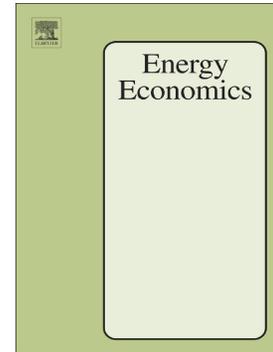


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The Impact of Oil Price Shocks on the Term Structure of Interest Rates[☆]

Christos Ioannidis^{a,*}, Kook Ka^b

^a*Aston Business School, Aston University, Birmingham, B4 7ET, United Kingdom*

^b*Economic Research Institute, The Bank of Korea, Seoul, 04514, Republic of Korea*

Abstract

In a structural VAR framework, we study the impact of oil price shocks in the global crude oil market on the dynamics of the entire yield curve in four industrialised countries with different positions on the oil market; the US, Canada, Norway, and South Korea. Responses of the term structure factors to oil market shocks are shown to differ contingent on the underlying sources that drive oil price shocks and the country's dependence on oil. Oil market-specific demand shocks result in increases in the level factor in oil-importing countries, but have no such effect in oil-exporting countries. Oil supply disruptions have short-lived negative responses of the slope factors in the US and Canada, associated with loosening monetary policy, whilst demand side shocks tend to lead to increases the slope in all countries. Overall, oil supply and demand shocks jointly account for a considerable amount of the observed variation in the term structure of interest rates.

Keywords: Oil prices shocks, Term structure of interest rates, Yield curve, Variance decomposition

JEL Classification: E43, E44, G12, Q43

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*Corresponding author.

E-mail addresses: c.ioannidis@aston.ac.uk (C. Ioannidis), kakook@bok.or.kr (K. Ka)

1. Introduction

Oil prices are considered as one of the main drivers of business cycle fluctuations. Since the sequential oil price shocks during the early and late 1970s, the impact of oil shocks on macroeconomic activity has been investigated by many empirical studies. Literature initiated by Hamilton (1983) has focused almost exclusively on the relationship between changes in the price of oil and economic activities, revealing a significant negative impact of oil price hikes on GDP growth (see, Hamilton 1985, 1996, 2009; Rotemberg and Woodford 1996). Attention has also been given to the role of oil prices in determining inflation (Hooker 2002) and inflation expectations (Harris et al. 2009; Coibion and Gorodnichenko 2015), and more recently their declining pass-through into inflation and economic activities (Blanchard and Galí 2007; Chen 2009; Clark and Terry 2010; Baumeister and Peersman 2013).

Even though much literature has studied the macroeconomic influences of oil price shocks, research on the relationship between oil prices and financial market variables has been limited and related studies (for example, Chen et al. 1986; Huang et al. 1996; Kilian and Park 2009) have mainly focused on the effects of oil shocks on stock returns. In comparison, little attention has been paid to the effect of oil prices changes on the bond market. Literature which considers the response of interest rates to oil price shocks has focused on the short-end of the yield curve, in an attempt to quantify the contribution of monetary policy responses to the propagation of oil price shocks (see, for example, Bernanke et al. 1997).

This paper attempts to fill this gap by incorporating the term structure factors and variables driving supply and demand in global crude oil markets into a structural VAR (SVAR) model. In this context, we examine the effects of

oil price shocks on the term structure of interest rates. Furthermore, to consider the different dynamics between oil shocks and the yield curve in oil-importing and oil-exporting economies, we study four industrialised countries with distinct positions in global oil market; the US, Canada, Norway, and South Korea.

More specifically, we examine the effects of three different oil shocks in the spirit of Kilian (2009)'s "Not all oil price shocks are alike." To relate the supply and demand oil shocks with the term structure of interest rates, we use the well established framework from the finance literature which summarises the entire term structure into several latent yield factors - level, slope, and curvature - as the only relevant factors to characterise the yield curve (see, for example Litterman and Scheinkman 1991). The factor model of the term structure combined with the decomposition of oil price shocks, into different causes, enable us to characterise the responses of the yield curve to various shocks and to calculate the entire yield curve movement after them. To our knowledge, this is the first paper answering this question, linking oil price shocks to the term structure of interest rates.

Our contribution to the literature is threefold. First, we examine the effects of oil price shocks on the entire yield curve, rather than limiting our focus on a particular interest rate, for example, short-term policy rate. To interpret the response of the latent yield factors, we follow the methodology of recent macro-finance literature which studies the macroeconomic forces that shape the term structure of interest rates (Ang and Piazzesi 2003; Diebold et al. 2006). Second, we estimate the different dynamic effects on the yield curve due to three demand and supply oil price shocks from distinct underlying sources. Third, we estimate the model using the term structures of four industrialised countries to establish whether the pattern of term structure responses to the oil price shocks is different according to their position in the crude oil market.

To ascertain the empirical robustness of our results we undertake the analysis over two periods, guided by the behaviour of the short-run rate of interest. From the onset of the financial crisis, central banks have taken drastic steps in reducing the monetary policy instrument to near zero and kept it as low for an unprecedented lengthy period. In addition, the introduction of quantitative easing in the US and UK has exercised strong downward pressure on the long-term rates altering the slope of the yield curve. In the light of such changes, we conduct our analysis over two periods. The sub-sample period ends in 2008, the onset of the crisis, where short-term rates were at their ‘historically’ normal levels. Our full sample period includes the period of the crisis and the exercise of unconventional monetary policy. The differences in responses, if any, between the ‘normal’ and ‘extended’ periods will be due to the unusual behaviour of the short-term rate and quantitative easing. This approach helps us establish the severity of the impact of oil shocks of any description in normal and crisis times.

Our estimation results show that the responses of the four countries’ term structure are not alike, depending upon the type of shocks and the countries’ position in the crude oil market. Broadly speaking, the response of the factors of the yield curve to the different sources of oil market shocks can be summarised as follows: The impulse response analysis shows that negative oil supply shocks have differential effects on the level (long-end), with rising levels in Norway and South Korea and little effect on US and Canada; in these two countries the shocks result in lower short rates, steepening the yield curve. This result is associated with the conventional monetary policy reaction aiming at offsetting the recessionary effects of oil supply disruption. Following an oil market-specific demand shocks, the level of the yield curve in oil-importing countries (the US and South Korea) increases noticeably, but the response of the same factor in oil-exporting countries (Canada and Norway) is very modest.

In all countries, the slope increases after oil market-specific demand shocks following a rise of the short rate, which is the consequence of the monetary policy's reaction to reduce inflationary pressures. Finally, aggregate demand shocks make the slope factor in oil-importing countries less steep, but have no such effect in oil-exporting countries. The same shocks decrease the curvature (middle-end) of the yield curve in oil-importing countries making yield curve less concave.

The rest of the paper is organised as follows: A brief literature review is presented in Section 2. Section 3 presents the Nelson-Siegel methodology and the SVAR model. Section 4 provides a description of the data. Section 5 discusses empirical results and comments on the dynamics of the term structure responses to oil shocks. Finally, Section 6 concludes.

2. Literature Review

Finance literature models treat nominal yields as functions of several unobservable factors. Imposing the no-arbitrage condition, yields of various maturities acquire consistent dynamic evolution according to underlying factors (Duffie and Kan 1996; Dai and Singleton 2002). However, these canonical arbitrage-free term structure models have not provided much intuition regarding the macroeconomic forces that drive the underlying yield factors. The empirical literature has attempted to include macro variables and builds macro-structures into financial term structure models to incorporate the fundamental macroeconomic drivers of the yield curve.

In a seminal work by Ang and Piazzesi (2003), the combination of macroeconomic and latent yield factors results in a state vector whose dynamics follow a first order Gaussian VAR. As macro variables, they use principal components of the series that represent inflation and output measures. The short rate is

assumed to be an affine function of the state variables. With the aid of no-arbitrage assumption, yields with various maturities become affine functions of the state variables which include both financial and macro factors. They conclude that macro factors explain significant of variations of bond yields and the model incorporating macro factors forecasts better in comparison to a model relying exclusively on financial factors.

The initial macro-finance models have included a limited number of macroeconomic aggregates such as output and inflation. Based on the tradition of Taylor (1993), these have focused on using information about output and inflation as determinants of the movements of the short-term rate. As reported in Ang and Piazzesi (2003), the shocks from these macroeconomic factors do not have sufficient explanatory power to account for interest rate movements with longer maturities.

Subsequently, a large number of empirical studies have followed and established the relationship between macroeconomic variables and the term structure of interest rates. They consider different structures in factor dynamics or introduce additional latent and macro factors.¹ For example, Diebold et al. (2006) and Ang et al. (2007) allowed for feedback between macro and yield factors in the dynamics of the state variables in a bidirectional way.² Rudebusch and Wu (2008) exploit this approach and attempt to interpret the evolution of the latent factors in terms of macroeconomic variables.³ In particular, the first factor, associated with level in the yield curve, is interpreted as an interim or medium-term inflation target and the slope factor is linked to the central bank's policy

¹This kind of research includes, for example, Bernanke et al. (2004), Dewachter and Lyrio (2006), Ang et al. (2006), and Lildholdt et al. (2007).

²The model of Diebold et al. (2006) is rooted on Nelson and Siegel (1987), but Ang et al. (2007) build their model under the no-arbitrage assumption.

³Other models with this strand include Hördahl et al. (2006) and Rudebusch et al. (2006). More recently, literature such as Bekaert et al. (2010) and Hördahl et al. (2008) extend the existing model in a way that allows more fully specified structural DSGE model.

responses to stabilise output and inflation fluctuations. Their empirical results conclude that the macroeconomic factors are closely related to the financial latent factors driving the yield curve.

Another strand of macro-finance literature uses a dynamic factor model which is originated from the term structure model of Nelson and Siegel (1987). For example, Diebold and Li (2006) reinterpret the Nelson-Siegel representation as a dynamic latent factor model. The advantage of the Nelson-Siegel type model is that it is free from the estimation problems of the canonical affine no-arbitrage term structure models that suffer from empirical performance in terms of fit and out-of-sample predictability (Duffee 2002) due to its parsimonious framework. Diebold and Li (2006)'s simplified model where factor dynamics are assumed to follow a first-order vector auto-regression has been used for forecasting purposes with some success.

To improve the performance of the original models and establish explicit links with the macroeconomic environment, additional macroeconomic factors have been added to account for the observed movements of the yield curve. Dai and Philippon (2005) using affine structures, and Afonso and Martins (2012) using the econometric approach of Diebold and Li (2006) incorporate additional elements representing fiscal conditions such as the government deficit. They argue that fiscal shocks indeed affect long-term rates through the expectations of the future short-term rate as well as the risk premium. Chadha and Waters (2014) consider a large number of macroeconomic variables into a macro-finance model and Dewachter and Iania (2012) introduce two additional financial factors, liquidity-related and return-forecasting factors. The liquidity-related factor is a measure of money market tension, whilst the return-forecasting is a factor driving the one period expected excess holding return. They found that the model fit with the two financial factors is enhanced, and that the additional

factors have a significant influence on the yield curve.

Even though the macro-finance literature has largely investigated the possible role of macroeconomic factors in the dynamics of the term structure, studies on the effect of oil price shocks on the term structure are relatively limited. The literature has been mostly focused on only the short-end of the yield curve, with the aim of evaluating the possible role of monetary policy response in the propagation of oil price shocks. Using US data in a VAR model, Bernanke et al. (1997) investigate endogenous monetary policy response to oil price shocks in an attempt to investigate whether it is the cause of past economic downturns which followed after them. They concluded that the systematic response to oil price shocks is indeed the main reason for these recessions and that different monetary policy could have been used to avoid their recessionary consequences.

