Journal of International Money and Finance 127 (2022) 102671

Contents lists available at ScienceDirect

Journal of International Money and Finance

journal homepage: www.elsevier.com/locate/jimf

Prime money market funds regulation, global liquidity, and the crude oil market

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A R T I C L E I N F O

Article history:
Available online 23 May 2022

JEL Codes:
F30
G20

Keywords:
Prime money market funds
Global liquidity
The real crude oil price
Sign-identified structural VAR models
Cross-border flows

A B S T R A C T

This paper explores how the 2016 US Prime Money Market Funds (PMMFs) regulation affected the crude oil market. This reform led to an increase in short-term dollar borrowing costs and the oil sector became particularly susceptible to disruptions in the global funding market due to a post-financial crisis debt expansion which far outpaced other commodity industries. Building on the global crude oil market SVAR model pioneered by Kilian and Murphy (2014), we find that tighter PMMFs funding conditions have a lagged negative effect on the real price of crude oil and a lagged positive effect on oil production. We show that these responses are driven primarily by a fall in certificates of deposits issued by global banks. Lastly, we evidence that the US nominal effective exchange rate acts as a transmission channel for the negative funding shock to the real price of oil.

1. Introduction

US Prime Money Market Funds, hereafter PMMFs, are a primary funding source of short-term liquidity, offering financial institutions and non-financial corporations access to wholesale funding.[1] PMMFs play a vital role in global dollar funding provision and represent an important source of US dollar funding for non-US borrowers, especially during crisis episodes such as the 2007–2009 Global Financial Crisis (GFC), the Eurozone crisis and the recent global outbreak of Covid-19, which has made them the centre of the current international policy debate (see IMF, 2021).

In 2016, a set of regulatory reforms for PMMFs were introduced to address the vulnerabilities which emerged during the GFC, according to which PMMFs were required to adopt a floating net asset value structure, liquidity fees and redemption gates in the event of a large increase in outflows (SEC, 2014).[2] This regulatory reform represented an important shift in the intermediation of wholesale bank funding as it led to higher short-term dollar borrowing costs in a number of ways (BIS, 2016). Firstly, the subsequent portfolio shifts of PMMFs resulted in significantly wider Libor-OIS spreads (BIS, 2016). Secondly, the rising market share of prime funds belonging to top fund families, triggered by the reform, indicates that smaller-sized prime funds were more likely to exit or convert to government or treasury funds. This resulted in a rise in the market power

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[1] Acknowledges funding from the South East Network for Social Sciences (SeNSS) (ES/P00072X/1).
[1] PMMFs are unsecured MMFs which invest in a combination of public *(repos)* and private sector obligations (e.g. certificates of deposit *(CDs)*, commercial paper *(CPs)* and asset-backed commercial papers *(ABCP)*).
[2] Government MMFs, which are secured money market funds investing solely in government securities or repos, were not subject to the new regulation.

https://doi.org/10.1016/j.jimonfin.2022.102671
0261-5606/

of the remaining funds, which were able to charge a higher price to banks with less elastic demand and weaker bargaining power (Aldasoro et al., 2019).

We propose two channels through which disruptions in the short-term funding of PMMFs can be transmitted to companies which borrow in US dollars: an indirect channel through cross-border bank flows and a direct channel through PMMFs (see Fig. 1). The cross-border bank lending model of Bruno and Shin (2015) suggests that global banks lend in US dollars to regional banks, which in turn lend to local borrowers (non-financial corporations). This cross-border lending is funded by global banks by raising US dollars in the major financial centers. US PMMFs are an important source of this funding (see Hanson et al., 2015; Aldasoro et al., 2019; Aldasoro et al., 2021).[3] More specifically, certificates of deposits (CDs) held by PMMFs became the most important unsecured wholesale funding source for banks following the GFC and a barometer for bank funding conditions (Eren et al., 2020b). Thus, short-term funding strains from PMMFs, particularly in the CDs market, will generate spillover effects to oil companies, which borrow in US dollars from banks via the cross-border bank lending channel.

Alternatively, disruptions in the short-term wholesale funding brought about by the US PMMFs reform can affect companies which borrow directly from PMMFs. The expansion of debt in the oil sector in the post-GFC period makes oil companies particularly susceptible to sudden disruptions in the global funding market. Post-GFC, oil companies have borrowed heavily in US dollars from both banks and in the bond markets, with the issuance of debt securities far outpacing the overall issuance of other commodity sectors (see Domanski et al., 2015 for further details).[4] Commercial papers (CPs) represent the primary financing source used to balance short-term liquidity requirements by major oil companies, accounting for roughly 6.2 percent to 25.5 percent of total debt as of the end of 2020.[5] As noted in Eren et al. (2020a,b), PMMFs are major global providers of short-term dollar funding to non-financial corporates. As of the beginning of 2020, PMMFs held a total amount of 255,545 dollars (in millions) of CPs.

Motivated by the effects of the 2016 US PMMFs regulation on global dollar funding conditions, the post-crisis debt expansion of the oil sector and the importance of oil price dynamics on the modern economy and environmental policies, we study the impact of this regulation on the crude oil price in the spot market. We model the global crude oil market using the pioneering SVAR model of Kilian and Murphy (2014), hereafter KM (2014), and refer to this model as our baseline model throughout the paper. We use monthly data for the four global crude oil market variables of KM (2014), namely, global crude oil production, global real economic activity, global crude oil inventories and the real price of crude oil, to which we add our funding variable, PMMFs investment holdings by global issuance.[6] We augment the SVAR model of KM (2014) by introducing CDs as an investment instrument held by PMMFs.[7] We thus aim to measure how the crude oil spot price is impacted according to the source of the dollar funding shock.

The US nominal effective exchange rate (NEER) is employed in our modelling approach of the exchange rate transmission channel of funding shocks, to account for an appreciation in the value of the dollar against other major currencies driven by thinner dollar supply from US PMMFs. Fluctuations in the value of the dollar affect the price of crude oil via oil supply, oil demand or cross-border bank lending. In particular, an appreciation of the US dollar (i.e., an increase in the US NEER) is associated with deleveraging of global banks and a reduction in cross-border dollar bank lending. The value of the dollar is thus an indicator of global credit conditions, with an appreciation of the dollar constituting a tightening of global financial conditions (see Bruno and Shin, 2015; Shin, 2016, for further discussion). We also include the consumer price index and VIX, as control variables for the feedback effects between inflation, risk appetite and uncertainty, and the price of crude oil (Belke et al., 2013; Beckmann et al., 2014; Cheng et al., 2015). The structural shocks are identified using Uhlig's (2005) pure-sign restriction approach. Sign restrictions have become increasingly popular in the recent literature on oil markets (Baumeister and Peersman, 2013a,b; Kilian and Murphy, 2012, 2014).

Our results empirically confirm our main hypothesis that tighter dollar funding conditions driven by the 2016 regulatory reform for US PMMFs affect the crude oil market. We also provide more general evidence of the impact of shifts in PMMFs funding conditions on the oil market. Hence, we capture not only the major disruptions from the introduction of the 2016 regulatory reforms, but also other relatively minor funding shocks. Specifically, we find compelling evidence of a lagged negative effect of tighter funding conditions on the real crude oil spot price, proxied through the US refiners' acquisition cost for imported crude oil, and of a lagged positive effect on oil production. These results are robust to measuring the real price of oil using the WTI spot price and the Brent spot price as well as to the inclusion of VIX.

Further, we find that the effect of the PMMFs funding disruption on the crude oil market is driven by a fall in the CDs, which constitute the most important unsecured wholesale funding for banks. Thus, we argue that the US dollar funding disruption triggered by the PMMFs reform is transmitted indirectly from PMMFs to the crude oil market, through cross-border bank flows. Lastly, we find that the US nominal effective exchange rate acts as a complementary transmission channel for the

[3] PMMFs are estimated to provide roughly 35 percent of the short-term, wholesale dollar funding to global financial institutions (Hanson et al., 2015). US and offshore PMMFs accounted for around 12 percent of the on-balance sheet funding for non-US banks at end of 2019 (Aldasoro et al., 2021).

[4] In particular, bonds outstanding in oil and gas sector increased from 455 billion US dollars in 2006 to 1.4 trillion US dollars in 2014, while syndicated loans increased from 600 billion US dollars in 2006 to an estimated 1.6 trillion US dollars in 2014. Debt issued by oil and other energy firms stands at 15 percent of both investment grade and high-yield major US debt indices, which represents a 5 percent increase in five years (see Domanski et al., 2015).

