver that increases the Brent price will affect the Dubai price more.

Table 1

Time-varying Brent–Dubai spread with drivers in the slope specified by AR(1) with drift.

Panel A: Signal equation ($dubai_t = \alpha_0 + \alpha_{c,t}brent_t + w_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Constant	0.236*** (6.217)	0.157*** (4.607)	0.162*** (5.446)	0.172*** (5.748)	0.275*** (6.014)	0.219*** (5.739)	0.095*** (2.598)	0.093*** (2.547)
Brent _t (Final state value _t)	0.942***	0.967***	0.965***	0.958***	0.934***	0.952***	0.979***	0.980***
Panel B: State equation ($\alpha_{c,t} = \beta_0 + \beta_1\alpha_{c,t-1} + \beta_m driver_{t-1} + v_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Constant	0.079*** (2.975)	0.013 (0.530)	−0.041 (−1.299)	0.033 (1.633)	0.106*** (3.117)	0.108*** (2.890)	0.218*** (6.362)	0.221*** (6.468)
Brent _{t-1}	0.887*** (22.562)	0.882*** (25.661)	0.867*** (23.867)	0.870*** (25.573)	0.886*** (24.365)	0.885*** (22.331)	0.776*** (22.230)	0.773*** (22.275)
Driver _{t-1}	0.006** (2.045)	0.055*** (2.596)	0.242*** (3.195)	0.077*** (2.955)	0.002* (1.799)	0.003** (2.105)	0.002 (1.173)	0.001 (1.201)
Log lik.	553.911	745.123	748.973	777.044	507.744	548.646	450.779	450.752
Aka. In.	−4.604	−4.348	−4.345	−4.356	−4.779	−4.599	−5.112	−5.112
Sch. cri.	−4.517	−4.280	−4.278	−4.291	−4.683	−4.511	−5.003	−5.003
H-Q cri.	−4.569	−4.321	−4.318	−4.330	−4.740	−4.563	−5.068	−5.068

Note: The values in parentheses are the z-statistics of the estimates of the corresponding parameters. ***, ** and * indicate the levels of significance at 1%, 5% and 10% respectively.

Similarly, the number of world air passengers, world oil demand, world steel production, the China–US growth differential and the China–Euro Area growth differential are statistically significant drivers affecting the link between Dubai and Brent oil prices. Another engine of world growth is India. We repeat the exercise that we performed on China for India. Although the estimated coefficient for the relative growth in the state equation is positive, these coefficients are not statistically significant.

It might be misleading to assume that the drivers affect only the slope of the Brent–Dubai spread since it is possible that the margin between Dubai and Brent prices might not be constant. This might be a too-restrictive assumption; therefore, we relax this assumption and allow the time dependence feature for both the intercept and slope terms. Panel B of Table 2 shows the world trade index; the coefficient of the world trade, β_m , is negative but not statistically significant. This suggests that we could not find statistically significant evidence that world trade does affect the Brent–Dubai spread

² The level of significance is at least 10% unless otherwise mentioned.

Table 2

Time-varying Brent–Dubai spread with drivers both in the intercept and the slope specified by AR(1) with drift.