Their argument is challenged by Hamilton and Herrera (2004) who show that the counter-factual paths of the policy rates assumed to eliminate the output decline are implausible and cannot be implemented. They also show that when alternative lag lengths were used in the estimation of the VAR these altered the size of the effect attributed to oil shocks. Kilian and Lewis (2011) re-validate this result: that there is no credible evidence that monetary policy responses in the 1970s and 1980s amplified the effects of oil price shocks causing significant fluctuations in real output. They argue that the monetary policy reaction framework in Bernanke et al. (1997) and other following studies have a weakness in the way that they assume policy makers respond regardless of their underlying sources.⁴

Kilian (2009) considers whether distinct oil price shocks driven by diverse

⁴Cognigni and Manera (2008) have studied endogenous monetary policy response to oil price shocks for the G-7 countries. Their simulation exercises using SVAR model suggest that the effects of the oil price shocks in the US is largely due to the monetary policy reactions, but for other countries such as Canada, France, and Italy the total impact is offset partly by monetary easing.

underlying determinants have differential effects on the economy. He classifies three kinds of shocks: shocks to the reduction in oil supply, shocks driven by increased overall demand, and shocks from the changes in the precautionary oil demand. Using a structural VAR model with recursive restrictions, he identifies oil price shocks and allocates them into the three categories. Estimation results show that historical oil price changes have been associated with a combination of all three types of shocks. What is of interest is that, after the decomposition, it emerges that certain oil price shocks are connected to demand-side, a finding that is inconsistent with the common belief that oil price shocks are mostly concerned to supply disruptions and these have been the main cause of oil price fluctuations. He also finds distinct effects of each shock on output growth and inflation. For example, a shock originating from supply disruption causes an immediate but temporary drop in current output associated with trivial effects on inflation. Whilst, a shock caused by an increase in global aggregate oil demand is results in a delayed and pronounced fall in output and increased inflation.

There is strong empirical evidence of their influence of inflation expectations and subsequently on both the short and long rates. More specifically in terms of the short rate Coibion and Gorodnichenko (2012) provide evidence that the FOMC in setting the policy rate take into account oil price shocks and Elliot et al. (2015) from the Bank of England show that even the expected 5-year inflation 5 years from now (5y5y inflation expectation) is influenced by current oil price movements.⁵ In the light of the existing empirical evidence that both ends of the yield curve are influenced by oil price shocks, the aim of this investigation is to calculate the impact of such shocks on the entirety of the yield curve

⁵In their regression exercises, a 10% increase in daily oil price has shown to cause around 4 basis points in the US 5y5y and 2 basis points in Euro area 5y5y inflation expectation.

as represented by its essential elements.

3. Methodology

We use the conventional macro-finance framework to establish the nature of the relationship between oil price shocks and the term structure of interest rates. Since Litterman and Scheinkman (1991), finance literature summarises the term structure of interest rates into three latent factors, representing level, slope, and curvature of the yield curve. In general, these three factors can explain more than 99% of the entire movement in the term structure. To extract three latent yield factors, we follow the approach of Diebold et al. (2006) who modify the Nelson and Siegel (1987)'s parsimonious exponential function form with time-varying parameters in state space setting. Unlike typical finance term structure model restricted with the no-arbitrage condition, the Nelson-Siegel model does not impose the no-arbitrage condition (Björk and Christensen 1999; Filipović 1999).

Our choice of model is based on the argument of Diebold and Rudebusch (2013) that the imposition of the no-arbitrage restriction is not necessarily important when the bond market is deep and liquid enough that its pricing satisfies the arbitrage free conditions. Coroneo et al. (2011) document that the Nelson-Siegel yield curve model is compatible with the models imposing no-arbitrage constraints in the case of US yield curve. Diebold and Li (2006) show that the parsimony but flexible functional form of the model enhances the empirical fit and results in good forecasting performance.

The estimation of the state-space yield curve and the analysis of macro-finance VAR approach follows two steps. First, we estimate the country-specific three latent yield factors using the Kalman filter, as Diebold et al. (2006). Second, we estimate SVARs with each country's three latent yield factors and

variables which enable to identify the supply and demand shocks in the global crude oil market. This procedure is similar to empirical methodology employed by Afonso and Martins (2012) who examine the effect of fiscal behaviour on the term structure of interest rates. They argue that the yield curve factors estimated using an integrated model with both macro and yield curve data do not differ much from ones attainable with the pure financial state-space model. Furthermore, this approach enables us to circumvent the restriction of the first-order specification, which is usually assumed in the finance literature.⁶ Using this methodology, we report the estimated latent yield factors and analyse the effects of the three different oil shocks on yield curve dynamics.

3.1. Term Structure Factor Model Representation

The conventional Nelson-Siegel model (1987) has the following functional form representing the cross-section of yields as

$$y(\tau) = \beta_1 + \beta_2 \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} \right) + \beta_3 \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau} \right), \quad (1)$$

where $y(\tau)$ denotes the set of yields at any moment with the corresponding maturity τ , which can be understood as a cross-sectional representation at any moment in time. Figure 1 shows the factor loading on each latent yield factor fixing the value of λ at 0.0609 as assumed in Diebold and Li (2006). The loading on β_2 begins at 1 and decays as the maturity increases, so it is interpreted as a short-term factor. The loading on β_3 starts at 0, increases until the maturity reaches around 24 months, and decays to zero, so it can be interpreted as a medium-term factor. Finally the loading for β_1 is 1, so it is interpreted as the

⁶Empirical studies investigating the transmission of oil price shocks usually selects a large number of lags to capture the delayed effect of oil price shocks on the economy. Hamilton and Herrera (2004) discuss that the importance of choosing a lag length and show that the number of lags is needed to be large enough, suggesting less than 12 lags can fail to ensure the reliability of the impulse response estimates.

long-term factor. According to their effect on the overall yield curve, the three factors can be interpreted as the level, slope, and curvature in a conventional yield curve model. Diebold et al. (2006) show that the estimated factors mimic closely their empirical proxies for level ($y_t(120)$), slope ($y_t(3) - y_t(120)$), and curvature ($2 \times y_t(24) - (y_t(3) + y_t(120))$), where the values in parenthesis indicate the months to maturity.

To extend Nelson-Siegel's framework to represent entire yield curve, Diebold and Li (2006) consider β_i 's as time-varying yield factors with factor loadings 1 , $(1 - e^{-\lambda\tau})/\lambda\tau$, $(1 - e^{-\lambda\tau})/\lambda\tau - e^{-\lambda\tau}$. Then we can rewrite Equation (1) to relate the β coefficients to the factors' interpretation as level, slope, and curvature as

$$y_t(\tau) = l_t + s_t \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} \right) + c_t \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau} \right), \quad (2)$$

where $t = 1, \dots, T$ and $\tau = 1, \dots, N$.

The dynamic movement of the three factors (l_t, s_t, c_t) is assumed to follow a first-order VAR which becomes the transition equation controlling the dynamics of the state vector as

$$\begin{pmatrix} l_t - \mu_l \\ s_t - \mu_s \\ c_t - \mu_c \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} l_{t-1} - \mu_l \\ s_{t-1} - \mu_s \\ c_{t-1} - \mu_c \end{pmatrix} + \begin{pmatrix} \eta_t(l) \\ \eta_t(s) \\ \eta_t(c) \end{pmatrix}, \quad (3)$$

where μ_l, μ_s , and μ_c are mean values and $\eta_t(l), \eta_t(s)$, and $\eta_t(c)$ are innovations for the respective factors. The measurement equation which relates yields with

N maturities to the three latent factors is

$$\begin{pmatrix} y_t(\tau_1) \\ y_t(\tau_2) \\ \vdots \\ y_t(\tau_N) \end{pmatrix} = \begin{pmatrix} 1 & \frac{1-e^{-\tau_1\lambda}}{\tau_1\lambda} & \frac{1-e^{-\tau_1\lambda}}{\tau_1\lambda} - e^{-\tau_1\lambda} \\ 1 & \frac{1-e^{-\tau_2\lambda}}{\tau_2\lambda} & \frac{1-e^{-\tau_2\lambda}}{\tau_2\lambda} - e^{-\tau_2\lambda} \\ \vdots & \vdots & \vdots \\ 1 & \frac{1-e^{-\tau_N\lambda}}{\tau_N\lambda} & \frac{1-e^{-\tau_N\lambda}}{\tau_N\lambda} - e^{-\tau_N\lambda} \end{pmatrix} \begin{pmatrix} l_t \\ s_t \\ c_t \end{pmatrix} + \begin{pmatrix} \varepsilon_t(\tau_1) \\ \varepsilon_t(\tau_2) \\ \vdots \\ \varepsilon_t(\tau_N) \end{pmatrix}, \quad (4)$$

where $t = 1, \dots, T$, and $\varepsilon_t(\tau_1), \varepsilon_t(\tau_2), \dots, \varepsilon_t(\tau_N)$ are measurement errors. We can rewrite this state-space system in a matrix form as

$$(f_t - \mu) = A(f_{t-1} - \mu) + \eta_t \quad (5)$$

$$y_t(\tau) = \Lambda f_t + \varepsilon_t(\tau). \quad (6)$$

where $f_t = (l_t \ s_t \ c_t)'$, $\mu = (\mu_l \ \mu_s \ \mu_c)'$, and $\eta_t = (\eta_t(l) \ \eta_t(s) \ \eta_t(c))'$. A is 3×3 matrix in the transition equation, and Λ is a factor loading matrix which connects the factors to the interest rates vector $y_t(\tau)$ with maturities $\tau_1, \tau_2, \dots, \tau_N$. The factor loadings are functions of maturities and determine the dynamics of $y_t(\tau)$.

We assume that the covariance matrix of the system is block diagonal as the measurement and transition innovations are uncorrelated to each other and to the initial state such that

$$\begin{pmatrix} \eta_t \\ \varepsilon_t \end{pmatrix} \sim WN\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} Q & 0 \\ 0 & H \end{pmatrix}\right), \quad (7)$$

$$E(f_0 \eta_t') = 0, \quad (8)$$

$$E(f_0 \varepsilon_t') = 0. \quad (9)$$

The factor disturbances (η_t) are allowed to be correlated, whilst the disturbances of measurement equation are assumed *i.i.d.*, resulting in a diagonal covariance

matrix (H) as is standard in the literature. The diagonal covariance matrix of the yield measurement equation means that the deviations of observed rates from the estimated yield curve are not correlated. The conditions of Equations (8) and (9) ensure the optimality of the Kalman filter delivering maximum-likelihood estimates and subsequently optimal smoothed estimates of the latent factors.

3.2. Identifying Oil Price Shocks

Even though crude oil prices are driven by distinct oil demand and supply changes related closely to the global economic conditions, the price of crude oil has long been regarded as an exogenous shock to any domestic economy. However, oil price fluctuations emanating from diverse sources can have different macroeconomic consequences. The different effects of oil price shocks with distinct underlying source have received much attention in recent literature. Kilian (2009) stresses that oil price shocks have different dynamic effects on macroeconomic aggregates depending on their underlying sources.

The two consecutive oil crises, manifested by sharp price increases, in the early and late 1970s were originated from supply disruptions in the Middle East and have been widely believed to be related to stagnant growth and price inflation. Kilian (2009) argues that similar oil price increases driven by growing global aggregate demand, instead of supply disruptions, will manifest themselves in higher output and inflation, in contrast to the stagflation normally associated with the same phenomenon. Interest rates with diverse maturities might react differently to the oil price shocks with various sources. For example, if the oil price increase originates from oil supply disruption, the effect from higher expected inflation will be partly offset by its stagnant effect on the real economy. On the contrary, if oil price increases due to global aggregate demand, overall interest rates in oil importing countries would result in temporary increases

reflecting expectations over inflation and economic growth in the future.

A structural VAR model is used to examine the relationship between oil price shocks and the term structure of interest rates. We separate three oil price shocks - global oil supply, global aggregate demand, and oil market-specific demand shocks - and examine their effect on the three yield latent factors. We use following p-order standard SVAR model:

$$A_0 x_t = c + \sum_{j=1}^p A_j x_{t-j} + \varepsilon_t, \quad (10)$$

where x_t represents a vector of endogenous variables $(\Delta prod_t \quad rea_t \quad rpo_t \quad l_t \quad s_t \quad c_t)'$. $\Delta prod_t$ denotes the percent change in global crude oil production, rea_t is the index of real economic activity built by Kilian (2009), and rpo_t is real price of oil. A_0 is the contemporaneous coefficient matrix, A_j denotes the auto-regressive coefficient matrices, c is a vector of constants, and ε_t is the vector of serially uncorrelated structural disturbances.