[5] These percentages were computed using information contained in the 2020 annual reports of Chevron, Exxon Mobil, BP, and Royal Dutch Shell.

[6] Global real economic activity is measured by the dry cargo shipping rate index as developed in Kilian (2009). A further discussion on the advantages of this index compared to measures of global real GDP or global industrial production is presented in Kilian and Zhou (2018).

[7] For completeness, we also consider the effect of *repos*, *other repos*, *CPs*, *ABCP* and other instruments held by PMMFs on the crude oil market. The estimation results are available upon request.

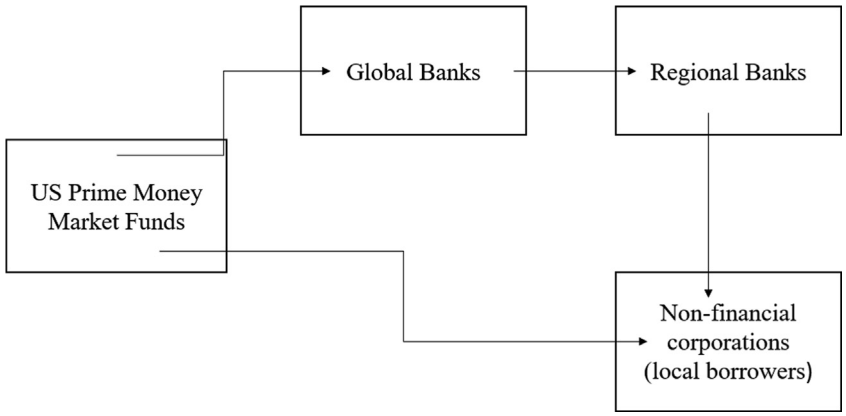

Fig. 1. Transmission channels of funding shocks from US PMMFs to non-financial corporations. *Notes:* Two channels through which disruptions in the short-term funding of PMMFs can be transmitted to companies which borrow in US dollars: an indirect channel through cross-border bank flows, discussed in Bruno and Shin (2015), and a direct channel through PMMFs.

negative funding shock to the real price of oil. We argue that an appreciation of the US dollar caused by a shortage of US dollars supplied by US PMMFs could decrease oil demand, as oil imports become more expensive in local currencies for non-US countries (De Schryder and Peersman, 2015). Alternatively, this US dollar appreciation could reduce the cross-border lending of non-US banks, thus affecting cross-border bank flows and generating a spillover effect to companies such as oil producers, which borrow in US dollars from non-US banks (Bruno and Shin, 2015; Avdjiev et al., 2019; IMF, 2019).

The main contribution of this paper to the extant literature, is that we are, to the best of our knowledge, the first to show that strains on US dollar funding from PMMFs, a vital source of short-term funding, affect the crude oil market. More specifically, we show that global liquidity matters for the price and the global production of crude oil. Secondly, whereas the existing literature on global liquidity and commodity spot prices uses global aggregates of broad money as a proxy for global liquidity, we account for the post-GFC shift in US dollar funding intermediation by using a novel measure capturing the short-term component of private global liquidity, namely the investment holdings of US PMMFs by global issuance and by instrument (see Belke et al., 2010; Anzuini et al., 2012; Ratti and Vespignani, 2013, among others).

In view of the importance of the US PMMFs, our findings are relevant for current global economic conditions as they show that unstable short-term money markets funds affect the crude oil market. We add to the literature by investigating the effect of global liquidity movements on crude oil prices, channelled through the activity of oil companies rather than the activity of financial investors and commodity consumers, which has been the focus of the recent studies on the oil market (Belke et al., 2010; Anzuini et al., 2012; Ratti and Vespignani, 2013; Beckmann et al., 2014, among others). Lastly, this study is relevant to the global economic outlook due to the persistent vulnerabilities faced by PMMFs, which are a major concern for regulators. Deteriorating global dollar funding conditions during the peak of the Covid-19 crisis, triggered by severe conditions in the PMMFs industry, is a further reminder of the high reliance of global banks and corporations on the short-term unsecured funding of PMMFs.[8]

The rest of the paper is organized as follows. Section 2 reviews the related literature. Section 3 sets out the methodology. In Section 4, we describe the data and provide some preliminary analysis. Section 5 discusses the empirical results. In Section 6, we introduce some robustness checks. Finally, Section 7 concludes.

2. Literature review

2.1. Global liquidity

Global liquidity, defined as the overall ease of financing in international financial markets, is a central subject of international policy debates and identified as one of the main factors behind the accumulation of financial vulnerabilities in the global financial system in the pre-GFC period (Borio et al., 2011; Committee on the Global Financial System, 2011; IMF, 2013; Cohen et al., 2017). Following the GFC, commodity producers have increasingly tapped international bond markets, with the oil and other energy companies far outpacing the overall issuance of other commodity sectors (see Domanski et al., 2015). Yet, literature on the relationship between global liquidity and commodity spot prices, particularly the crude oil spot prices, is still quite sparse.

[8] PMMFs experienced severe disruptions during mid-March of 2020 as investors switched from core unsecured funding markets to secured funding markets and Government MMFs. PMMFs suffered outflows which led to a shortage of funding for banks and corporations and a significant shortening of funding maturities. This episode exposed the persistent susceptibility of PMMFs to rapid redemptions, despite the efforts of the 2016 US PMMFs regulation to address the structural weaknesses which surfaced during the GFC (see IMF, 2021; Avalos and Xia, 2021).

Relatively few studies have investigated the impact of global liquidity on commodity spot prices and, when doing so, mainly in terms of a cointegrated relationship (see Belke et al., 2010; Belke et al., 2013; Beckmann et al., 2014). These studies find evidence of a positive long-term relationship between global liquidity, proxied through global aggregates of broad money, and the CRB commodity price index.[9] With a particular focus on the oil market, Ratti and Vespignani (2013) show that unanticipated increases in the liquidity of BRIC countries, measured by M2, lead to significant and persistent increases in real oil prices, global oil production and global real aggregate demand. In contrast, Anzuini et al. (2012) find that global liquidity, proxied through M2, leads to a sharp, but temporary increase in the price of oil which lasts until month ten.

The empirical studies mentioned above have used global aggregates of broad money as a proxy for global liquidity. However, intermediation in advanced economies has moved away from the traditional deposit-based funding towards international debt securities (Turner, 2014; Aldasoro and Ehlers, 2018; Avdjiev et al., 2020b). This recent change in the composition of global liquidity has been referred to as the "second phase of global liquidity" (Shin, 2014; Avdjiev et al., 2020b). The shift in international financial intermediation implies that global funding conditions have become more sensitive to developments in bond markets, and more connected to US monetary policy as a key driver of global liquidity conditions.[10] Therefore, monetary aggregates, which have been traditionally used to capture global liquidity, have become less suited to capture movements in liquidity (IMF, 2013).

Credit aggregates have been recently proposed as an alternative measurement of global private liquidity (Committee on the Global Financial System, 2011; Domanski et al., 2011; Bruno and Shin, 2013).[11] International credit has continued to expand in recent years from 33 percent of global GDP in 2015 to 38 percent in 2018 (Aldasoro and Ehlers, 2018). This growth has been driven primarily by the issuance of international debt securities, rather than bank loans (Turner, 2014; Avdjiev et al., 2020b). Empirical literature on global liquidity, proxied through credit aggregates, and commodity prices is sparse. Abdel-Latif and El-Gamal (2020) use a GVAR model consisting of Middle East countries and the BIS series for credit from all sectors to the private non-financial sector as a measure of global financial liquidity, and find a temporary decline in oil prices in response to a negative shock in global financial liquidity.