Panel A: Signal equation ($dubai_t = \alpha_{c1,t} + \alpha_{c2,t}brent_t + w_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Intercept _{1t} (Final state value _{1t})	0.211***	0.259***	0.213***	0.134***	0.140***	0.148***	−0.022	0.047***
Brent _t (Final state value _{2t})	0.947***	0.939***	0.950***	0.967***	0.971***	0.970***	1.005***	0.989***
Panel B: State equation 1 ($\alpha_{c1,t} = \beta_0 + \beta_1\alpha_{c1,t-1} + \beta_m driver_{t-1} + v_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Constant	0.083 (0.997)	−0.172 (−0.608)	0.505 (1.442)	0.365 (1.118)	0.029*** (2.698)	0.029*** (2.621)	0.032*** (2.815)	0.036*** (3.039)
Intercept _{1,t-1}	0.859*** (21.805)	0.868*** (24.694)	0.913*** (31.511)	0.825*** (20.991)	0.874*** (24.563)	0.854*** (21.530)	0.746*** (14.427)	0.767*** (18.747)
Driver _{t-1}	−0.010 (−0.571)	0.115 (0.711)	−0.690 (−1.361)	−0.279 (−0.978)	−0.031 (−1.552)	−0.017 (−1.085)	−0.102* (−1.863)	−0.057* (−1.718)
Panel C: State equation 2 ($\alpha_{c2,t} = \gamma_0 + \gamma_1\alpha_{c2,t-1} + \gamma_m driver_{t-1} + \varphi_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Constant	0.593** (2.245)	0.364 (0.532)	−2.643 (−1.063)	−0.404 (−0.765)	0.936* (1.809)	0.938 (1.311)	0.251*** (5.308)	0.958 (1.580)
Brent _{t-1}	0.000 (−0.001)	−0.114 (−0.348)	0.002 (0.002)	0.001 (0.007)	0.000 (0.001)	0.006 (0.008)	0.740*** (15.272)	−0.001 (−0.001)
Driver _{t-1}	0.074** (2.468)	0.369 (0.962)	5.128 (1.102)	1.139** (2.281)	0.087 (1.600)	0.054 (1.096)	0.027** (1.961)	0.066 (1.304)
Log lik.	563.456	762.047	711.656	796.296	508.605	550.460	444.650	448.097
Aka. in.	−4.679	−4.417	−4.533	−4.461	−4.736	−4.648	−5.095	−5.018
Sch. cri.	−4.547	−4.316	−4.425	−4.362	−4.593	−4.514	−4.930	−4.855
H-Q cri.	−4.626	−4.376	−4.490	−4.421	−4.678	−4.594	−5.028	−4.952

Note: The values in parentheses are the z-statistics of the estimates of the corresponding parameters. ***, ** and * indicate the levels of significance at 1%, 5% and 10% respectively.

with a fixed margin. On the other hand, in Panel C of the same table, the coefficient of the world trade index, γ_m , is positive and statistically significant. This indicates that the world trade index has a positive and significant effect on the slope of the Brent–Dubai spread. In other words, as world trade rises, the Dubai oil price will be affected more by the changes in the Brent oil price.

When we allow both the intercept and the slope term to change with drivers for the Brent–Dubai spread, generally speaking, we do not find statistically significant coefficients at the 5% significance level for either the constant or the slope term. Put differently, selected drivers do not have statistically significant effects on either the fixed margin or the linear relationship between Brent and Dubai prices. The world trade index (0.074) and world steel production (1.139) have a positive and significant effect on the slope indicating that as the world trade index or world steel production increases changes in the price of Brent will affect the price of Dubai more. Any increase in the world trade index or world steel production points to rising demand for oil, which in turn inflates oil prices. In this situation, our model proposes that as the price of Brent increases, the price of Dubai rises more. The relative growth of India over the Euro Area (GDP India/GDP EA) has a negative and statistically significant effect (−0.057) on the intercept only, suggesting that as the GDP India/GDP EA ratio increases, the fixed margin between the prices of Dubai and Brent decreases. In other words, as India grows more compared to the Euro Area, the price of Dubai approaches the price of Brent at a constant margin. The possible scenario behind this might be the following: As India grows, its demand for sour and heavier oil increases, which in turn increases the price of Dubai and the gap between the prices of Dubai and Brent decreases at a fixed margin. As for a driver affecting both the intercept and the slope simultaneously, the India–US growth differential (GDP India/GDP US) is the only driver affecting both the level (−0.102) and strength (0.027) of the Brent–Dubai spread at the 10% significance level. However, compared to Table 1, although almost all of the drivers (except the India–US and the India–Euro Area growth differentials) are found to be positive and statistically significant, this finding disappears to some extent in Panel C of Table 2. This weaker statistical evidence might be due to overparameterization of the specification as reported in Table 2.

In order to account for the overparameterization problems and provide robustness analyses, another specification of the model is estimated; we allow only the intercept term to vary. The results are reported in Table 3. Here, the drivers

Table 3

Time-varying Brent–Dubai spread with drivers in the intercept specified by AR(1) with drift.