The system relies on the simple contemporary recursive restrictions. Using the Cholesky triangular factorization, i.e. A_0^{-1} has a recursive structure, the reduced form errors ($e_t = A_0^{-1} \varepsilon_t$) are linear combinations of the structural errors (ε_t) as,

$$e_t = \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \\ e_t^l \\ e_t^s \\ e_t^c \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & 0 \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{oil \text{ supply shock}} \\ \varepsilon_t^{aggregate \text{ demand shock}} \\ \varepsilon_t^{oil \text{ specific-demand shock}} \\ \varepsilon_t^{level \text{ shock}} \\ \varepsilon_t^{slope \text{ shock}} \\ \varepsilon_t^{curvature \text{ shock}} \end{pmatrix}. \quad (11)$$

The rationale for identification is motivated by Kilian (2009), Kilian and Vega (2011), and Afonso and Martins (2012). Specifically, oil supply shocks are all shocks that affect oil production ($\Delta prod_t$) within a month, based on the fact that oil production cannot be adjusted in a short period. Aggregate demand shocks are other shocks affecting the demand for industrial commodities (rea_t), approximating global real economic activity within a month. Oil market-specific demand shocks are all the other shocks which affect the real price of oil (rpo_t) and are related to the precautionary demand for oil.⁷

We assume country-specific financial variables, i.e. the three latent term structure factors (l_t , s_t , and c_t) are affected instantaneously by oil price shocks, but variables of global crude oil market are not affected contemporaneously by the domestic yield factors. Kilian and Vega (2011) test whether energy prices respond instantaneously to US domestic macroeconomic news at daily and monthly horizons. They find no evidence of systematic feedback from macroeconomic news to energy prices, which support the identifying restriction in the model that assumes no contemporaneous effect from country-specific macroeconomic and finance shocks.⁸

In constructing the SVAR, the choice of lag length is an important consideration. Hamilton (2003) allows four lags in quarters to test for the nonlinear relation between oil price changes and GDP growth using quarterly data. Re-

⁷In recent study, Baumeister and Hamilton (2015) propose a less restrictive identification strategy using Bayesian formulation. They reveal that traditional approaches to SVAR models by Kilian (2009) and Kilian and Murphy (2014) can be understood as a special cases of Bayesian inferences with strong prior assumptions. However, they confirm that the model with relaxed prior beliefs produces core implications similar to those in previous studies.

⁸Three oil price shocks identified in our six-variable VAR model are highly correlated with those identified with Kilian (2009)'s model with correlation coefficients for the US are 0.85 (oil supply shocks), 0.90 (aggregate demand shocks), and 0.92 (oil market-specific demand shocks). For the other countries, the relations are less close due to shorter sample period. However, we confirm that all the correlation coefficients between the shocks identified by the two models are above 0.72 in any case.

lated literature typically reports the effects of oil price shocks on macroeconomic variables peak after three to four quarters (Kilian 2008 among many others). In a more recent paper, Kilian (2009) allows for 24 monthly lags. We choose 12 lags because the series of monthly interest rates are not long enough to produce reliable decompositions for the four countries in this study. This choice can also be justified considering a potentially long delay of the effects on the term structure from structural oil price shocks.⁹

4. Data

The data representing global oil supply and the status of global demand are available from 1973 on a monthly basis. The data for oil supply is world crude oil production and is provided by EIA (US Energy Information Administration). A monthly index representing demand for industrial commodities is used to proxy global real economic activity.¹⁰ The real price of oil is the monthly average refiner acquisition cost of imported crude oil provided by the US Department of Energy and is deflated by the US CPI available from FRED (Federal Reserve Economic Data) by Federal Reserve Bank of St. Louis.¹¹

End-of-month nominal interest rates data for the US, Canada, Norway, and South Korea are used representing countries with different compositions in oil production and consumption. The US and South Korea are classified as oil

⁹Estimation with 24 lags for the US and Canada, however, gives qualitatively similar results.

¹⁰This index is proposed in Kilian (2009). The extended series can be retrieved from Kilian's website (<http://www-personal.umich.edu/~lkilian/paperlinks.html>). The index is based on freight rates for dry bulk cargoes deflated by US CPI. The main advantage of this index representing global economic activity is that it does not require summarising procedure using exchange-rate weighting. It is also free from shifting country weights covering the demand from global markets, which is typically not satisfied by alternative measures such as the OECD industrial production.

¹¹The imported refiner acquisition cost (IRAC) has traditionally considered as a good indicator for the global price of crude oil since the US imports various types of crude oil (Baumeister and Kilian 2014). The correlation of the monthly average IRAC and the WTI between 1980 and 2015 is 0.993 and that between IRAC and the Brent is 0.997. The series of IRAC since 1974:1 is provided by the US Department of Energy and extended backwards in Kilian (2009).

importing countries, and Norway and Canada represent oil exporting countries. Each country has kept its position as a net oil exporter or oil importer during the whole estimation period. Figure 2 shows the status of the countries' dependencies and intensities of oil.¹² Norway marked the lowest energy dependency (-485.9%, net energy imports divided by total energy usage) among OECD countries (18.5% on average) whilst South Korea, is among countries with the highest dependency (83.5%). Total trade volume compared to GDP of the US is 29.9%, so it represents large closed economy. The others can be classified as small open economies and their trade volumes are larger than 60% of GDP (as of 2013, OECD National Accounts data).

The US Treasury yield curve is obtained from the updated data-set built by Gürkaynak et al. (2007) on the Federal Reserve website and Canadian yield curve for zero-coupon bonds are provided by Bank of Canada. The Norwegian yield curve is from Wright (2011) and updated using data from Norges Bank. Government zero-coupon rates for South Korea are provided by Korea Asset Pricing. As the available maturities of the yield curves are different among countries, we build yield curves with 17 maturities for each country using Svensson (1994)'s methodology and extract three latent term structure factors. Figure 3 plots end-of-month bond yields at 17 maturities ranging from 3 months to 10 years for the four countries.

The estimation periods by country vary due to data limitations for government zero coupon rates. For the US, the longest estimation period for the SVAR model is from January 1973 to December 2015. For the other countries, the estimation periods are: Canada (January 1986 to December 2015), Norway

¹²Energy dependency is net energy imports divided by energy usage as of 2013. Net energy imports are estimated by IEA (International Energy Agency) as energy use less production, both measured in oil equivalents. The oil intensity is the ratio of oil consumption (Mtoes) over gross domestic product measured in constant US dollar at market exchange rates as of 2014.

(January 1998 to December 2015), and South Korea (January 2001 to December 2015).

Table 1 presents the descriptive statistics of the interest rates of selective maturities and the empirical level, slope, and curvature of the yield curves for the four countries, across the whole and reduced periods. Over the crisis periods, rates for all maturities have fallen to unusually low levels by any historical reference. Since the onset of the financial crisis the slope of the yield curve in all countries decreased steepening the curve, as the sharp fall of the short rates was not followed by corresponding proportional falls of the long rates.

In the light of such important differences of the behaviour of interest rates, we undertake the study of the impact of oil shocks on the yield over two periods for the US and Canada. The whole sample period covering all the available data for both countries and the shorter pre-crisis period when short-term interest rates were ‘historically normal’, up to December 2008. This distinction will allow for the study of the impact of oil shocks during ‘normal periods’, a situation more likely to occur in the future as monetary policy reverts to its usual standard, and compare them to a period characterised by both ‘normality’ and rates at the zero-bounds accompanied by the exercise of unconventional monetary policy.¹³

5. Empirical Results

5.1. Term Structure Factors

We first present the estimation results for yield curve latent factors for the four countries with their empirical counterparts defined earlier. Figure 4 shows the estimated factors using maximum-likelihood estimation with Kalman filter.

¹³Bodenstein et al. (2013) demonstrate that the propagation of oil price shocks are different when policy rates are at the zero lower bound. Specifically, when policy rates are at the zero lower bound, inflation caused by oil price shocks can lower real rates, stimulating economic activities and offsetting the usual contractionary effects.

The estimated value for λ is different amongst the four countries (US 0.0393, Canada 0.0672, Norway 0.0695, and South Korea 0.0522 with standard errors 0.0001, 0.0003, 0.0003, and 0.0016, respectively). The higher the value of λ is indicative that the curvature factor reaches its maximum value at the shorter maturity, and that the loading on the slope factor decays relatively faster across maturities.

The estimated factors move closely together with their empirical proxies as in related literature (for example, Diebold et al. 2006). The level moves most persistently with least variation, whereas the curvature exhibits the higher volatility. Our estimate of the level of the US yield curve is high during prominent inflation episodes in 1979 and 1982; subsequently the level has shown decreasing trend. For all the countries in the sample, the same pattern is apparent regarding the evolution of the level. In fact, the correlation between the level factor and actual monthly CPI inflation is quite high (US 0.53, Canada 0.52, Norway 0.20, and South Korea 0.49), confirming the close relationship between level and inflation. Recent macro-finance literature interprets the level factor as representing the medium-term inflation expectations (Ang and Piazzesi 2003 among many others)¹⁴ or market participants' view of the underlying medium-term inflation target of the central bank (Rudebusch and Wu 2008). The slope for each country is negative in most periods implying that on average yields increase along maturities. For any given estimated loadings, higher values of the slope factor (i.e. less steep or sometimes inverted yield curve) are associated with high values of the curvature factor a finding also reported by Afonso and Martins (2012). The estimated curvature moves closely with its empiri-

¹⁴The Federal Reserve Bank of Cleveland and the Federal Reserve Bank of Philadelphia provide measures of inflation expectation in the US. The correlations between the estimated level factors based on the model and the ten-year expected inflation estimates by the banks are 0.93 (FRB Cleveland, between 1982:01 and 2015:12) and 0.33 (FRB Philadelphia, between 1998:01 and 2015:12).

cal proxy (mid-term rate minus the average of short-term and long-term rate), with high correlation ranging from 0.68 (US) to 0.96 (Norway). The spread of the yield curve (gap between long-term and short-term rates) has long been demonstrated to have some predictive power for economic growth and recessions (Harvey 1988; Stock and Watson 1989; Estrella and Hardouvelis 1991; Ioannidis and Peel 2003), which establishes the factor's close relationship to real economic activity. The patterns of association between slope and curvature, discussed above, provide support for the argument of Mönch (2012) that increases of the curvature precede a flattening of the yield curve, which is followed by a significant decline of output.

5.2. VAR Analysis - Impulse Responses (Full Sample)

In this section, we report the responses of the latent factors characterising the yield curve to three different oil price shocks, using the whole sample period ending at December 2015, which includes the epoch of the financial crisis resulting in the exceptional behaviour of the short rate of interest since late 2008. Unlike the majority of studies evaluating the impact of oil market shocks on economic indices in terms of real shocks, the results presented here in terms of nominal values. The shocks are normalised to represent one-standard deviation of the innovation and are designed to represent an initial increase in the real price of oil imitating either a negative supply or a positive demand shock.

5.2.1. Oil Supply Disruption

The first column of Figure 5 shows impulse response of three latent yield curve factors of the four countries to sudden oil supply disruption. Solid lines represent impulse response functions to the oil price shocks, and dashed lines are one standard error bands computed using recursive-design wild bootstrap proposed Gonçalves and Kilian (2004) with 2,000 replications. Shocks due an

unexpected oil supply disruption cause an instantaneous increase of the level factor in Canada, Norway and South Korea. Although these effects do not persist long for Canada and Norway, they do persist in the case of South Korea. In the US there is no response of the level factor to the shocks. This finding regarding the US level is consistent with Kilian (2009)'s as he also found that the impact of oil supply shocks on the overall price and subsequently to inflation is limited.

The temporary increase of term structure levels in oil exporting countries (Canada and Norway) is in line with the results of Charnavoki and Dolado (2014) and Korhonen and Ledyaeva (2010), where shocks which increase commodity prices can have a favourable effect on the economy. The increase of interest rates level is prominent in South Korea, peaking around 12 months following a negative oil supply shock. This pronounced and persisting response in South Korea may be related to its high dependency on crude oil, leading to greater concerns about future inflation compared to other countries. This result is in line with Baumeister et al. (2010) who found that countries with higher oil dependency suffer more from consumer prices increases following an oil shock, whereas inflationary pressures in net energy-exporting countries are negligible.