We argue that our main funding measure, PMMFs investment holdings by global issuance, is a suitable proxy for global liquidity for the following reasons. Firstly, it captures international debt securities characterized by short maturities and minimal credit risk, which are the main driver of the "second phase of global liquidity". Secondly, it is a quantity-based measure of global private liquidity as it captures both bank and non-bank credit in both advanced and emerging market economies. This provides an identification of liquidity creation by the private sector and can help track global liquidity cycles (Committee on the Global Financial System, 2011). Moreover, our proxy takes the US dollar currency denomination perspective. Since the GFC, the US dollar has increased its dominance as the prime international funding currency (Maggiori et al., 2018). Lastly, the use of PMMFs investment holdings by instrument, allows us to differentiate between short-term debt issuance by banks and non-banks.[12]

2.2. PMMFs as short-term US dollar credit providers

US dollar funding intermediation has faced major structural changes since the GFC. While global banks have diminished their loan and debt security positions, non-banks have increased their dominance in driving global liquidity (Shin, 2014; Aldasoro and Ehlers, 2018; Committee on the Global Financial System, 2020).[13] Several studies have investigated the role of PMMFs in the provision of short-term US dollar funding (Hanson et al., 2015; Parlatore, 2016; Aldasoro et al., 2019; Eren et al., 2020a,b, among others). Hanson et al. (2015) argue that the dominance of PMMFs as providers of short-term funding for global financial institutions has remained stable since prior to the GFC.[14] They estimate that PMMFs provide roughly 35 percent of short-term, wholesale dollar funding to large global financial institutions. *CDs* represent the highest proportion of PMMFs investment holdings (an average of 18 percent) during our sample period 2011:2–2021:10 (see Fig. 1A in the Appendix).

Few studies have highlighted the importance of PMMFs as funding providers to global banks. For instance, Aldasoro et al. (2019) investigate the interactions between global banks and PMMFs, arguing that PMMFs from which non-US global banks obtain a significant amount of dollar funding are not perfectly competitive, with a few top funds serving the funding needs of global banks. Aldasoro et al. (2019) find that PMMFs charged a higher price to banks with weaker bargaining positions such

[9] The CRB spot index consists of energy (39 percent), softs/tropicals (21 percent), grains/livestock (20 percent), and industrial/precious metals (20 percent).

[10] An extensive literature investigates the effect of US monetary policy on oil prices, having yet to reach a consensus. Rosa (2014) and Basistha and Kurov (2015) find that an unexpected cut in the Fed funds rate increases the oil futures price during the intraday event window following the announcement. Hammoudeh et al. (2015) find that an increase in policy interest rates leads to a persistent reduction in energy prices. In contrast, Kilian and Vega (2011), Chatrath et al. (2012), Chan and Gray (2017) and Scrimgeour (2015) do not find a statistically significant relationship between US interest rates and oil prices.

[11] Most global liquidity today is privately created through cross-border operations by both bank and non-bank financial institutions (BIS, 2011). Total credit is defined by the BIS as the sum of bank loans to non-banks and debt securities issuance by non-banks.

[12] *CPs* are commonly issued by both banks and non-financial corporations, while *CDs* are only issued by banks.

[13] This shift been driven by several factors such as new regulatory reforms, the recovery and recapitalisation of weak banks, and changing business models of intermediaries in many jurisdictions. Furthermore, the sustained performance of the US and several emerging market economies (EMEs) in the past few years and their elevated interest rates compared to advanced economies has led to a shift in global portfolios towards US securities and US dollar cross-border lending into EMEs (Committee on the Global Financial System, 2020).

[14] PMMFs have reduced their funding to US banks following the GFC, but this decrease was reversed by an increase in funding for non-US banks (largely European banks). However, the funding for European banks declined during the Eurozone crisis, which was offset by an increase in funding to Japanese and Australian banks (Hanson et al., 2015).

as Japanese banks following the 2016 PMMF reform. Eren et al. (2020b) propose that during the recent Covid-19 crisis, redemptions from US PMMFs resulted in a loss of funding for global banks and to a significant shortening of funding maturities, which in turn affected bank funding costs such as the LIBOR-OIS spread.

The anticipation of the 2016 regulatory reforms led to a reduction in the size of PMMFs of almost 75 percent and a decline in the total assets of PMMFs of more than 1 trillion US dollars, over the period October 2015 to October 2016 (BIS, 2016). As a result, the amount of credit provided by these funds to financial institutions across the world fell by around 130 billion US dollars, which amounted to no less than a 70 percent contraction in short-term dollar funding obtained from PMMFs (BIS, 2016). This funding contraction was particularly evident for banks in Canada, France and Japan, with the latter two countries being two of the five major creditor countries, alongside Germany, UK and US.[15] Thus, we argue that this newly implemented regulation could have broader implications for funding markets.

2.3. Determinants of historical oil price fluctuations

In recent years, a vast literature on the determinants of oil price fluctuations has emerged. At first, major fluctuations in the price of oil were associated with disruptions in the flow of global oil production led by exogenous political events such as wars and changing conditions in the OPEC member countries (Hamilton, 2003). The research on the determinants of historical oil price fluctuations has evolved to show that disruptions in oil supply are not as important as initially thought and has found that most major movements in the price of oil since 1973 can be explained to a great extent by fluctuations in the demand for crude oil associated with global economic activity (Barsky and Kilian, 2002, 2004; Kilian, 2009; Kilian and Murphy, 2012, 2014; Bodenstein et al., 2012; Lippi and Nobili, 2012; Baumeister and Peersman, 2013a,b; Kilian and Hicks, 2013; Kilian and Lee, 2014).

Research has shown that fluctuations in the price of oil may reflect changes in expectations about future shortages in the oil market, which affect future demand for above-the-ground inventories of crude oil (Adelman, 1993; Pindyck, 2004; Kilian, 2009; Alquist and Kilian, 2010). Historically, higher demand for oil inventories has been observed during geopolitical tensions in the Middle East, low spare capacity in oil production, and strong expected global economic growth (Baumeister and Kilian, 2016). Thus, the existing literature identifies oil supply shocks, oil demand shocks and speculative demand shocks as major causes of fluctuations in the price of oil.

However, despite the developments made in recent years in understanding historical oil price fluctuations, such movements still surprise economists, policymakers, consumers, and financial market participants as the oil price determinants remain difficult to predict in practice, as discussed in Baumeister and Kilian (2016). For example, global economic activity, a key determinant of the price of oil, can be predicted at best at short term horizons and even under these circumstances the prediction remains imprecise. A second difficulty in predicting oil price fluctuations relates to disruptions in global oil production caused by political events in oil-production countries, which can be relatively difficult to anticipate. Moreover, changes in inventory demand, another key determinant of oil prices, depend on continuously evolving expectations about future oil supply influenced by uncertainty about geopolitical or economic crises. Lastly, the accuracy of predicting fluctuations in the price of oil can be subject to how expectations are formed.[16]

3. Methodology

3.1. The transmission channel of funding shocks to the crude oil market

We propose two channels through which US dollar funding shocks stemming from deteriorating US dollar credit conditions in the US PMMFs industry can be transmitted to oil companies: an indirect channel through cross-border bank flows and a direct channel through PMMFs. These two transmission channels of funding shocks from US PMMFs to oil companies are depicted in Fig. 1 and discussed in the following two subsections.

3.1.1. Cross-border bank flows

The notion of global liquidity has been associated in policy discussions with permissive credit conditions in financial centers resulting in capital flows to other parts of the world (BIS, 2011). The propagation of gross capital flows, particularly through the banking sector, has been widely debated in the literature (see Lane and Pels, 2012; Forbes and Warnock, 2012; Obstfeld, 2012a; Obstfeld, 2012b; Shin, 2012; and Rey, 2015, among others). For instance, Bruno and Shin (2015) document that capital flows transmitted through the international banking system represent a substantial proportion of the total capital flows and propose a model which captures the cross-border bank lending in US dollars (see Fig. 1). According to this model, regional banks borrow in US dollars from global banks to lend to local borrowers, which are typically non-financial corporates. Global banks fund their cross-border lending to regional banks by raising US dollars in the major financial centers. PMMFs are a vital source of dollar funding. The US dollar is the foremost funding and investment currency in the

[15] These five creditor countries account for 55 percent of the global cross-border credit (see Aldasoro and Ehlers, 2018).

[16] The literature discusses four alternative measure of oil price expectations (e.g. economists' oil price expectations, policymakers' oil price expectations, financial market oil price expectations and consumers' oil price expectations). A detailed discussion of the limitations of these four measures of oil price expectations can be found in Baumeister and Kilian (2016).

international monetary and financial system and its broad international usage suggests that the resilience of global economic and financial activity is conditional on the continuous flow of US dollar funding (Committee on the Global Financial System, 2020).