Panel A: Signal equation ($dubai_t = \alpha_{c,t} + \alpha_1 brent_t + w_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Intercept _t (Final state value _t)	0.298***	0.343***	0.308***	0.352***	0.266***	0.289***	0.163***	0.159***
Brent _t	0.927*** (76.445)	0.920*** (76.902)	0.928*** (91.168)	0.915*** (83.653)	0.936*** (75.186)	0.935*** (75.925)	0.964*** (90.797)	0.965*** (92.684)
Panel B: State equation ($\alpha_{c,t} = \beta_0 + \beta_1 \alpha_{c,t-1} + \beta_m driver_{t-1} + v_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Constant	-0.108*** (-2.702)	-0.457*** (-3.033)	-0.779*** (-3.848)	-0.489*** (-3.937)	0.035*** (3.182)	0.040*** (3.800)	0.030** (2.372)	0.031*** (2.850)
Intercept _{t-1}	0.851*** (23.873)	0.864*** (24.093)	0.834*** (21.903)	0.827*** (21.294)	0.855*** (21.641)	0.837*** (21.400)	0.774*** (12.939)	0.756*** (18.056)
Driver _{t-1}	0.032*** (3.194)	0.275*** (3.112)	1.189*** (3.900)	0.462*** (4.036)	0.012** (2.244)	0.015*** (3.300)	0.007 (1.098)	0.006 (1.199)
Log lik.	566.652	766.202	770.968	801.181	509.734	561.087	448.486	455.173
Aka. in.	-4.731	-4.498	-4.473	-4.505	-4.844	-4.724	-5.175	-5.163
Sch. cri.	-4.643	-4.430	-4.406	-4.440	-4.747	-4.636	-5.065	-5.054
H-Q cri.	-4.696	-4.471	-4.447	-4.479	-4.805	-4.689	-5.131	-5.119

Note: The values in parentheses are the z-statistics of the estimates of the corresponding parameters. ***, ** and * indicate the levels of significance at 1%, 5% and 10% respectively.

were positive and statistically significant except for India's growth rate over the US and Euro Area. This finding further supports our argument regarding the effect of the drivers on the Brent–Dubai price spread.

As another robustness analysis, we force the relationship between Dubai and Brent to be one-to-one. In other words, the coefficient of Brent is restricted to one, and only the intercept is to vary. The corresponding estimates are reported in Table 4. This time, all drivers are found to be positive and statistically significant, indicating stronger results for the role played by economic drivers in the Brent–Dubai oil price spread.

The drivers that we consider may have a common trend and one may proxy another. In order to account for this, we include all the drivers to specification and drop the variables with the Backward Elimination Method. The estimated model is reported in Table 5.

The variables that still have statistically significant coefficients are China growth relative to the Euro Area, world oil demand and world trade. However, the estimated coefficient of world oil demand is negative. Although this seems to be

Table 4

Time-varying Brent–Dubai ratio with drivers in the intercept specified by AR(1) with drift.

Panel A: Signal equation ($dubai_t - brent_t = \alpha_{c,t} + w_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Intercept _t (Final state value _t)	-0.011	0.003	0.001	-0.010	0.017	0.016	0.001	0.002
Panel B: State equation ($\alpha_{c,t} = \beta_0 + \beta_1 \alpha_{c,t-1} + \beta_m driver_{t-1} + v_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Constant	-0.133*** (-3.379)	-0.305*** (-2.853)	-0.427*** (-2.946)	-0.209*** (-2.735)	-0.007*** (-2.822)	-0.008*** (-3.283)	-0.008*** (-2.995)	-0.008*** (-3.042)
Intercept _{t-1}	0.720*** (14.326)	0.769*** (18.611)	0.768*** (18.432)	0.787*** (20.912)	0.734*** (12.458)	0.694*** (12.312)	0.760*** (14.215)	0.762*** (14.426)
Driver _{t-1}	0.027*** (3.171)	0.165*** (2.774)	0.606*** (2.891)	0.172*** (2.629)	0.014*** (2.633)	0.015*** (3.544)	0.019** (2.278)	0.016** (2.252)
Log lik.	558.023	761.610	758.550	791.942	512.726	554.459	433.971	433.885
Aka. in.	-4.667	-4.412	-4.407	-4.421	-4.790	-4.676	-4.793	-4.792
Sch. cri.	-4.594	-4.356	-4.351	-4.367	-4.711	-4.603	-4.704	-4.703
H-Q cri.	-4.637	-4.389	-4.384	-4.399	-4.758	-4.647	-4.757	-4.756