Slopes initially decrease after oil supply shocks in both the US and Canada. This response is consistent with the central bank's reaction, lowering the policy rate, to offset possible negative effects on economic activity from oil supply disruption. On the contrary, the decreases in slope factors of Norway and South Korea are negligible and even begin increasing after a year. We interpret this result in the case of Norway as follows: the oil price increase following an oil supply shock acts as stimulating effect when crude oil constitutes large share of exports. The response of slope factor to the same shock in South Korea can be explained by the policy reaction, increasing the short rate, to reduce

the inflationary pressure possibly associated with its high energy intensity and dependency.¹⁵

Curvatures of Norway and South Korea increase after oil supply shocks and persist longer in South Korea. This result may be understood by construing oil supply shocks leading to short-lived inflation uncertainty in these countries, affecting the risk premium of medium-term bonds delivering higher yield.¹⁶

5.2.2. Aggregate Demand Shocks

The responses of estimated yield factors to aggregate demand shocks are shown in the middle column of Figure 5. The level factor in all countries increase, with the response of the level being faster and stronger in Norway and South Korea whilst for the US and Canada such responses were not statistically significant.

The slope factor in oil importing countries (the US and South Korea) increased after aggregate demand shocks, which is consistent with the central bank's policy reaction using conventional Taylor rules, as shocks to aggregate demand move output and price in the same direction requiring tightening monetary policy. The increases in slope is more prominent in South Korea, which may be related to its higher dependency on oil (and its products) in its role as input to production and as a consumption good. The impact of the shocks on the slope on the Canadian yield curve is negligible, indicating a very mild

¹⁵The response of central banks to the variety of shocks can only be inferred by subsequent policy reactions rather by explicit announcements by policy makers. Work by Krichene (2006) concludes that, for the US, the relationship between oil prices and interest rates is a two-way interconnection that depends on the type of oil shocks. During a supply shock, rising oil prices caused interest rates to increase; whereas during a demand shock, falling interest rates caused oil prices to rise. In the case of South Korea, Lee and Song (2009), in the context of a simulated DSGE model found that an accommodative policy yields more stable outcomes.

¹⁶The macroeconomic content of term structure curvature is under-explored. Diebold et al. (2006) report the effect of curvature surprises on macroeconomic variables is negligible. Empirical evidence by Evans and Marshall (2007) shows that the curvature is not largely affected by various macroeconomic shocks. However, Mönch (2012) argues that surprises in curvature are followed by slope increases, announcing a deterioration of output growth more than a year ahead.

response of the central bank to the shock. A more surprising result is the response of the same factor in Norway, where the yield curve steepens, contrary to conventional expectations regarding the reaction of monetary policy, suggesting that the shocks have resulted in increases in the long-rate as investors assess the reaction of the short rate was not sufficient to control future expected inflation.

5.2.3. Oil Market-Specific Shock

The last column of Figure 5 shows the responses of the yield curve factors to oil market-specific demand shocks. The levels in the US, Canada, and South Korea increase for around six months; this response can be understood as the effect of the high real price of oil and related products on inflation. It is interesting to see that level decreases significantly in Norway. This negative responses of the yield curve level in Norway might be due to the expected currency appreciation.

In the investigation to provide some potential explanations for a decline of the inflationary pressure from oil price rises in the 2000s, Chen (2009) argues that the appreciation of the domestic currency has been one of the major causes. Basher et al. (2016) study the responses of exchange rates to the different sources of oil shocks and show that currencies of oil-exporting countries appreciate after oil market-specific demand shocks, but find no significant patterns in the adjustment of exchange rates after oil supply and aggregate demand shocks in both oil-exporting and oil-importing countries. Buetzer et al. (2012) and Buetzer et al. (2015) find that oil exporters tend to counter appreciation pressures after an oil demand shocks by accumulating foreign exchange reserves and sovereign wealth funds. The authors argue that these counter-balancing forces, preventing large fluctuations in the nominal exchange rates, are the main reason for finding no clear relationship between oil prices and exchange rate movements as theories imply. However, the countries, especially with floating currencies, still experience a nominal appreciation following oil demand shocks. Bergholt et al. (2017)

build two-country New Keynesian model to test the role of oil price shocks for Norway and show that fiscal regime including a sovereign wealth fund and a fiscal rule spending oil wealth plays an important role stabilizing its economy against oil price shocks.

The significant increases of slopes in all countries are consistent with Kilian (2009)'s argument that oil market-specific shocks, associated with precautionary demand for oil, have been the main driver of real oil price fluctuations and act as the largest inflation pressure.

Term structure curvature responses vary across countries. In the US, the initial response is decreased curvature indicating a relative fall in mid-maturity rates, stemming, in all probability from the response of the level, and the temporal marked rise in the short rate; subsequently these pressures on the short rate abate and the curvature returns to its previous value. The responses are possibly related with the expectations over output deterioration due to the negative impact of the oil price hike. It can also be understood as a result of the systematic policy response offsetting the anticipated inflationary effect (see, for example, Bernanke et al. 1997) in the medium term. There is no immediate reaction in Canada, after a period of two-three months the curvature increases, indicating a possible over-reaction of the the mid-maturity rates to the tightening of monetary policy and steady level factor. Eventually as short rates return to their pre-shock level the curvature returns to its equilibrium value. In Norway the small decrease in the level factor associated with an increase in the short rate puts upwards pressure on the mid-maturity rates, increasing temporarily the curvature of the yield curve. As the short rate begins to fall and the long rate returns to its previous value, this pressure subsides and the yield loses concavity. Finally in the case of South Korea, initially all neighbouring rates (to the short rate) move together leaving the curvature unchanged for up to a year

after the shocks. Subsequently as short rate falls, is followed by an accelerated decrease in the mid-maturity rates, manifesting as a falling curvature of the South Korean yield curve.

The results reveal considerable variation of the responses of the curvature factor across countries. Mönch (2012) and Argyropoulos and Tzavalis (2016) suggest that the curvature factor, entering with the opposite sign of the slope factor, has predictive power for short run movements of economic activity due to the monetary policy stance. The results obtained here can be considered the consequences of such predictions conditional on the monetary policies across the four countries in the study.

5.2.4. Yield Curves after the Shocks

To describe the entire term structure dynamics after each oil price shock, in Figure 7, we provide the changing shape of yield curve after selective months from the shocks. Each row represents the country-specific yield curve and each column shows the shocks to oil supply, aggregate demand, and oil market-specific demand. The curves with a solid line are average yield curve for estimation periods. The dotted and dash-dot line are for the yield curve after 3 and 12 months, respectively. The dashed line represents the yield curve after 24 months.

To the shocks in oil supply disruption, the US yield curve becomes steeper during the first six months which is related to monetary policy response. However, as expectations over the future negative impact on growth dominate, the yield curve begins to shift downwards after 12 months. In Canada, the dynamics of yield curve show a similar pattern to the US, but the magnitude is slightly larger than that of the US. The yield curves for Norway and South Korea react more to oil price shocks, both in terms of position and shape, which is reasonable as these two countries are more exposed to oil shocks. The yield curve for

Norway shifts upwards after an oil supply shock and returns below its initial level after 24 months, whilst in South Korea following the initial shift upwards the yield curve is set at a lower level but above its original position.

Aggregate demand shocks have smaller impact on the dynamics of the term structure of interest rates in all four countries. For oil exporting countries such as Canada and Norway the yield curve settles eventually at below its pre-shock level, the difference is more pronounced in the case of Norway. For both the US and South Korea the total effect after 24 months is almost negligible.

In most cases, following an oil market-specific demand shock the yield curves shift upwards in the immediate aftermath, in line with Kilian (2009)'s finding that oil market-specific shocks have the largest impact on the real price of oil which imply its highest influence on inflation expectation despite the policy rate response to moderate its impact on overall price. Regarding real oil price shocks, similar results are also reported by Kapetanios and Tzavalis (2010) showing that such shocks lead to predictions of higher expected inflation and subsequent increases in the short rates, worsening the economic outlook. Generally speaking the yield curves after 24 months have become steeper, lying below their original levels, with the short rate remaining at the same level in the US and Canada and falling in Norway and South Korea. This is due to the dominant negative effect on output following such shocks. In this case, central banks eventually reduce short rates pushing downwards all the near-by maturities.

5.3. Variance Decompositions

To quantify the importance of the structural shocks in global oil market on the dynamics of the yield curve, Table 2 reports the forecast error variance decompositions of the three yield factors to oil supply, global aggregate demand, and oil market-specific demand shocks.

Panel A of Table 2 shows the results for the US. On impact, the effect of

three identified global oil market shocks on the level, slope, and curvature are negligible, with 1.0%, 1.2%, and 0.5% of total variability in the respective factors associated with all the shocks from the global oil market. The variability of level accounted by oil market shocks increases to 4.0% after 12 months with most of the effect coming from oil market-specific demand shock. Global oil market shocks do not explain much for the US slope factor, only 4.6% is explained by them after 60 months. Aggregate demand and oil market-specific demand shocks have non-negligible explanatory power on the yield curve curvature, accounting for more than 10% after 24 months.

The results of the decomposition of the forecast errors variance for the Canadian yield factors are summarised in Panel B of Table 2. After 12 months, shocks in global oil market shocks account for around 5% of the forecast error variance, of the level factor, similar share for the slope and up to 9.5% for the curvature. However, over time, and after 48 months these proportions rise to 9.3%, 6.3% and 19.9% respectively, evidence that impact of oil shocks, from different sources, have a pronounced medium term effect on both the slope, level and curvature of the yield curve.

Panels C and D of Table 2 show that innovations from global oil market explain a large part of the forecast error variance of the yield factors in Norway and South Korea. Initially, the variances of the level factors are mainly explained by their own innovations. However, along longer forecast horizons, say 12 months or more, at least 20% of the forecast error variances of these factors are explained by the oil market shocks, and these proportions increases significantly after 48 months. The same pattern emerges in the case of the variance decomposition of the slope and curvature factors for both countries.

More specifically oil market-specific demand shocks explain a considerable proportion of the forecast error variable of the interest rates level in Norway.

They account for around a third of the level variance among the overall variances due to oil price shocks after 12 months and the proportion rising to 61.9% after 48 months, whilst for the slope, the shocks account on the average for 80% of the slope variance over the same time span. Regarding the shocks impact on the decomposition of the variability of the curvature forecast error the share rises from 46.9% to 63.0%, indicating the increasing importance of this type shock on Norway's yield curve.

In the case of South Korea, more than 36% of the variability of each yield factor can be attributed to the presence of the shocks within the first 24 months and the share remains stable, albeit with different decomposition, over the 60 month period. Interestingly, oil supply shocks have large explanatory power for the variance of the forecast errors of level factor in South Korea after the first 12 months, thereafter its importance decreases somewhat after 36 months. The shocks' impact on the variance of the slope and curvature rises fast reaching almost 20% within the same period.

It is of interest that aggregate demand shocks have a modest but very steady impact on all the factors of the yield curve, indicating a very modest movement of the yield curve. Oil market-specific demand shocks explain a substantial proportion of the variance of South Korean yield slope. It is remarkable that whilst within 12 months in contribution is only 2.8%, by the end of month 48 this has risen to 15.7%, whilst for slope and curvature this shock accounts for 17.8% and 15.7% respectively.

Although since late 2008 nominal short-term interest rates have assumed almost zero values and the long-term rates have been below 4% and interest rates in other economies have also recorded on unprecedented low level, this analysis has established the importance of the impact of shocks from the global oil markets on the shape and positions of the yield curves for four countries.

Our result suggests that there is no universal outcome from such shocks and that their impact has to be calculated on a country basis taking into account its position as an oil exporter or importer. Whilst the yield curve of large economies as the US do not exhibit substantial changes after such innovations, for small open oil importing economies like Norway and South Korea, such incidents have pronounced and persistent impact on their financial markets as bond yields are affected by oil shocks.

5.4. Robustness Check

We next consider the impact of oil market shocks on the yield curve by considering the period from the beginning of the available sample to the end of 2008, where interest rates were fluctuating near their historical levels. From the onset of the financial crisis, financial and commodity markets witnessed a truly unusual conduct of monetary policy in almost all Western economies. Policy rates in the US have reached to all intents and purposes the zero lower bound and have been kept at this rates for almost 9 consecutive years. For example during the first period the average three-month rate is 6.2% and the ten year rate 7.5%. From January 2009 the same maturity rates averaged 0.2% and 2.7% respectively. Over the same period in Canada, the impact of the financial crisis was less pronounced. Although the yield curve shifted downwards, the average of the the three month rate was around 1% compared to its before crisis mean of 5.7% and the long-term rates have also declined from 6.8% to 2.5%.