Global cross-border bank credit flows are dominated by a small number of very large cross-border linkages, with the US being one of the five major creditor economies alongside France, Germany, Japan and the United Kingdom, together accounting for 70 percent of the credit volume of the largest bilateral country-level links (Aldasoro and Ehlers, 2018).[17] Hence, in the light of the importance of the US financial system and the US dollar in the provision of global cross-border bank credit, we argue that deteriorating dollar funding conditions in the US, particularly for the US PMMFs, can reduce global bank cross-border flows. The rationale behind this transmission channel is that a broad US dollar appreciation increases the credit risk of global banks with globally diversified dollar-loan portfolios, thereby reducing their cross-border lending capacity for any given level of economic capital (see Bruno and Shin, 2015; Avdjiev et al., 2019). This induced financial strain on the recipient economy's banking system will generate a spillover effect to companies such as oil producers, that borrow in US dollars from non-US banks (IMF, 2019).

3.1.2. Prime money market funds

Hanson et al. (2015) reported that of the 50 largest nongovernment issuers of money market instruments held by PMMFs only two are non-financial firms. Although PMMFs are a major funding source for financial institutions, they remain a significant provider of short-term US dollar funding to non-financial corporations. Thus, we propose that funding constrains in the US PMMFs industry can be transmitted directly to companies such as oil firms that borrow heavily in US dollars. This channel is depicted in Fig. 1.

3.2. Modelling the global crude oil market

There has been extensive debate in the academic literature on the modelling of the global market for crude oil. A traditional approach in the literature has been to estimate the exogenous variation in the crude oil production in OPEC countries and to relate this variation to changes in the crude oil prices (Hamilton, 2003; Kilian, 2008). Building on this work, Kilian (2009) attributes the variation in oil price which cannot be explained by shifts in crude oil supply, to shocks to the global demand for industrial commodities driven by fluctuations in the global business cycle, and to higher precautionary crude oil demand associated with expectations about the availability of future oil supplies. The theoretical and empirical work of Hamilton (2009) and Alquist and Kilian (2010) further examines the role of expectations on the dynamics of oil prices, proposing that shifts in expectations of forward-looking traders are reflected in changes in the real oil price and changes in oil inventories. The rationale is that, given that crude oil is storable and assuming that the price elasticity of demand is different from zero, any expectation of a shortfall of future oil supply relative to future oil demand not already captured by flow demand and flow supply shocks causes an increase in the demand for above-ground oil inventories and hence in the real price of oil.[18] KM (2014) later refer to shifts in demand for above-ground oil inventories arising from increased uncertainty about future demand or supply conditions as a speculative demand shock in the spot market of crude oil.[19]

KM (2014) were the first to introduce a structural vector autoregressive (SVAR) model of the global oil market that explicitly accounts for speculative demand and allows for forward-looking behavior in oil markets. This model, presented in (1), has become one of the leading models for the analysis of the oil market and is employed as our baseline model throughout the rest of the paper.

$$B_0 y_t = \alpha + \sum_{n=1}^{N} B_n y_{t-n} + \epsilon_t \tag{1}$$

where $y_t = [RealActivity_t, OilProduction_t, OilInventories_t, RealCrudeOilSpotPrice l_t]\prime, \epsilon_t$ is a vector of orthogonal structural innovations, *Real crude oil spot price* refers to the real spot price of crude oil, *Oil inventories* represents global crude oil inventories, *Oil production* is global crude oil production and *Real activity* is a measure of global real economic activity.

3.2.1. The global crude oil market model of KM (2014): an estimation

We estimate the baseline model of KM (2014) presented in (1) using Kilian's updated and corrected index for global real economic activity, for our sample period 2011:2–2021:10. The choice of the beginning and ending of this sample period is motivated by data availability of our funding variables, *PMMFs* and *CDs*.[20] We estimate this model by identifying structural shocks using Uhlig's (2005) pure-sign restriction approach. The sign restrictions are reported in Table 1.

[17] Roughly 2.4 percent of all bilateral cross-border bank linkages were larger than 50 billion US dollars as of 2018. However, they represent two thirds of the global cross-border bank credit volumes (Aldasoro and Ehlers, 2018).

[18] The flow demand shock captures unexpected fluctuations in the global business cycle, while the flow supply shock refers to supply disruptions related to exogenous political events in oil-producing countries, unexpected politically-driven supply decisions by OPEC as well as to other shocks to the supply of crude oil.

[19] The speculative demand shock is associated with shifts in the demand for above-ground oil inventories driven by speculation.

[20] For completeness, we estimate the baseline model of KM (2014) for the sample periods 1973:3–2009:8 and 1973:3–2021:10. The estimation results are qualitatively similar and are available upon request. The nature of the corrections to the global real economic activity index is discussed in Kilian (2019).

Table 1
Sign restrictions for the KM (2014) baseline model.

Panel A. Impact sign restrictions for the KM (2014) baseline model			
	Negative flow supply shock	Flow demand shock	Speculative demand shock
Oil production	–	+	+
Real activity	–	+	–
Real crude oil spot price	+	+	+
Oil inventories			+
Panel B. Dynamic sign restrictions to a flow supply shock KM (2014) baseline model			
	Oil production	Real activity	Real crude oil spot price
Negative flow supply shock	–	–	+

Notes: All structural shocks have been normalized to imply an increase in the real price of oil. Missing entries mean that no sign restriction is imposed. The responses of oil production and global real activity to an unanticipated flow supply disruption are negative for the first 12 months, while the response of the real price of oil is positive for the first 12 months starting in the impact period.

3.2.2. Funding shocks and the global crude oil market

To evaluate the impact of the funding shock induced by the US PMMFs reform on the real crude oil spot price, we extend the global crude oil market model of KM (2014) by introducing PMMFs investment holdings by global issuance, *PMMFs*, as our funding measure. The augmented model (1) now has $y_t = [PMMFs_t, RealActivity_t, OilProduction_t, OilInventories_t, RealCrudeOilSpotPrice_t]'$, where *PMMFs* represents the US PMMFs investment holdings. The model uses 1 lag, determined by AIC information criteria. The sign restrictions are reported in Table 2 (Panel A) and discussed in the next subsection.

In the next step, we alter y_t by introducing the *CDs* as an alternative to the aggregate PMMFs investment holdings by global issuance to capture the direct channel. We then introduce the nominal effective exchange rate of the US dollar (*NEER*) to the baseline model to identify the exchange rate channel. The sign restrictions used to construct the impulse response estimates are reported in Table 2 (Panel B). Lastly, we further analyze the transmission channel of our funding shock of interest on the real crude oil spot price by augmenting the baseline model, with the following control variables: *CPI*, the consumer price index for the US and *VIX* as our measure of investor risk appetite. The augmented model (1) now has $y_t = [PMMFs_t, VIX_t, CPI_t, NEER_t, RealActivity_t, OilProduction_t, OilInventories_t, RealCrudeOilSpotPrice_t]'$. The model uses 1 lag, once again determined by AIC information criteria.

3.3. SVAR identification

Structural interpretations of VAR models require identifying assumptions motivated by economic theory or institutional knowledge. Several approaches to the identification of structural shocks within the framework of a reduced-form VAR model have been advanced in the literature (e.g. short-run restrictions, long-run restrictions, sign restrictions, heteroskedasticity). While the first oil market VAR models were based on exclusion restrictions imposed on the impact multiplier matrix (see Kilian, 2009), increasing skepticism towards traditional identification by short-run exclusion restrictions has subsequently led to the development of an alternative approach in which structural shocks are identified by restricting the sign of the responses of the variables used in the model to structural shocks.[21]

Sign-identified VAR models have become increasingly popular in the more recent literature on oil markets (see Baumeister and Peersman, 2013a,b; Kilian and Murphy, 2012, 2014). In line with this literature, we use sign restrictions to identify structural shocks and to construct impulse response estimates. We employ Uhlig's (2005) pure sign-restriction rejection method as a complementary approach to the KM (2014) set of identifying assumptions.[22] This is a standard method employed in the literature to identify structural shocks. The key difference between KM's (2014) set of identifying assumptions and Uhlig's (2005) approach is that the latter does not allow bounds on the price elasticity of oil supply and oil demand. The use of Uhlig's (2005) approach rather than KM's (2014) set of identifying assumptions is motivated by the latter being essential to distinguish between speculative demand, oil demand and oil supply shocks. Hence, KM (2014) assumptions are not effective in the identification of our funding shock of interest.