Note: The values in parentheses are the z-statistics of the estimates of the corresponding parameters. ***, ** and * indicate the levels of significance at 1%, 5% and 10% respectively.

Table 5

Time-varying Brent–Dubai spread with three drivers in the slope specified by AR(1) with drift.

Panel A: Signal equation ($dubai_t = \alpha_0 + \alpha_{c,t}brent_t + w_t$)	
Constant	0.235*** (6.106)
Brent _t (Final state value _t)	0.942***
Panel B: State equation ($\alpha_{c,t} = \beta_0 + \beta_1\alpha_{c,t-1} + \beta_{m1}(gdpChn - gdpEA)_{t-1} + \beta_{m2}(oil\ demand)_{t-1} + \beta_{m3}(trade\ index)_{t-1} + v_t$)	
Constant	1.183*** (3.206)
Brent _{t-1}	0.752*** (12.283)
GDP Chn/GDP EA _{t-1}	0.009** (2.309)
World oil demand _{t-1}	-1.612*** (-3.002)
World trade index _{t-1}	0.036*** (2.837)
Log lik.	487.272
Aka. In.	-4.817
Sch. cri.	-4.684
H-Q cri.	-4.763

Note: The values in parentheses are the z-statistics of the estimates of the corresponding parameters. ***, ** and * indicate significance at the 1%, 5% and 10% levels respectively.

Table 6

Correlation matrix for GDP Chn/GDP EA, world oil demand, and world trade index.

	GDP Chn/GDP EA	World oil demand	World trade index
GDP Chn/GDP EA	1.000		
World oil demand	0.965*** (55.111)	1.000	
World trade index	0.954*** (47.605)	0.978*** (71.022)	1.000

Note: The values in parentheses are the t-statistics of the estimates of the corresponding parameters. ***, ** and * indicate significance at the 1%, 5% and 10% levels respectively.

contradictory to the result found in Table 1, it is worth considering that there might be multicollinearity problems. For this, we checked the correlation coefficients for these three variables, as given in Table 6.

It can be seen that the growth rate of China over the Euro Area, world oil demand and the world trade index are positively and significantly correlated to each other, which may lead to the multicollinearity problem for the specification considered in Table 5. Given these findings, it is reasonable to argue that drivers crowd each other out and result in a multicollinearity problem when considered simultaneously. Therefore, we do not pursue this avenue further. Overall, the estimates suggest that the global economic activities represented by the world trade index, world oil demand, world steel production, the number of world airline passengers and regional dynamics proxied by the growth rate of China over the US and the Euro Area have explanatory power on the Brent–Dubai spread (see Tables A.1, A.2 and B.1–B.5 in the Appendix).

8. Conclusion

In the world oil market, numerous oil grades are extracted from different parts of the world and classified according to their physical properties, namely API gravity and sulfur level. For each of these oil classes, globally accepted representative benchmark blends are used for pricing. Although the physical characteristics of these benchmarks are central to the pricing of all types of oil, refinery yield rates of oils and demands for oil end products are becoming more important in the determination of benchmark oil prices since the world crude oil market follows the market demands for petroleum products. Therefore, in order to understand the crude oil price dynamics, it is important to examine the underlying drivers of demands for petroleum products.