The previous analysis is based on the whole data sample that is constituted by these very distinct periods regarding the statistical behaviour of the yield curve, both in terms of position and shape. The limited number of data points available in the aftermath of the financial crisis does not allow for the separate econometric analysis from January 2009. To examine the possible future impact of the oil shocks in a period where interest rates are set without reference to the

immediacy dictated by the financial crisis, we conduct the same econometric analysis over the pre-crisis period only. This exercise will allow to test whether the current unusual conduct of monetary policy has cushioned the impact of oil market shocks on the yield curves of the US and Canada.

Figure 6 reports impulse response of three yield factors to oil price innovations. The effect of an oil supply shock has no initial discernible effect on the level, slope and curvature factors. Over the subsequent periods there is a predicted decrease in the slope and a corresponding increase in curvature implying a fall in the short rate to ameliorate the predicted impact of the shock on output. The major impact on the US yield curve is due to oil market-specific demand shocks. In this case there is a strong and persistent increase of the level factor, followed by a corresponding increase in the slope and decrease in curvature. The response is qualitatively similar to the one calculated using the whole sample period, however in this case unlike the previous, the impact of the shock on the level is significant and very persistent. This may signify that once interest rates return to their previous levels the sensitivity of the yield curve to oil market shocks will far more noticeable.

There is also a remarkable increase of the contribution of the same shocks on the variance decomposition of the level, slope and curvature factors as reported in Table 3. These now stand at 7.1%, 5.2% and 10.0% after 12 months, compared to 4.0%, 2.9%, and 9.2% when the whole sample was used, and the equivalent contributions after 48 months now stand at 17.2%, 5.2% and 11.3% rather than 2.6%, 3.7% and 10.9%. The main conclusion from this analysis is that this type of oil market disturbances cause substantial increases of the ‘equilibrium’ rate of interest during ‘normal’ periods. Currently the extremely low rates of interest provide for a protective cushion, keeping such rate unaffected.

In Canada, similarly to the US an oil supply shock does affect the level and

has a strong and persistent affect on the slope. The slope declines, implying a fall of the short-term rate. This finding is consistent with the expected response of any central bank to the expected fall in activity, following such an oil market disturbance. Unlike the case of the US, oil market-specific demand shocks exercise downward pressure on the level factor and tend to flatten the yield curve as short rates are rising whilst the long rate tends to fall, as the slope rises. It seems that the reaction of the Canadian central bank to this shock, by raising the short rate, is sufficient signal to indicate lower future inflation, pushing downwards the long rate. Aggregate demand shocks lead again the short-term rate rises, flattening the yield curve and this impact is more pronounced during the pre-crisis period. These findings point towards the existence of a ‘recent reluctance’ by the Central Banks to raise the short rate in the presence of oil market shocks. The contributions of these shocks to the variance decomposition of the three factors is higher overall in both 12 month and 48 month horizons, with marked increased contributions in the level and curvature factors. The more striking point from this analysis is that in both countries we found that the level factor was far more sensitive to oil market shocks in the pre-crisis period.

6. Conclusion

We study the impact of the oil price shocks on the term structure of interest rates across four industrial countries; the US, Canada, Norway, and South Korea. Our results indicate that the yield curve factors (level, slope, and curvature) react differently to oil market shocks contingent on the underlying sources that drive them, the country’s dependence on oil, and the manner of conduct of monetary policy.

Undertaking the analysis over the whole sample, we find that oil market-specific demand shocks result in increases of level factor in oil-importing countries, whilst have no such effect in oil-exporting countries. Oil supply disruptions have short-lived negative responses of the slope factors in the US and Canada, associated with the loosening of monetary policy, whilst demand side shocks lead to slope increases in all countries, resulting from short-term rate rises. The supply and demand shocks jointly account for a considerable amount of the observed variation in the term structure of interest rates, explaining up to almost half of the changes of the South Korea, 20% in Canada and Norway, whilst have limited impact on the US. It is evident that South Korea as net oil importer is relatively very sensitive to oil market fluctuations, compared to oil exporting countries like Canada and Norway. The combined contribution of these shocks to the variance decomposition of the US yield curve is limited to approximately 10%.

Despite the significant variations between the four countries, found on the impact of oil market shocks, we established that all yield curves respond via some factor. This effect has been neglected in the literature as it has focused almost exclusively on macroeconomic aggregates and their relationship with financial variables has been limited in stock market. Our results suggest that oil shocks independently of their sources will affect the discount factors as they alter the position and shape of the yield curves.

Sub-sample estimation exercise reveals that the unusual monetary policy condition during the crisis time had altered the relationship between oil price and the term structure of sovereign yields. For both the US and Canada we find that the impact of these shocks on yield curve is more noticeable and persistent. The current monetary policy, keeping extremely low policy rates, has limited the

impact of oil markets developments on the factors of the yield curve, providing additional stability in these rather uncertain times.

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Table 1: Summary Statistics for the Full and Sub-Sample Periods

		3M	2Y	5Y	Level	Slope	Curvature
United States	1973M1 - 2015M12	5.20	5.67	6.19	6.72	-1.52	-0.59
	1973M1 - 2008M12	6.17	6.66	7.09	7.50	-1.33	-0.34
	2009M1 - 2015M12	0.24	0.54	1.55	2.74	-2.51	-1.90
Canada	1986M1 - 2015M12	4.56	4.89	5.35	5.81	-1.25	-0.60
	1986M1 - 2008M12	5.72	6.03	6.44	6.81	-1.09	-0.47
	2009M1 - 2015M12	0.77	1.14	1.77	2.53	-1.76	-1.02
Norway	1998M1 - 2015M12	3.56	3.56	3.78	4.15	-0.58	-0.59
	1998M1 - 2008M12	4.81	4.75	4.85	5.03	-0.23	-0.33
	2009M1 - 2015M12	1.61	1.69	2.11	2.75	-1.14	-0.98
South Korea	2001M1 - 2015M12	3.51	4.02	4.34	4.67	-1.16	-0.14
	2001M1 - 2008M12	4.42	4.94	5.18	5.49	-1.07	-0.03
	2009M1 - 2015M12	2.47	2.97	3.39	3.74	-1.27	-0.27

Notes: This table reports the average values of the yields with selective maturities and three factors of yield curves. The level, slope, and curvature in this table represent the average values of the empirical counterparts for the yield factor estimates, and are calculated as $y_t(120)$, $y_t(3) - y_t(120)$, and $2 \times y_t(24) - (y_t(3) + y_t(120))$, respectively.

Table 2: Yield Curve Factor Variance Decomposition

Periods	Oil supply shocks	Aggregate demand shocks	Oil demand shocks	Level	Slope	Curvature	Oil market shocks aggregated
<i>Panel A. Yield Factors Variance Decomposition for the US (Jan 1973 - Dec 2015)</i>							
<i>(Level)</i>							
1	0.000	0.005	1.043	98.951	0.000	0.000	1.049
12	0.157	1.318	2.478	89.342	2.144	4.561	3.952
24	0.108	0.759	1.623	78.012	14.326	5.173	2.489
36	0.102	0.875	1.417	59.435	30.401	7.769	2.394
48	0.115	1.200	1.330	46.822	40.700	9.833	2.645
60	0.126	1.407	1.243	40.235	46.072	10.917	2.777
<i>(Slope)</i>							
1	0.727	0.133	0.364	14.250	84.527	0.000	1.223
12	1.164	0.724	1.043	7.537	82.065	7.467	2.931
24	1.088	0.570	0.792	5.542	79.639	12.369	2.450
36	1.074	0.555	1.172	5.204	79.068	12.926	2.802
48	1.077	0.717	1.952	5.189	78.212	12.853	3.746
60	1.073	0.966	2.557	5.167	77.475	12.762	4.596
<i>(Curvature)</i>							
1	0.074	0.010	0.420	16.098	0.034	83.364	0.504
12	0.716	6.698	1.756	8.299	3.170	79.360	9.170
24	0.804	6.527	3.270	7.326	4.511	77.564	10.600
36	0.745	5.868	4.068	7.778	7.953	73.588	10.681
48	0.714	5.370	4.808	8.613	11.380	69.115	10.892
60	0.694	5.246	5.436	9.008	14.050	65.566	11.376
<i>Panel B. Yield Factors Variance Decomposition for Canada (Jan 1986 - Dec 2015)</i>							
<i>(Level)</i>							
1	0.000	0.217	0.928	98.855	0.000	0.000	1.145
12	0.809	1.989	1.646	86.416	1.127	8.013	4.444
24	0.744	1.474	1.910	77.552	5.790	12.530	4.129
36	1.157	2.536	2.241	59.500	17.834	16.732	5.934
48	1.468	5.251	2.541	48.024	24.494	18.222	9.260
60	1.682	9.270	2.917	41.938	25.948	18.245	13.869
<i>(Slope)</i>							
1	1.233	0.008	0.087	6.166	92.505	0.000	1.329
12	2.093	0.265	2.345	4.094	83.586	7.617	4.703
24	1.724	0.223	3.888	2.764	80.605	10.796	5.835
36	1.680	0.245	4.321	2.808	79.865	11.081	6.247
48	1.683	0.251	4.339	2.811	79.836	11.081	6.272
60	1.689	0.253	4.340	2.810	79.817	11.091	6.282
<i>(Curvature)</i>							
1	0.458	0.084	0.327	12.952	1.045	85.134	0.869
12	3.574	3.297	2.585	6.544	4.641	79.360	9.455
24	6.755	4.577	8.004	9.601	8.330	62.732	19.336
36	7.026	4.642	8.089	11.543	7.995	60.706	19.756
48	7.140	4.612	8.101	11.718	8.355	60.075	19.852
60	7.202	4.625	8.087	11.813	8.508	59.765	19.914

Notes: This table reports percent contributions of oil price shocks to each term structure factor. The forecast error variance decomposition is obtained using the structural VAR model described in the text. The last column is the sum of the contributions of the three oil price shocks in explaining the factor variances.

Table 2: Yield Curve Factor Variance Decomposition (continued)

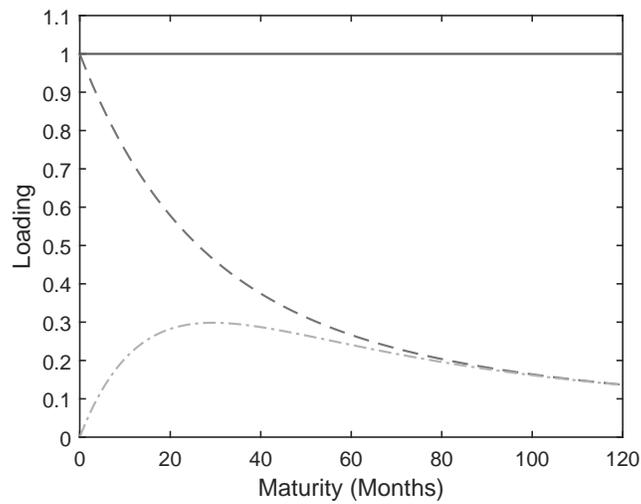
Periods	Oil supply shocks	Aggregate demand shocks	Oil demand shocks	Level	Slope	Curvature	Oil market shocks aggregated
<i>Panel C. Yield Factors Variance Decomposition for Norway (Jan 1998 - Dec 2015)</i>							
<i>(Level)</i>							
1	0.032	1.953	0.072	97.944	0.000	0.000	2.056
12	7.376	11.505	8.520	67.873	3.240	1.486	27.401
24	5.267	8.434	7.711	54.050	4.602	19.936	21.412
36	3.526	5.873	11.243	46.033	2.993	30.333	20.641
48	4.313	5.983	16.746	43.162	2.464	27.332	27.043
60	5.260	6.895	19.251	40.898	2.452	25.244	31.407
<i>(Slope)</i>							
1	0.322	4.339	2.404	52.192	40.742	0.000	7.065
12	0.772	1.925	21.895	17.894	28.645	28.868	24.593
24	1.974	2.680	19.356	19.080	24.009	32.902	24.009
36	2.696	3.389	18.959	21.502	22.649	30.806	25.043
48	2.985	3.706	19.334	21.458	22.196	30.321	26.025
60	3.070	3.811	19.264	21.345	22.035	30.475	26.145
<i>(Curvature)</i>							
1	0.190	0.002	0.862	36.991	0.637	61.317	1.054
12	3.278	0.749	3.562	26.416	5.745	60.250	7.589
24	4.930	0.811	9.490	26.267	6.781	51.720	15.232
36	6.124	0.910	11.285	26.699	6.570	48.412	18.319
48	6.338	1.077	12.648	25.945	6.690	47.302	20.063
60	6.400	1.173	12.629	25.848	6.870	47.080	20.203
<i>Panel D. Yield Factors Variance Decomposition for South Korea (Jan 2001 - Dec 2015)</i>							
<i>(Level)</i>							
1	0.573	0.001	3.169	96.257	0.000	0.000	3.743
12	27.119	8.098	2.815	58.503	2.558	0.907	38.032
24	34.116	7.941	4.857	45.002	3.846	4.238	46.914
36	32.231	6.183	8.453	32.285	10.759	10.090	46.866
48	24.850	4.681	15.729	24.222	19.519	10.999	45.260
60	20.943	4.455	22.597	19.918	22.270	9.818	47.995
<i>(Slope)</i>							
1	0.146	0.782	0.070	68.495	30.507	0.000	0.997
12	0.668	7.927	23.286	25.958	40.153	2.009	31.881
24	7.466	9.343	19.627	20.559	40.526	2.479	36.436
36	13.605	9.806	20.555	17.366	35.481	3.187	43.966
48	19.256	9.141	17.824	14.988	34.785	4.006	46.220
60	18.723	8.522	19.544	13.952	34.722	4.537	46.789
<i>(Curvature)</i>							
1	1.574	0.520	0.001	0.158	0.224	97.523	2.095
12	15.572	8.233	10.897	4.352	4.671	56.275	34.702
24	15.130	9.611	14.291	6.418	4.825	49.726	39.032
36	19.884	9.269	13.587	6.065	7.148	44.047	42.740
48	18.784	8.391	15.722	5.916	10.684	40.504	42.896
60	17.908	8.134	18.789	5.571	11.995	37.603	44.831