3.3.1. A discussion of the sign restrictions used in the extended models

This subsection discusses the sign restrictions used in our extended models of the KM (2014) SVAR framework. First, we introduce the sign restrictions imposed to identify the negative funding shock driven by the US PMMFs reform. We argue that this negative funding shock is associated with an immediate reduction in *Real Activity* and *PMMFs* (Table 2, Panel A). A sharp reduction in the credit availability associated with a negative shock to credit supply results in a decline in aggregate

[21] Unless a convincing rationale for a particular recursive ordering exists, the resulting VAR impulse responses are economically meaningless (Kilian and Lutkepohl, 2017).

[22] KM (2014) set of identifying assumptions relies on a combination of sign restrictions, bounds on the implied price elasticities of oil demand and oil supply, and dynamic sign restrictions, to distinguish between speculative demand, oil demand and oil supply shocks.

Table 2
Impact sign restriction for the extension of KM (2014) baseline model, 2011:2 – 2021:10.

Panel A.

	Negative flow supply shock	Flow demand shock	Speculative demand shock
Oil production	–	+	+
Real activity	–	+	–
Real crude oil spot price	+	+	+
Oil inventories			+

Panel B.

	Real crude oil spot price	Oil production	Real activity	Oil inventories	VIX	NEER	CPI	PMMFs
Negative funding shock			–		+	+	–	–

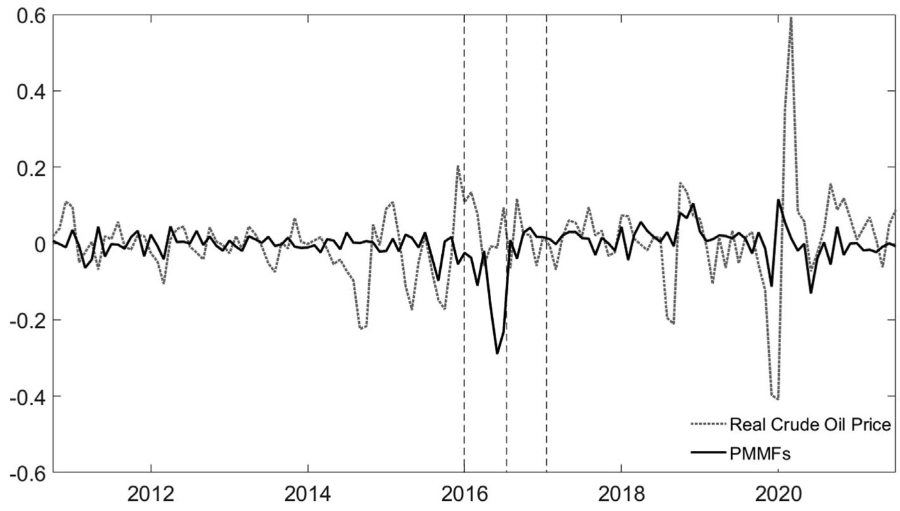

Fig. 2. Percentages changes in *PMMFs* and the *Real crude oil spot price*. *Notes:* The evolution of *PMMFs* and the *Real crude oil spot price*, measured in percentage changes, over the sample period 2011:2–2021:10. The dotted lines represent the period associated with the introduction of the 2016 PMMFs reform.

economic activity (Friedman et al., 1993). We also impose the additional restriction that the response of *PMMFs* to a negative PMMFs funding shock must be negative for three months, starting in the impact period. This restriction is based on our identification of a 3-month structural break in the percentage changes of *PMMFs*, which coincides with the implementation of the US PMMFs reform (see Fig. 2). This additional information allows us to make a fine distinction between funding shocks generated by our reform of interest and funding shocks driven by other factors. Furthermore, we relax this restriction to assess the general impact of funding shocks on oil market.[23]

Furthermore, we argue that a negative funding shock results in an increase in the *NEER*, a decrease in *CPI* and an increase in *VIX* (Table 2).[24] The positive response of the *NEER* to a negative funding shock is motivated by the reduction in US dollar supply from market-based intermediaries, which has resulted in elevated indicators of dollar funding costs following the announcement of the 2016 reform (Avdjiev et al., 2020a). As documented by Avdjiev et al. (2020a), dollar exchange rate and dollar funding costs tend to move together. Secondly, we follow the theoretical prediction that an appreciation of domestic currency tends to raise the price levels by making imports cheaper and attribute a negative response of *CPI* to a negative funding shock. We leave the responses of *Real crude oil spot price*, *Oil production* and *Oil inventories* to the negative funding shock unrestricted as these are our variables of interest in terms of outcome.

Next, we introduce the additional sign restrictions used to identify a negative oil supply shocks, a positive oil demand shock and a speculative oil demand shock for our extended models. We impose a positive response of *CPI* to a negative oil supply shocks, a positive oil demand shock and a speculative oil demand shock (Table 2). These sign restrictions are motivated by KM (2014), who document an increase in the price of oil as a result of negative oil supply shocks, positive oil demand shocks and speculative oil demand shocks and by Chen (2009), who find that oil price shocks pass partially through to inflation.

[23] Results are very similar. We do not report the results for brevity, but we make them available upon request.
[24] The US NEER is a measure of the value of the dollar against a weighted average of several foreign currencies. An increase in NEER corresponds to an appreciation of the dollar against the weighted basket of foreign currencies.

4. Data

4.1. Description of the data

The main data set analysed in this paper comprises of monthly data for four global crude oil market variables, global crude oil production *(Oil production)*, global real economic activity *(Real activity)*, global crude oil inventories *(Oil inventories)* and the real spot price of crude oil *(Real crude oil spot price)*, two macroeconomic variables, consumer price index *(CPI)*, nominal effective exchange rate *(NEER)*, and two funding variables, PMMFs investment holdings by global issuance *(PMMFs)* and by instrument *(CDs)* and *VIX*. The sample period is 2011:2–2021:10.[25] This particular sample period is chosen due to limited data availability for our funding variables, *PMMFs* and *CDs*. Each of the variables mentioned is described in the following subsections.

4.1.1. Global crude oil market

We measure changes in global real activity by employing the dry cargo shipping rate index developed in Kilian (2009). This business cycle index, stationary by construction, is designed to capture changes in the global use of industrial commodities. Global crude oil production data is collected from the *Monthly Energy Review of the Energy Information Administration (EIA)* and includes lease condensates but excludes natural gas plant liquids (KM, 2014). We proxy the global crude oil inventories through the US crude oil inventories, scaled by the ratio of OECD petroleum stocks over US petroleum stocks, as discussed in Hamilton (2009) and KM (2014). Data on US crude oil inventories, OECD petroleum stocks and US petroleum stocks is collected from EIA. We follow KM (2014) in defining the real price of oil as the US refiners' acquisition cost for imported crude oil, deflated by the US CPI.[26] Data on US refiners' acquisition cost is collected from EIA.[27] Due to potential non-stationarity, we express the *Real crude oil spot price* in percentage changes for the sample period 2011:2–2021:10.

4.1.2. PMMFs investment holdings

The SVAR models in the tradition of Kilian (2009) and KM (2014) face the potential limitation of not being able to differentiate between shocks originating in different geographical regions of the world or to recognise the difference between the underlying drivers of these shocks. Yet, these structural VAR models are able to capture average responses to these shocks.[28] We overcome this limitation by employing two funding variables, the US PMMFs investment holdings by global issuance *(PMMFs)* and US PMMFs investment holdings by instrument *(CDs)*, as reported by the Federal Reserve. These two quantity-based measures of global private liquidity are able to capture PMMFs funding disruptions originating in the US. Moreover, the latter variable allows us to differentiate between the source of the funding shock and capture the indirect channel of transmission of funding shocks on oil market via cross-border bank flows.[29]

The inclusion of *CDs* held by PMMFs is motivated by their growing importance as a source of unsecured wholesale funding for banks following the GFC. During the GFC, PMMFs adjusted the risk of their investment mix by shifted their portfolios from riskier *CPs* to safer *CDs*. This resulted in PMMFs holding a larger share of non-US banks as issuers of *CDs* than of *CPs* (Baba et al., 2009). *CDs* became the most important unsecured wholesale funding source for banks, being thus regarded a barometer for bank funding conditions (Eren et al., 2020b).[30]

4.1.3. US dollar exchange rate, inflation and uncertainty

A number of empirical studies confirm the importance of the US nominal effective exchange rate in explaining variations in the crude oil prices in both the short run (Amano and Van Norden, 1998; Sadorsky, 2000) and the long run (Zhang et al., 2008; Akram, 2009; Fratzscher, Schneider and Van Robays, 2014). The price of crude oil is denominated in US dollar in the World markets, with the US dollar increasing its dominance as the prime foreign currency for international funding. Thus, following the theoretical and empirical predictions of the studies documenting that an appreciation of the US dollar exchange rate decreases the price of crude oil via oil supply, oil demand, financial markets channels or via the law of one price for tradeable commodities, we employ the *NEER* as an explanatory variable in our refined model.[31]

We are further expanding the work of KM (2014) by controlling for a macroeconomic variable, *CPI*, and for global risk aversion, *VIX*. In line with the literature investigating the effect of global liquidity on commodity prices, we include the *CPI* as measure of inflation (see Belke et al., 2013; Beckmann et al., 2014; to name a few).[32] We also follow Cheng et al. (2015) in controlling for the strong real effect of risk appetite and uncertainty on crude oil prices by employing the stock option

[25] We use the sample period 1973:3–2009:8 to replicate KM's (2014) model and sample period 1973:3–2021:10 and 2011:2–2021:10 to verify the robustness of the results of KM (2014) to an extended time-frame. Results are qualitatively similar and are available upon request.