Within this framework, this paper examines the link between the demand for oil products and benchmark oil prices using some selected economic drivers. In our analyses, demand for oil products is captured by various economic drivers, which are employed as quantified indicators of oil end product demand. Oil prices are represented by the price spread of two globally accepted oil benchmarks, the Brent–Dubai spread. The reason for selecting the Brent–Dubai spread is that the pricing mechanism of these benchmarks plays a major role in the world oil market as Brent and Dubai are globally accepted markers for light-sweet and medium-sour oil blends, respectively. The main contribution of this study is to address and quantify the effects of potential economic drivers on the Brent–Dubai oil price spread using the time-dependent Kalman filtering technique.

The estimates of the Kalman filter specifications suggested that the global economic activities represented by the world trade index, world oil demand, world steel production, the number of world airline passengers and regional dynamics

proxied by the China–US growth differential and the China–Euro Area growth differential are influential on the Brent–Dubai spread. Here, the number of air passengers is a direct indicator for jet/kerosene demand in line with aviation activities. Other industrial activities such as steel production, growth in Eastern/ Southeastern Asian economies would have a direct impact on gasoil demand since nearly all of the vehicles used in heavy industries consume gasoil. It is no surprise that the Dubai price is more reactive against such economic activities and their drivers.

A number of factors have not been incorporated in this paper. The Brent–Dubai spread could be moving more in response to geopolitical risks, financial risks or even natural risks such as hurricanes. Generally speaking, Brent reflects the effect of global incidents more, while Dubai remains focused more on regional issues in the Middle East and East/Southeast Asia. However, as the global trade weight of countries such as China, Japan and South Korea rises, Dubai becomes more sensitive to global economic activities than Brent, as Dubai’s target regions are the main drivers of global economy and trade at the moment.

We also considered the global PMI, OPEC spare oil capacity, global oil production, global oil exports, global rig count, the Baltic dry index and the Kilian index; they were not statistically significant. This does not mean that these factors are not relevant, just that we could not obtain statistically significant evidence. As for the limitations of the study, we did not take into account all the variables – such as political risks (e.g. potential problems related to transportation through Hurmuz Straits), weather conditions that affect oil extraction and shipping or traffic congestion at the major oil ports. The important thing here is that the Brent–Dubai relationship changes relative to changes in petroleum product demands. Hence, a future research direction would be to investigate different global and regional economic drivers that affect the Brent–Dubai spread.

The findings of this paper are important in various ways. Brent being the world’s largest crude oil-based financial hedging instrument, its prices also convey financial risk hedging positions as with the Dubai and other benchmarks. Both oil exporting and oil importing countries as well as the firms that use oil as important inputs may choose their benchmark oil to hedge their risk exposure. Depending on the integration of their economies to regional economies such as Asia, the US or Europe, the selection of a benchmark may also change. Moreover, depending on a firms’ expectations regarding economic variables, risk exposure might also be hedged with mixture of the two benchmarks rather than a single one. As the world oil market becomes more and more complex, global oil benchmarks are expected to display a reliable pricing scheme to the players of global oil market for decision making purposes. Furthermore, the Brent–Dubai spread is important for its own sake. These two oil contracts are used not only for hedging the risk but also as financial tools. Depending on the expectations of financial analyses on the eight variables that we considered, analysts may take their financial positions. Therefore, it becomes vital for policymakers to observe the formation of oil prices and the drivers affecting them so that proactive measures can be taken to hedge country or firm risks. This makes oil price spreads and their determinants more important to follow.

Appendix A

Tables A.1 and A.2.

Table A.1

Time-varying Brent–Dubai spread with drivers in the intercept specified by AR(1) with drift and the slope specified by random walk.