Notes: This table reports percent contributions of oil price shocks to each term structure factor. The forecast error variance decomposition is obtained using the structural VAR model described in the text. The last column is the sum of the contributions of the three oil price shocks in explaining the factor variances.

Table 3: Yield Curve Factor Variance Decomposition (Sub-Sample)

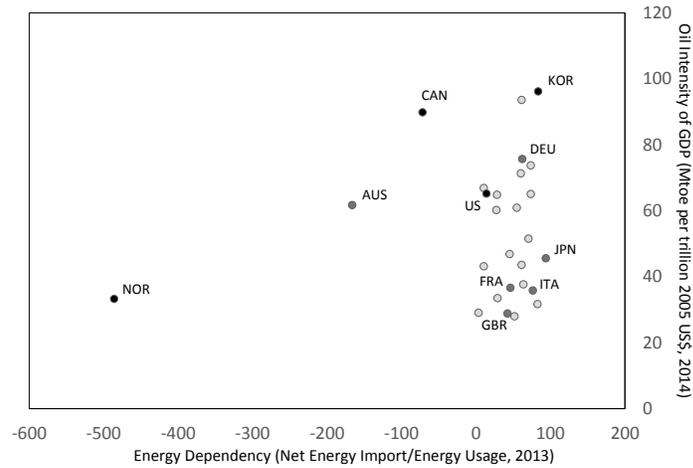
Periods	Oil supply shocks	Aggregate demand shocks	Oil demand shocks	Level	Slope	Curvature	Oil market shocks aggregated
<i>Panel A. Yield Factors Variance Decomposition for the US (Jan 1973 - Dec 2008)</i>							
<i>(Level)</i>							
1	0.006	0.859	0.945	98.190	0.000	0.000	1.810
12	0.118	0.562	6.404	80.891	3.430	8.594	7.084
24	0.172	1.267	9.476	66.378	17.743	4.965	10.915
36	0.224	2.437	12.792	48.472	31.921	4.154	15.453
48	0.200	2.604	14.413	36.904	40.371	5.508	17.218
60	0.172	2.315	14.734	30.468	44.799	7.513	17.220
<i>(Slope)</i>							
1	0.890	0.147	0.130	9.543	89.290	0.000	1.167
12	0.864	2.731	1.620	4.154	80.900	9.730	5.216
24	0.600	1.918	1.388	2.878	78.210	15.005	3.906
36	0.578	2.229	1.495	2.671	77.878	15.148	4.302
48	0.593	2.665	1.932	2.643	77.178	14.989	5.190
60	0.600	2.793	2.186	2.658	76.780	14.983	5.579
<i>(Curvature)</i>							
1	0.085	0.703	0.484	14.162	0.008	84.558	1.271
12	1.024	6.453	2.535	6.828	2.876	80.284	10.012
24	1.024	5.649	5.302	7.508	3.736	76.780	11.975
36	0.988	5.520	5.174	9.916	7.824	70.577	11.682
48	1.003	5.492	4.802	11.217	12.044	65.443	11.296
60	1.021	6.400	4.650	11.314	14.066	62.549	12.071
<i>Panel B. Yield Factors Variance Decomposition for Canada (Jan 1986 - Dec 2008)</i>							
<i>(Level)</i>							
1	0.050	1.932	0.096	97.922	0.000	0.000	2.078
12	1.424	3.135	0.680	84.000	2.761	7.999	5.240
24	0.998	2.889	1.597	73.000	13.724	7.792	5.484
36	0.852	9.467	1.712	53.370	23.395	11.204	12.032
48	0.798	12.202	1.681	43.089	24.341	17.889	14.681
60	0.769	12.554	2.375	37.250	24.336	22.716	15.697
<i>(Slope)</i>							
1	0.867	0.264	0.071	7.365	91.434	0.000	1.201
12	2.094	0.484	2.048	5.117	83.632	6.625	4.626
24	1.719	0.535	3.102	3.576	81.521	9.546	5.356
36	1.687	0.833	3.371	3.645	80.540	9.924	5.891
48	1.687	0.937	3.390	3.649	80.377	9.960	6.014
60	1.693	0.958	3.458	3.640	80.190	10.060	6.110
<i>(Curvature)</i>							
1	0.201	1.152	0.126	13.122	0.815	84.583	1.480
12	3.271	9.700	4.148	6.723	4.095	72.063	17.119
24	5.716	17.691	9.479	7.078	6.641	53.396	32.886
36	6.086	17.171	9.089	8.951	6.796	51.907	32.347
48	6.195	18.090	8.923	9.118	6.794	50.880	33.208
60	6.260	18.051	8.984	9.167	6.868	50.669	33.295

Notes: This table reports percent contributions of oil price shocks to each term structure factor. The forecast error variance decomposition is obtained using the structural VAR model described in the text. The last column is the sum of the contributions of the three oil price shocks in explaining the factor variances.

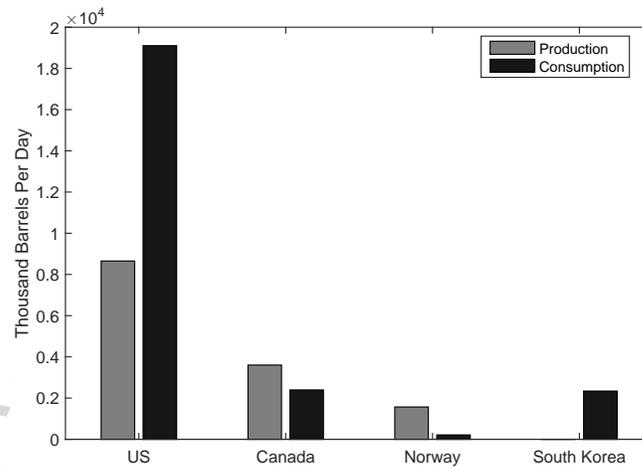
Figure 1: Loadings for Three Yield Factors ($\lambda = 0.0609$)

Notes: This figure shows the factor loadings as a function of maturities from 0 to 120 months, for $\lambda = 0.0609$. Solid line, which is constant at 1, represents the loading for level. Decreasing dashed line is the loading for slope and the dash-dot line is the loading for curvature. The value for λ is from Diebold and Li (2006).

Figure 2: Countries' Characteristics in Oil Production and Consumption



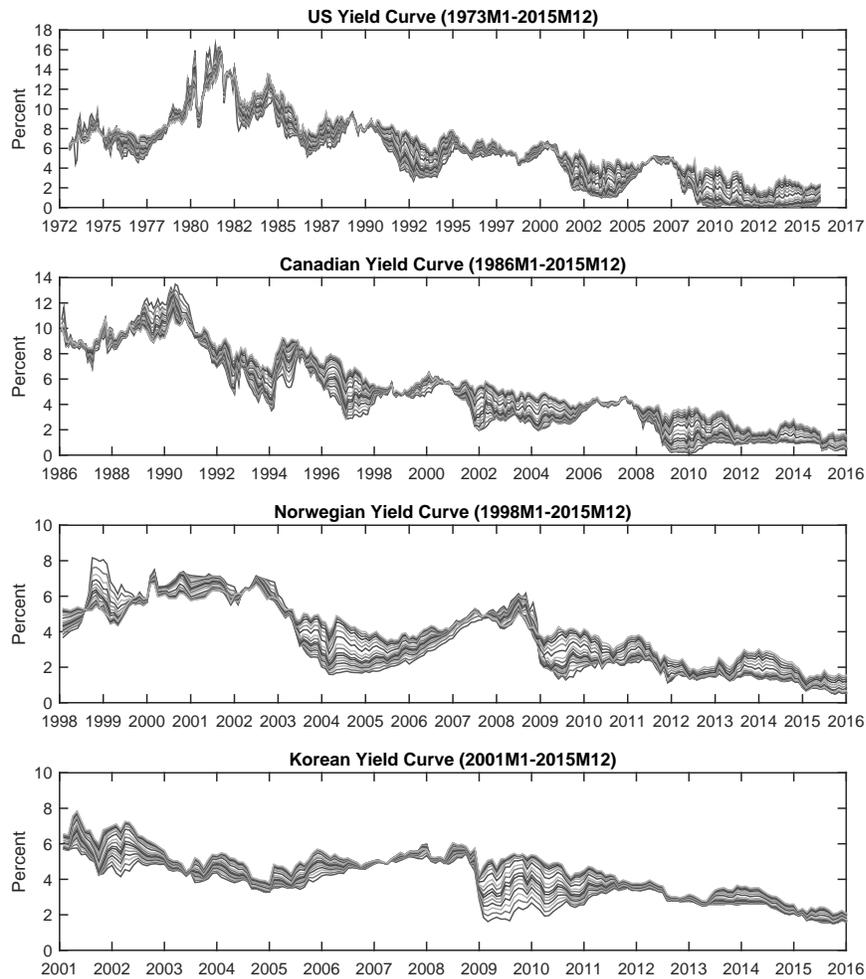
a. Energy Dependency and Oil Intensity of GDP



b. Crude Oil Production and Consumption

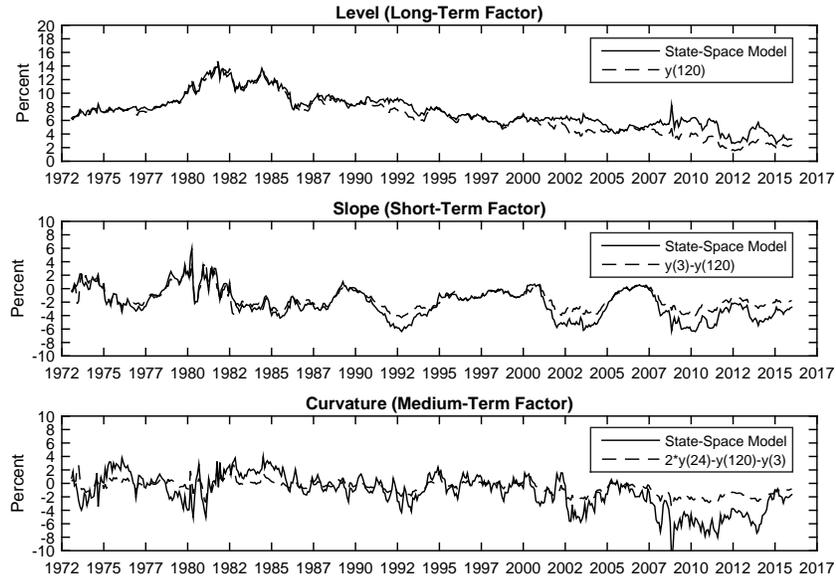
Notes: Energy dependency is net energy imports divided by the total energy usage as of 2013. Net energy imports are estimated by IEA (International Energy Agency) as energy usage less production, both measured in oil equivalents. The oil intensity is the ratio of oil consumption (Mtoes) over gross domestic product measured in constant US dollar at market exchange rates as of 2014. Crude oil production and consumption are from IEA as of 2014. Crude oil production includes lease condensate.