[26] We employ Brent and WTI oil prices as alternative oil price indicators in the robustness section.

[27] We report the details of sources, construction and data sample availability of the variables included in the analysis in Table 1A in the Appendix.

[28] DSGE models have the ability to make such distinctions and to provide more detailed answers about the transmission of oil price shocks. However, this comes at the cost of full specification of the microeconomic structure of the model, which involves making ad hoc assumptions (Kilian, 2014).

[29] We use an alternative measure for global liquidity, the *VIX*, in the robustness test section.

[30] Non-US banks lacking access to insured retail dollar deposits are particularly dependent on *CDs* funding to finance dollar assets (Eren et al., 2020b).

[31] We refer the reader to the work of Beckmann et al. (2020) for a review of the existing theoretical and empirical research on the relationship between oil prices and exchange rates.

[32] Description and sources of the data are given in Table 1A in the Appendix.

Table 3
Descriptive statistics of PMMFs investment holdings and real crude oil spot price.

a. PMMFs investment holdings by global issuance (PMMFs)	
Levels (include units in US dollars)	
Mean	1,290,133
Median	1,412,814
St dev	456,387
Max	1,851,013
Min	545,284
Percentage changes	
Mean	−0.43
Median	0.16
St dev	4.96
Max	11.61
Min	−28.92
b. PMMFs investment holdings by instrument (CDs)	
Percentage changes	
Mean	−0.90
Median	−0.03
St dev	7.07
Max	15.75
Min	−46.51
c. Real crude oil spot price	
Percentage changes	
Mean	0.33
Median	1.03
St dev	10.87
Max	59.32
Min	−40.87

Notes: Descriptive statistics are reported for the PMMFs investment holdings by global issuance *(PMMFs)* in Panel a and by instrument in Panel b *(CDs)*. Panel c reports the descriptive statistics of monthly percentage changes in the *Real crude oil spot price*. The sample is 2011:2–2021:10.

prices-based measure of implied volatility, the *VIX*. Cheng et al. (2015) show that high financial uncertainty, proxied by the *VIX*, reverses the flows from financial investors into commodity markets, thereby depressing oil prices.

4.2. Preliminary analysis of the variables

Table 3 (Panel a) reports the descriptive statistics of PMMFs investment holdings by global issuance, *PMMFs*. *PMMFs* account for an average amount of investment holdings of nearly 1.29 million US dollars. The average monthly percentage change is 0.43 percent, with a standard deviation of 5 percent, suggesting a large variation in the investment holdings of *PMMFs*. The evolution of *PMMFs*, measured in percentage changes, during the sample period 2011:2–2021:10 is depicted in Fig. 2. Fig. 2 shows a low variation of 2 percent during the sample period 2011:2–2015:6 and of 1 percent during the sample period 2017:1–2021:10. The greatest variation is exhibited from 2015:6 to 2017:1 (9 percent), period which coincides with the implementation of the US PMMFs regulation.

Table 3 (Panel b) displays the descriptive statistics of PMMFs investment holdings by instrument, *CDs*, measured in percentage changes. The average monthly percentage change of *CDs* stands at roughly 0.9 percent, while the standard deviation of *CDs* is 7 percent. The evolution of *CDs*, *CPs* and *PMMFs* measured in percentage changes is presented in Fig. 3. We note that the three funding measures experience the greatest decline over the period 2016:7 – 2016:9, which coincides with the implementation of the US PMMFs regulation. The second substantial decline is seen in March 2020 during COVID-19 market disruption. Noteworthy, in both periods, *CDs* see a more pronounced decline as compared to *CPs*.

Table 3 (Panel c) reports descriptive statistics of the *Real crude oil spot price*. *Real crude oil spot price* has an average monthly percentage change of 0.3 percent and experiences a strong variation of 10.9 percent over the sample period. The variation in the percentage changes in *Real crude oil spot price* and *PMMFs* throughout our sample period is depicted in Fig. 2. The figure points towards a negative relationship between *Real crude oil spot price* and *PMMFs* during the period 2016–2017.[33]

The correlation matrix reported in Table 4 depicts the correlation coefficients among the variables included in our SVAR model. As expected, we find that the *Real crude oil spot price* is negatively correlated with the *Oil production*, with *Real activity*, and with *NEER* with a correlation coefficient of −32 percent, −16 percent, −38 percent respectively. We also note a strong

[33] The correlation coefficient for the period 2016:1 – 2017:1, for the variables *PMMFs* and *Real crude oil price*, is −0.17 (17 percent).

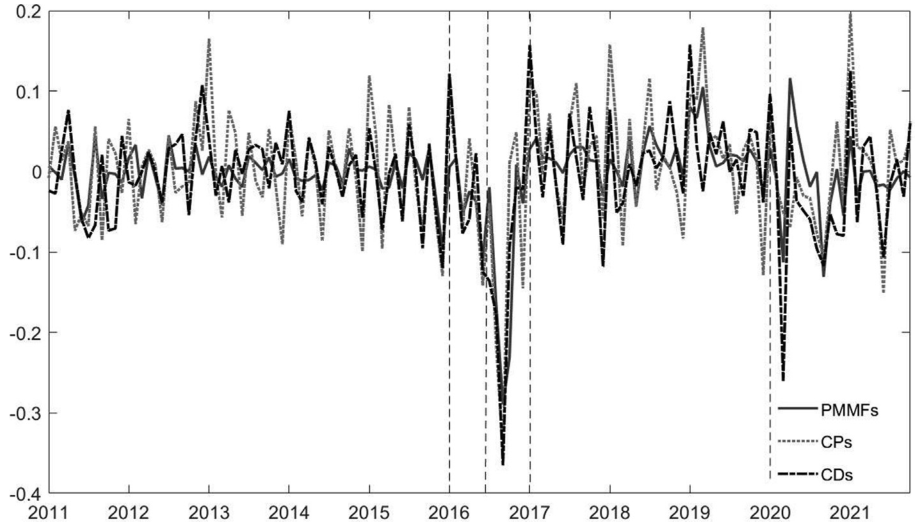

Fig. 3. PMMFs Investment Holdings by Instrument (*CDs*, *CPs*) and by global issuance (*PMMFs*). *Notes:* The evolution of *CDs*, *CPs* and *PMMFs* measured in percentage changes, over the sample period 2011:2–2021:10. The dotted lines represent the periods associated with the introduction of the 2016 PMMFs reform and the COVID-19 market turmoil.

Table 4
Correlation matrix of the variables involved in the analysis.

	Oil inventories	Oil production	Real activity	PMMFs	Real crude oil spot price	CPI	VIX
Oil production	−0.15***						
Real activity	0.09	−0.14					
PMMFs	0.08	−0.13	0.02				
Real crude oil spot price	−0.08	−0.32*	−0.16***	0.03			
CPI	−0.06	−0.07	−0.12	−0.01	0.52*		
VIX	−0.05	0.04	0.01	−0.16**	−0.20*	−0.05	
NEER	0.09	0.10	0.05	−0.09	−0.38*	−0.12	0.09

Notes: The correlation matrix reports the correlation coefficients between the variables, measured in percentage changes. *** indicates significance at 5 percent,** indicates significance at 5 percent and * indicates significance at 1 percent.

negative correlation of −20 percent between *VIX* and the *Real crude oil spot price* and a strong positive correlation of 52 percent between *CPI* and the *Real crude oil spot price*. *Oil production* is negatively correlated with the *Oil inventories*, with a low coefficient of −15 percent. We identify a positive correlation of around 16 percent between *VIX* and *PMMFs*.