Panel A: Signal equation ($dubai_t = \alpha_{c1,t} + \alpha_{c2,t}brent_t + w_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Intercept _{1t} (Final state value _{1t})	0.317***	0.326***	0.311***	0.301***	0.294***	0.106***	0.171***	0.170***
Brent _t (Final state value _{2t})	0.922***	0.921***	0.924***	0.926***	0.933***	0.979***	0.960***	0.960***
Panel B: State equation 1 ($\alpha_{c1,t} = \beta_0 + \beta_1\alpha_{c1,t-1} + \beta_m driver_{t-1} + v_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Constant	-0.258 (-0.574)	-0.261 (-0.785)	-0.328 (-0.833)	-0.135 (-0.436)	0.051** (2.389)	0.269 (1.126)	0.032*** (2.835)	0.032*** (2.878)
Intercept _{1,t-1}	-0.097 (-0.188)	0.739*** (16.945)	0.747*** (13.444)	0.733*** (16.947)	0.825*** (11.311)	-0.281 (-0.264)	0.783*** (14.985)	0.787*** (15.684)
Driver _{t-1}	0.126 (1.229)	0.187 (0.996)	0.578 (0.997)	0.180 (0.664)	-0.005 (-0.278)	-0.274 (-1.165)	0.006 (0.882)	0.005 (0.832)
Panel C: State equation 2 ($\alpha_{c2,t} = \alpha_{c2,t-1} + \varphi_t$)								
Log lik.	543.821	762.588	764.095	789.339	505.303	537.230	441.723	441.670
Aka. in.	-4.539	-4.451	-4.433	-4.463	-4.733	-4.540	-5.008	-5.008
Sch. cri.	-4.451	-4.383	-4.366	-4.397	-4.637	-4.452	-4.899	-4.899
H-Q cri.	-4.503	-4.424	-4.407	-4.437	-4.694	-4.505	-4.964	-4.964

Note: The values in parentheses are the z-statistics of the estimates of the corresponding parameters. ***, ** and * indicate the levels of significance at 1%, 5%, and 10%, respectively.

Table A.2

Time-varying Brent–Dubai spread with the intercept specified by random walk and the slope specified by AR(1) with drift and the drivers.

Panel A: Signal equation ($dubai_t = \alpha_{c1,t} + \alpha_{c2,t}brent_t + w_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Intercept _{1t} (Final state value _{1t})	0.368***	0.074***	0.391***	0.258***	0.131***	0.278***	0.242***	0.214***
Brent _t (Final state value _{2t})	0.909***	0.984***	0.905***	0.936***	0.974***	0.938***	0.944***	0.950***
Panel B: State equation 1 ($\alpha_{c1,t} = \alpha_{c1,t-1} + v_t$)								
Panel C: State equation 2 ($\alpha_{c2,t} = \gamma_0 + \gamma_1\alpha_{c2,t-1} + \gamma_m driver_{t-1} + \varphi_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Constant	0.939*** (4.701)	-0.075*** (-2.682)	-0.106 (-0.229)	-0.096 (-0.367)	0.088 (1.497)	0.919 (1.205)	1.172*** (11.470)	1.400*** (4.140)
Brent _{t-1}	-0.364** (-2.425)	0.974*** (141.728)	0.481 (1.523)	0.454* (1.752)	0.905*** (14.168)	-0.007 (-0.009)	-0.266** (-2.394)	-0.499 (-1.376)
Driver _{t-1}	0.063** (2.305)	0.055*** (3.127)	0.822 (1.056)	0.504* (1.710)	0.013 (1.411)	0.054 (1.042)	0.058 (1.413)	0.051 (1.073)
Log lik.	556.325	760.422	751.242	782.793	502.257	543.306	432.849	426.805
Aka. in.	-4.625	-4.412	-4.371	-4.376	-4.749	-4.612	-4.851	-4.922
Sch. cri.	-4.537	-4.345	-4.303	-4.311	-4.653	-4.523	-4.742	-4.811
H-Q cri.	-4.589	-4.385	-4.344	-4.350	-4.710	-4.576	-4.807	-4.877

Note: The values in parentheses are the z-statistics of the estimates of the corresponding parameters. ***, ** and * indicate significance at the 1%, 5%, and 10% levels respectively.

Appendix B

Tables B.1–B.5.

Table B.1

Time-varying Brent–Dubai spread with drivers in the slope specified by AR(1) without drift.