Figure 3: Monthly Bond Yields

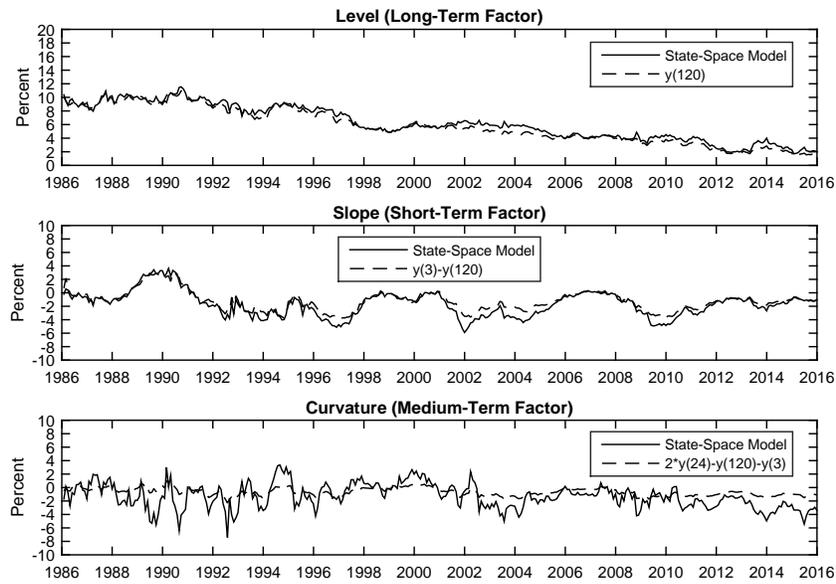


Notes: This figure shows end-of-month bond yields for the US, Canada, Norway, and South Korea. Each yield curve has 17 maturities (3, 6, 9, 12, 15, 18, 21, 24, 30, 35, 48, 60, 72, 84, 96, 108, and 120 months). The sample periods are different among countries due to availability.

Figure 4: Estimates of Level, Slope, and Curvature



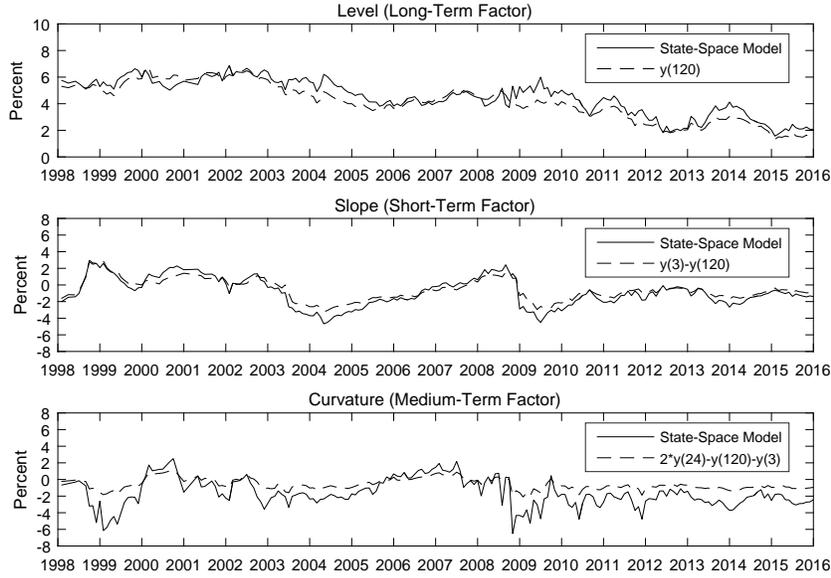
a. United States



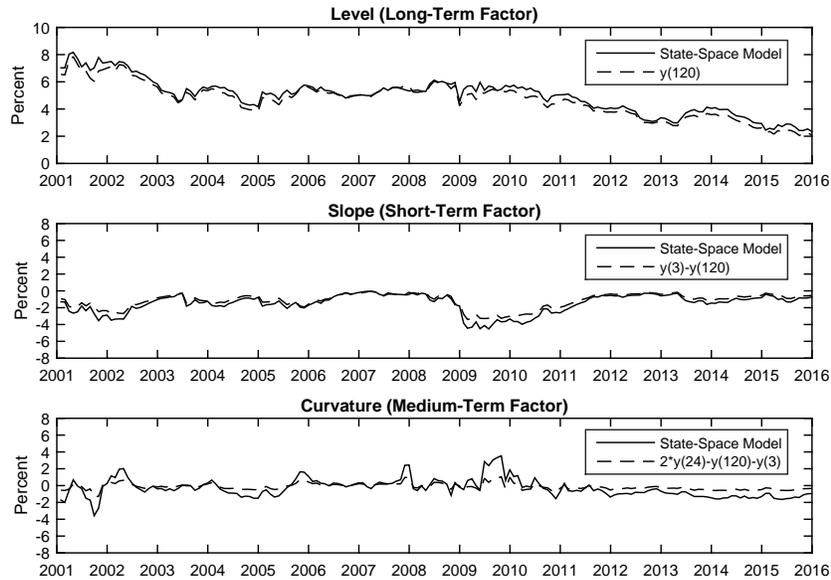
b. Canada

Notes: Solid lines are estimated yield factors (level, slope, and curvature for each country) using state-space model. We show empirical counterparts of the factors ($y_t(120)$, $y_t(3) - y_t(120)$, and $2 \times y_t(24) - (y_t(3) + y_t(120))$) with dashed lines.

Figure 4: Estimates of Level, Slope, and Curvature (continued)



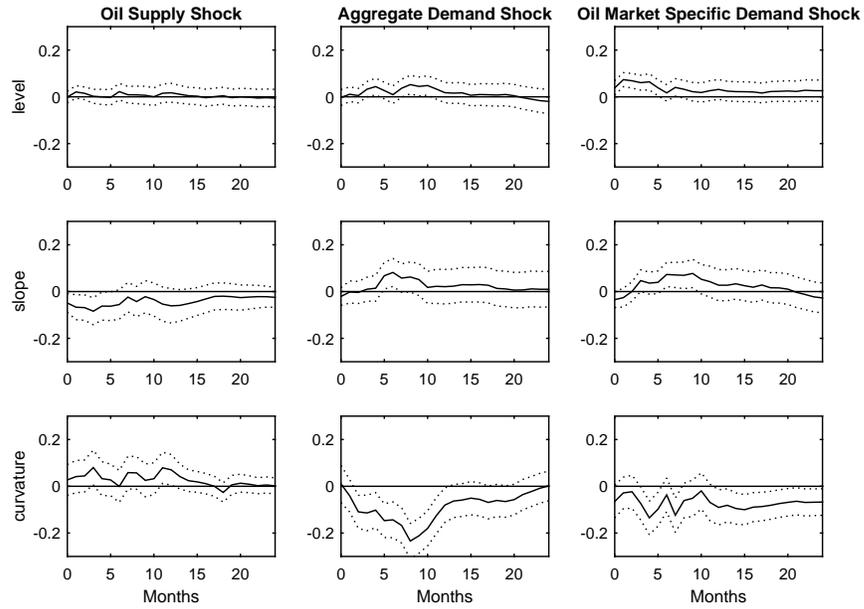
c. Norway



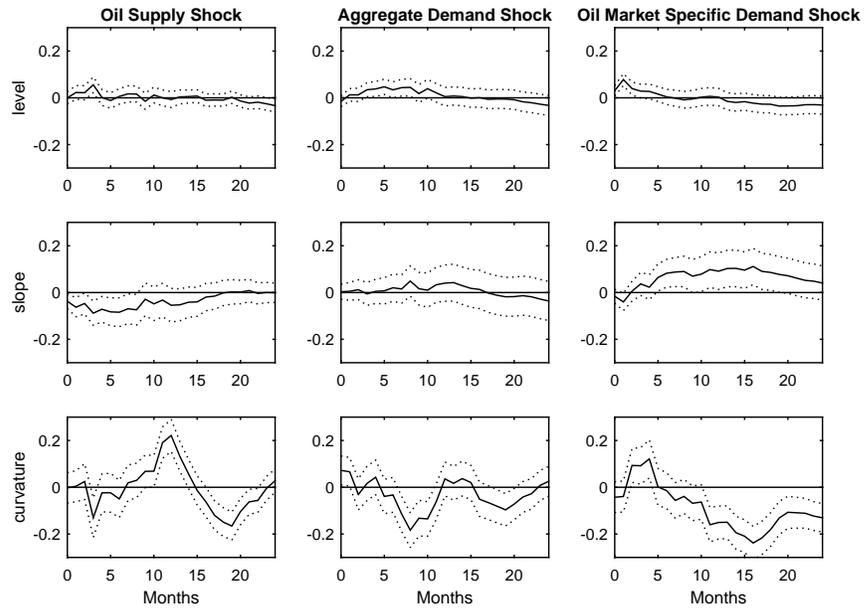
d. South Korea

Notes: Solid lines are estimated yield factors (level, slope, and curvature for each country) using state-space model. We show empirical counterparts of the factors ($y_t(120)$, $y_t(3) - y_t(120)$, and $2 \times y_t(24) - (y_t(3) + y_t(120))$) with dashed lines.

Figure 5: Responses of the Yield Curve Factors to Structural Oil Market Shocks



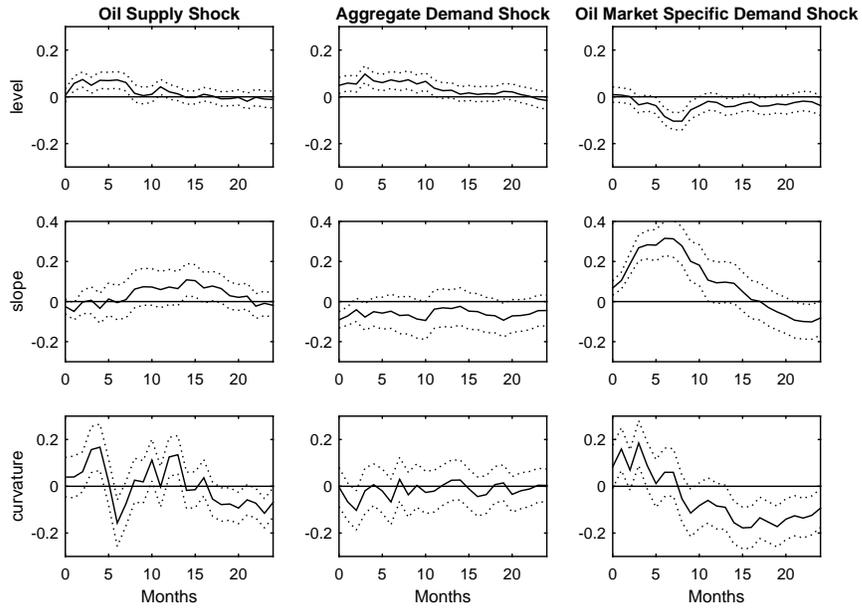
a. United States (Jan 1973 - Dec 2015)



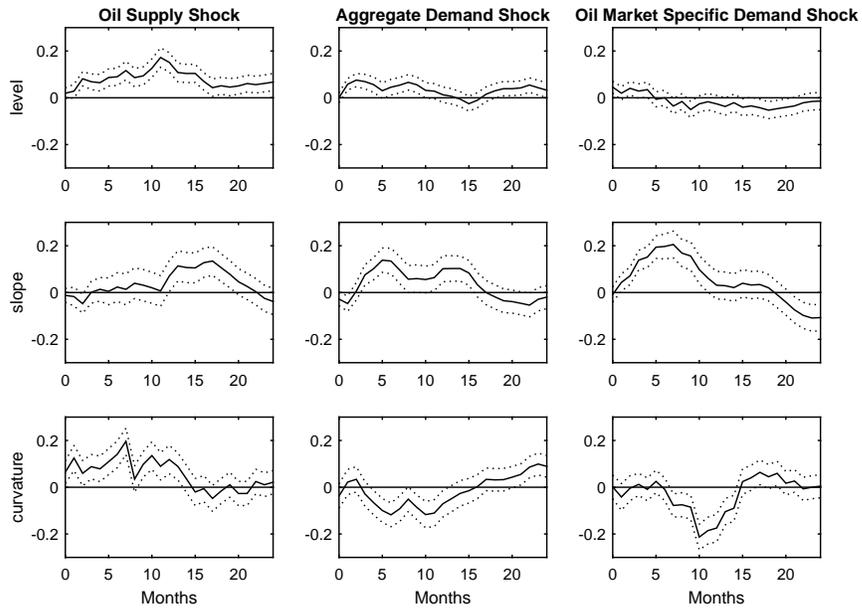
b. Canada (Jan 1986 - Dec 2015)

Notes: Responses are to one-standard deviation structural shocks in oil market shocks based on the SVAR model. Dotted lines represent one standard error bands constructed using a recursive-design wild bootstrap proposed by Gonçalves and Kilian (2004).