5. Empirical results

5.1. The global crude oil market model of KM's (2014)

This section discusses the empirical results for our estimation of KM's (2014) model for the sample period 2011:2–2021:10. The results are presented in Fig. 4. Overall, our empirical results confirm the findings of KM (2014). In particular, a negative flow supply shock is associated with a persistent drop in *Oil production* and *Real activity* (Fig. 4, Panel 1). *Real crude oil spot price* sees a persistant rise 6 months from the impact, while *Oil inventories* see a temporary fall (Fig. 4, Panel 1). A positive flow demand shock, in contrast, is associated with an immediate and persistent jump in the *Real activity* (Fig. 4, Panel 2). *Real crude oil spot price* sees a small and temporary increase on impact, followed by a temporary fall from month 6 to month 15, while *Oil production* increases immediately and temporarily. *Oil inventories* do not see a statistically significant response (Fig. 4, Panel 2). A positive speculative demand shock is associated with a persistent increase in *Oil inventories* and *Oil production* (Fig. 4, Panel 3). *Real crude oil spot price* increases until month 3, before declining gradually, while *Real activity* sees a small and persistant drop on impact (Fig. 4, Panel 3).

Yet, our results differ from the findings of KM (2014) in two ways. Firstly, we note a persistent positive response of *Oil production* to a speculative demand shock, while KM (2014) report a small negative response. While this result is in contrast with the findings of KM (2014), it is in line with the KM (2014) prediction that a positive speculative demand shock on impact stimulates *Oil production*. Secondly, we provide evidence of a small temporary (3 months) increase in *Real crude oil spot price* in response to a positive speculative demand, results which contrasts with KM (2014) finding of an immediate

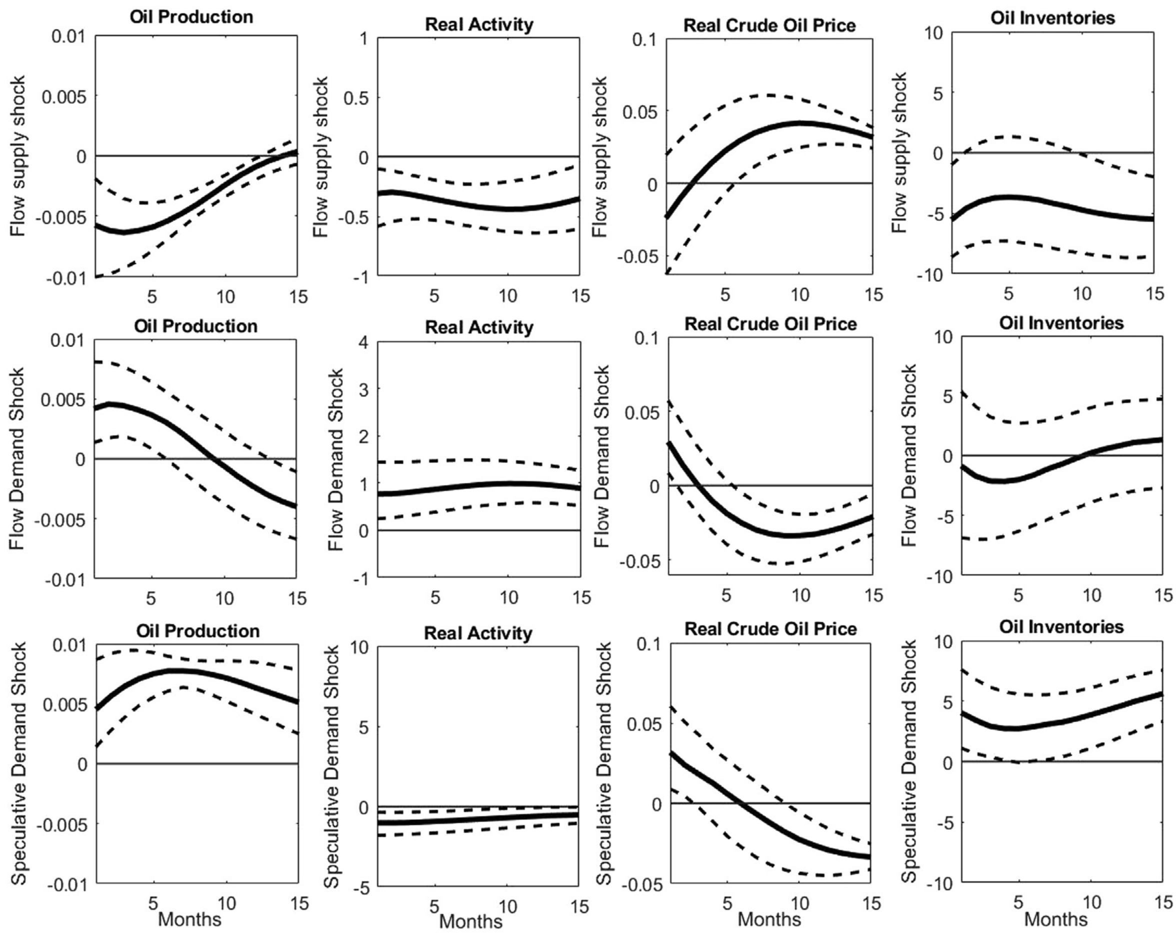

Fig. 4. Structural impulse responses identified using Uhlig's (2005) method, 2011:2–2021:10. KM (2014) baseline model replication. *Notes:* Solid lines indicate the impulse response estimates for the model to a one-standard deviation shock in flow demand, flow supply and speculative demand. Structural shocks are identified using Uhlig's (2005) pure-sign restriction rejection method. Impulse response curves are generated based on Bayesian inference which accommodates sign restrictions in the VAR model. Dashed lines indicate the corresponding pointwise 68 percent posterior error bands. Error bands are calculated using all the draws which have been kept. *Oil Inventories* refer to cumulative changes in oil inventories. *Oil Production*, *Real crude oil spot price*, *Real Activity* and *PMMFs* are measured in cumulative percentage changes. The model is estimated using 1 lags, according to AIC criteria.

jump in *Real crude oil spot price*, which persists up to 10 months from the impact. These slight differences can be explained given the different sample periods.[34]

5.2. Funding shocks of PMMFs and the price of crude oil

We augment the model of KM (2014) by our main funding variable, *PMMFs*. Structural impulse response estimates to a negative one-standard deviation shock in *PMMFs* are depicted in Fig. 5. Fig. 5 indicates that a negative funding shock is associated with a lagged temporary decline in the *Real crude oil spot price* and a lagged and temporary increase in *Oil production*.

Real crude oil spot price temporary decreases 20 months following the negative funding shock, while *Oil production* raises 8 months following the funding shock. It peaks after 12 months and declines to its pre-shock levels after 23 months. The impulse response estimates of *Real activity* and *PMMFs* are negative on impact, as imposed through our sign restriction identification approach. However, the decline in *Real activity* and *PMMFs* is persistent until month 19 and 10, respectively. Thus, these results indicate that the response of our global crude oil market variables to negative funding shocks is persistent.

Our empirical results confirm the theoretical predictions of Domanski et al. (2015) who argue that, in response to higher short-term dollar funding costs, oil producers seek to increase their output levels to raise short-term cash flow. Sustaining the continuity of short-term cash flows is needed for oil producers to meet obligations and to avoid supressing market

[34] It should be noted that when we estimate the KM model using their sample period (i.e., 1973:3–2009:8) we find analogous results to them, when using their set of identifying restrictions. For the extended sample period (i.e., 1973:3–2021:10), we find a positive response of oil production to a speculative demand shock, when using the KM (2014) set of identifying restrictions, result which is in line with our findings for the sample period 2011:2–2021:10.