Panel A: Signal equation ($dubai_t = \alpha_0 + \alpha_{c,t}brent_t + w_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Constant	0.312*** (7.502)	0.179** (6.292)	0.121*** (4.786)	0.234*** (9.050)	0.345*** (7.125)	0.261*** (6.065)	0.138*** (3.108)	0.139*** (3.123)
Brent _t (Final state value _t)	0.924***	0.962***	0.974***	0.944***	0.917***	0.941***	0.971***	0.970***
Panel B: State equation ($\alpha_{c,t} = \beta_1\alpha_{c,t-1} + \beta_m driver_{t-1} + v_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Brent _{t-1}	0.988*** (87.353)	0.888*** (26.496)	0.866*** (23.518)	0.886*** (27.325)	1.000*** (2314.060)	1.000*** (2324.376)	1.000*** (3639.604)	1.000*** (3605.795)
Driver _{t-1}	0.002 (1.033)	0.059*** (3.314)	0.187*** (3.626)	0.091*** (3.501)	0.000 (-0.434)	0.000 (-0.423)	-0.001 (-0.974)	-0.001 (-0.901)
Log lik.	548.431	744.981	748.128	775.564	499.461	542.921	436.533	436.469
Aka. in.	-4.586	-4.353	-4.346	-4.353	-4.732	-4.617	-5.018	-5.017
Sch. cri.	-4.513	-4.297	-4.290	-4.299	-4.652	-4.543	-4.926	-4.926
H-Q cri.	-4.556	-4.330	-4.323	-4.332	-4.699	-4.587	-4.981	-4.980

Note: The values in parentheses are the z-statistics of the estimates of the corresponding parameters. ***, ** and * indicate the levels of significance at 1%, 5% and 10% respectively.

Table B.2

Time-varying Brent–Dubai spread with drivers in the slope specified by random walk.

Panel A: Signal equation ($dubai_t = \alpha_0 + \alpha_{c,t}brent_t + w_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Constant	0.264*** (6.155)	0.209*** (5.982)	0.194*** (6.178)	0.191*** (6.229)	0.345*** (7.268)	0.261*** (6.104)	0.139*** (3.166)	0.135*** (3.071)
Brent _t (Final state value _t)	0.935***	0.953***	0.957***	0.953***	0.917***	0.941***	0.970***	0.971***
Panel B: State equation ($\alpha_{c,t} = \alpha_{c,t-1} + \beta_m driver_{t-1} + v_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Driver _{t-1}	0.000 (0.488)	0.000 (0.493)	0.000 (0.464)	0.000 (0.411)	0.000 (-0.564)	0.000 (-0.689)	-0.001 (-0.778)	0.000 (-0.466)
Log lik.	548.130	736.068	738.518	767.201	499.411	542.821	436.024	430.410
Aka. in.	-4.631	-4.306	-4.295	-4.312	-4.741	-4.625	-5.024	-5.017
Sch. cri.	-4.572	-4.261	-4.251	-4.268	-4.677	-4.566	-4.950	-4.943
H-Q cri.	-4.607	-4.288	-4.278	-4.294	-4.715	-4.601	-4.994	-4.987

Note: The values in parentheses are the z-statistics of the estimates of the corresponding parameters. ***, ** and * indicate significance at the 1%, 5% and 10% levels respectively.

Table B.3

Time-varying Brent–Dubai spread with drivers both in the intercept and the slope specified by random walk.

Panel A: Signal equation ($dubai_t = \alpha_{c1,t} + \alpha_{c2,t}brent_t + w_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Intercept _{1t} (Final state value _{1t})	0.009	0.262***	0.224***	0.281***	0.720***	0.603***	0.426***	0.239***
Brent _t (Final state value _{2t})	0.995***	0.937***	0.946***	0.931***	0.829***	0.858***	0.900***	0.945***
Panel B: State equation 1 ($\alpha_{c1,t} = \alpha_{c1,t-1} + \beta_m driver_{t-1} + v_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Driver _{t-1}	0.000 (-1.415)	0.000 (-0.396)	-0.001 (-0.682)	0.000 (0.037)	0.019*** (3.432)	0.010*** (2.584)	0.002 (0.211)	0.001 (0.128)
Panel C: State equation 2 ($\alpha_{c2,t} = \alpha_{c2,t-1} + \gamma_m driver_{t-1} + \varphi_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Driver _{t-1}	0.0002*** (2.971)	0.0002* (1.869)	0.001** (2.444)	0.000 (1.067)	-0.006*** (-3.904)	-0.003*** (-3.492)	-0.002 (-0.778)	0.000 (-0.187)
Log lik.	555.663	752.842	754.247	783.551	485.790	548.435	431.012	413.163
Aka. in.	-4.667	-4.386	-4.382	-4.374	-4.737	-4.625	-4.897	-4.978
Sch. cri.	-4.593	-4.330	-4.325	-4.319	-4.655	-4.551	-4.806	-4.883
H-Q cri.	-4.637	-4.364	-4.359	-4.352	-4.704	-4.595	-4.860	-4.939