Figure 5: Responses of the Yield Curve Factors to Structural Oil Market Shocks (continued)



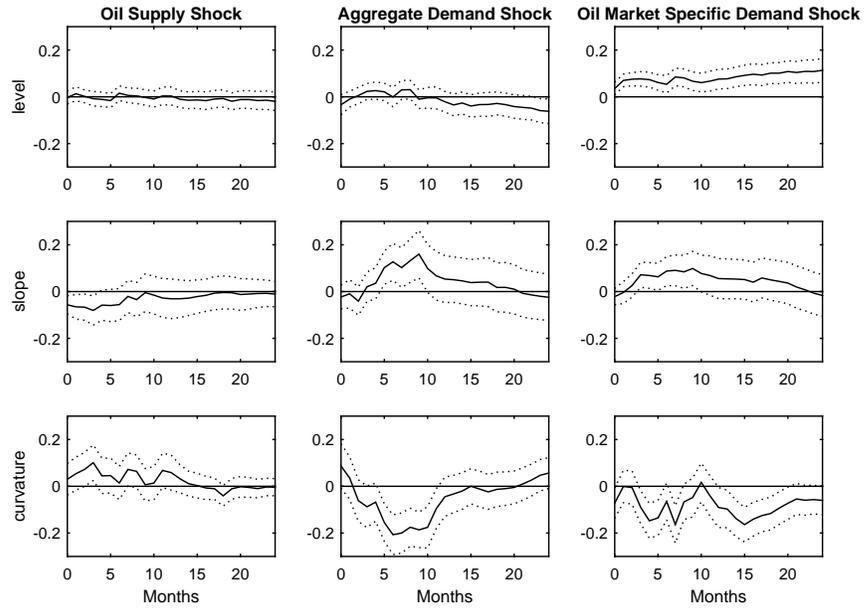
c. Norway (Jan 1998 - Dec 2015)



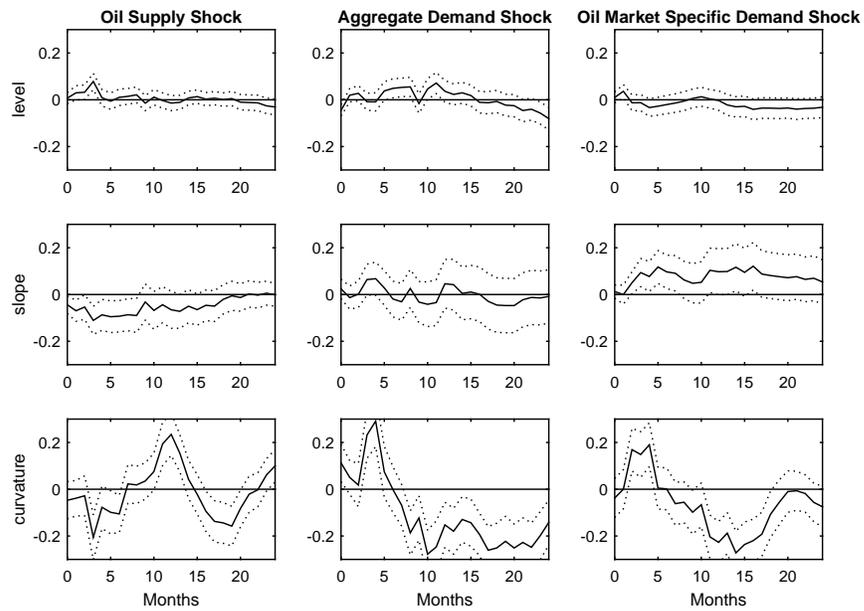
d. South Korea (Jan 2001 - Dec 2015)

Notes: Responses are to one-standard deviation structural shocks in oil market shocks based on the SVAR model. Dotted lines represent one standard error bands constructed using a recursive-design wild bootstrap proposed by Gonçalves and Kilian (2004).

Figure 6: Responses of the Yield Curve Factors to Structural Oil Market Shocks (Sub-Sample)



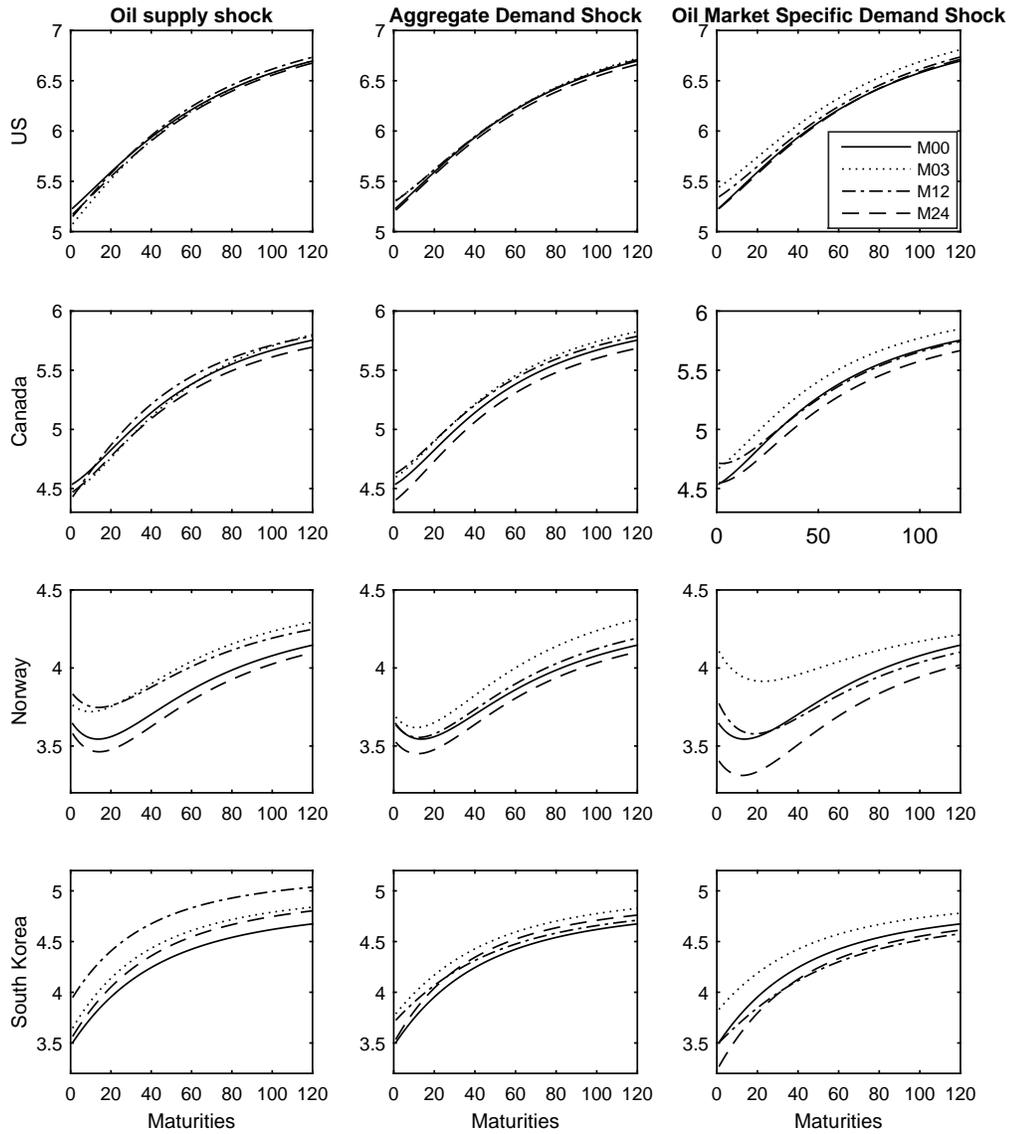
a. United States (Jan 1973 - Dec 2008)



b. Canada (Jan 1986 - Dec 2008)

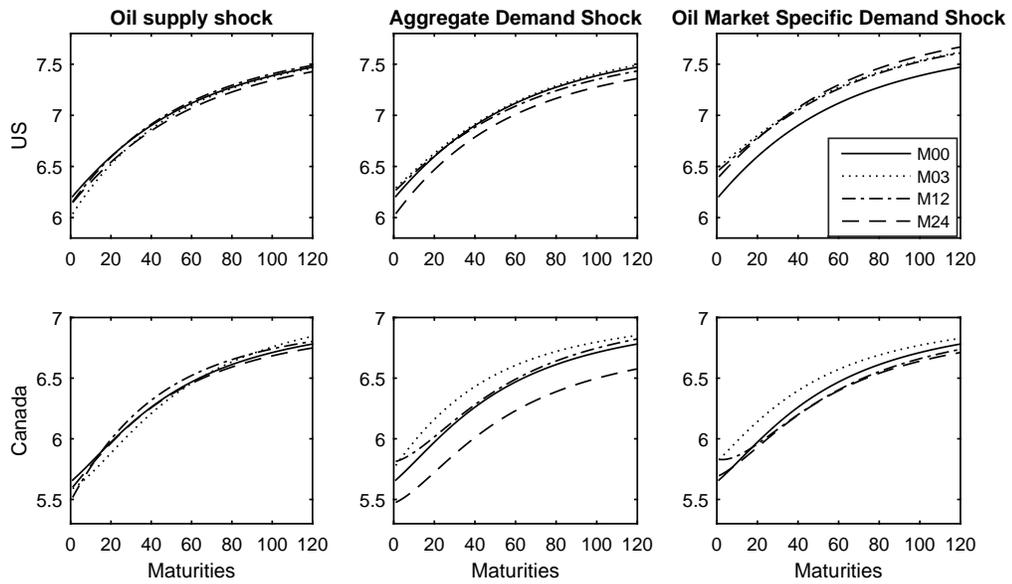
Notes: Responses are to one-standard deviation structural shocks in oil market shocks based on the SVAR model. Dotted lines represent one standard error bands constructed using a recursive-design wild bootstrap proposed by Gonçalves and Kilian (2004).

Figure 7: Yield Curve Dynamics after Oil Market Shocks (Full Sample)



Notes: Figures show the changing shapes of yield curves in 3, 12, and 24 months to three oil market shocks. Initial curves with solid line have the average shapes of the yield curves for the corresponding estimation periods. The dotted and dash-dot line are for the yield curve after 3 and 12 months, respectively. The dashed line represents the yield curve after 24 months.

Figure 8: Yield Curve Dynamics after Oil Market Shocks (Sub-Sample)



Notes: Figures show the changing shapes of yield curves in 3, 12, and 24 months to three oil market shocks. Initial curves with solid line have the average shapes of the yield curves for the corresponding estimation periods. The dotted and dash-dot line are for the yield curve after 3 and 12 months, respectively. The dashed line represents the yield curve after 24 months.

Highlights

- Term structures of interest rates react differently to different types of oil price shocks.
- Yield factors of the countries with high oil dependency fluctuate more to oil price shocks.
- The impact of oil shocks on yield curve is more noticeable and persistent in normal times.