Note: The values in parentheses are the z-statistics of the estimates of the corresponding parameters. ***, ** and * indicate the levels of significance at 1%, 5% and 10% respectively.

Table B.4

Time-varying Brent–Dubai ratio with drivers in the intercept specified by AR(1) without drift.

Panel A: Signal equation ($dubai_t - brent_t = \alpha_{c,t} + w_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Intercept _t (Final state value _t)	-0.017	-0.003	-0.003	-0.014	0.024	0.026	0.005	0.005
Panel B: State equation ($\alpha_{c,t} = \beta_1 \alpha_{c,t-1} + \beta_m driver_{t-1} + v_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Intercept _{t-1}	0.795*** (19.674)	0.865*** (30.537)	0.865*** (30.481)	0.871*** (32.452)	0.849*** (22.790)	0.817*** (23.101)	0.880*** (26.547)	0.884*** (27.661)
Driver _{t-1}	-0.001*** (-2.885)	-0.003*** (-2.782)	-0.009*** (-2.772)	-0.005*** (-2.721)	0.011** (2.177)	0.013*** (3.346)	0.008 (1.047)	0.006 (0.892)
Log lik.	552.053	755.271	752.675	786.490	506.836	546.214	428.096	427.899
Aka. in.	-4.625	-4.381	-4.378	-4.396	-4.744	-4.615	-4.739	-4.736
Sch. cri.	-4.566	-4.336	-4.333	-4.352	-4.680	-4.556	-4.667	-4.665
H-Q cri.	-4.601	-4.363	-4.360	-4.379	-4.718	-4.591	-4.710	-4.707

Note: The values in parentheses are the z-statistics of the estimates of the corresponding parameters. ***, ** and * indicate significance at the 1%, 5% and 10% levels respectively.

Table B.5

Time-varying Brent–Dubai ratio with drivers in the intercept specified by random walk.

Panel A: Signal equation ($dubai_t - brent_t = \alpha_{c,t} + w_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Intercept _t (Final state value _t)	-0.007	0.008	0.008	-0.005	0.021	0.020	0.003	0.003
Panel B: State equation ($\alpha_{c,t} = \alpha_{c,t-1} + \beta_m driver_{t-1} + v_t$)								
	World trade index	# of world air passengers	World oil demand	World steel prod.	GDP Chn/GDP US	GDP Chn/GDP EA	GDP Ind/GDP US	GDP Ind/GDP EA
Driver _{t-1}	0.000 (0.038)	0.000 (0.249)	0.000 (0.278)	0.000 (0.222)	0.001 (0.396)	0.001 (0.449)	0.001 (0.220)	0.001 (0.239)
Log lik.	542.338	745.406	742.840	776.559	499.272	537.326	422.443	422.433
Aka. in.	-4.551	-4.329	-4.327	-4.346	-4.682	-4.547	-4.687	-4.686
Sch. cri.	-4.507	-4.295	-4.293	-4.313	-4.634	-4.503	-4.633	-4.633
H-Q cri.	-4.534	-4.316	-4.313	-4.333	-4.663	-4.530	-4.665	-4.665

Note: The values in parentheses are the z-statistics of the estimates of the corresponding parameters. ***, ** and * indicate significance at the 1%, 5% and 10% levels respectively.

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