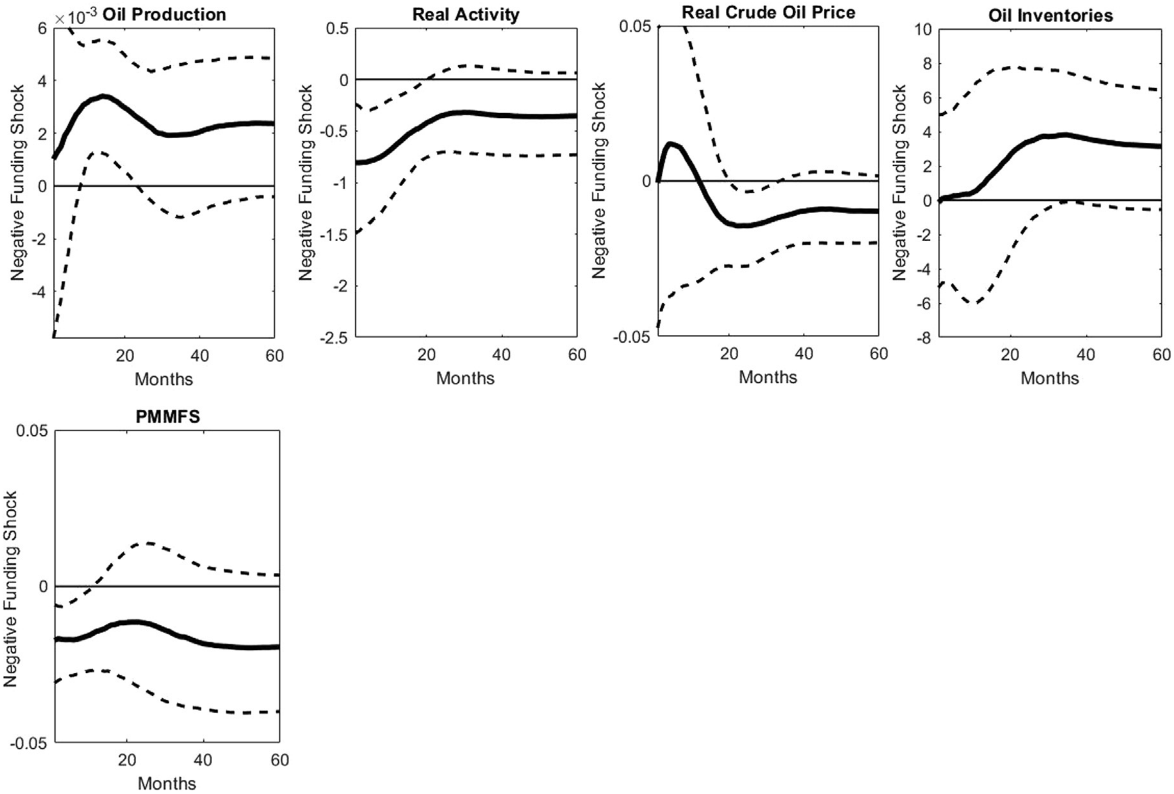

Fig. 5. Structural impulse responses to funding shocks, Uhlig's (2005) identification, 2011:2–2021:10. *Notes:* Solid lines indicate the impulse response estimates for the model to a one-standard deviation shock in PMMFs funding.

demand in the long run. The 6-months lagged response of oil production to a negative funding shock is line with the general consensus in the literature that even in the presence of spare capacity, the response of oil production within the month to price fluctuations is close to zero, if not effectively zero, due to the costs incurred by changing oil production (Kilian, 2009).[35]

Considering these findings, we then proceed to analyse the effect of the negative funding shock, proxied through *CDs*, on the *Real crude oil spot price*. The response estimates are presented in Fig. 6. The results indicate that the *Real crude oil spot price* is negatively affected by a fall in *CDs*. Furthermore, we notice that a decline in *CDs* causes an increase in *Oil production* and *Oil inventories*. This result highlights the role of cross-border bank flows in the transmission of the funding disruptions generated by the 2016 US PMMFs reform to the crude oil market.

When we relax the 3-month sign-restriction, we find very similar results of a negative response of the oil price and a positive response of oil production to funding shocks. Thus, we document that funding shocks have a general significant impact on oil markets.[36]

5.2.1. Discussion

Several arguments can be advanced to explain the lagged negative impulse response of real crude oil spot price to our negative funding shock of interest. Firstly, an increase in oil production levels will temporarily decrease real crude oil spot price and will increase oil inventories (KM, 2014). Secondly, an appreciation of the dollar could suppress oil demand in the long-term, as oil imports become more expensive in local currencies for non-US countries (De Schryder and Peersman, 2015). As a result of lower demand, the real crude oil spot price will temporarily decrease and oil inventories will temporarily increase (KM, 2014). Lastly, real crude oil spot price could temporarily decrease due to oil producers hedging their future

[35] Revenues for 43 US oil companies increased from a low of roughly 25 dollars per barrel of oil equivalent in 2016, to over 45 dollars per barrel of oil by the end of 2017, together with the ratio of cash flows generated from operating activities to capital expenditures (EIA, 2019). Noteworthy, oil companies with higher production levels had higher ratios of cash from operations to capital expenditures (EIA, 2019). Net oil export revenues for OPEC also increased in 2017 and 2018 after reaching a low in 2016 of under 500 billion dollars (see Fig. 2A in the Appendix).

[36] Results are qualitatively similar when the 3-months sign restriction imposed on *PMMFs* and *CDs* is relaxed. These results are available upon request.

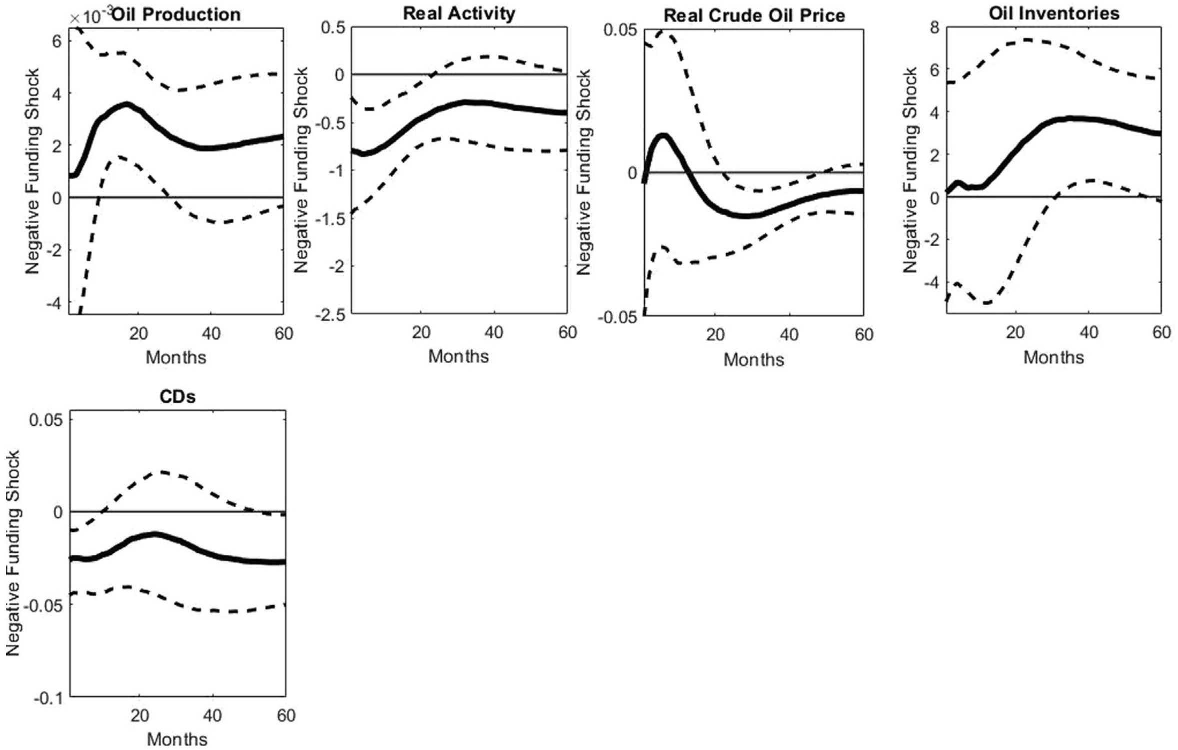

Fig. 6. Structural impulse responses to funding shocks using CDs, 2011:2–2021:10. *Notes:* Solid lines indicate the impulse response estimates for the model to a one-standard deviation shock in CDs funding.

production by selling futures contracts. Current and future sales of oil will create downward pressures on real crude oil spot price (Domanski et al., 2015). Hence, our negative funding shock of interest can lead to a lagged decline in real crude oil spot price via its effect on oil production, oil demand or on the hedging activity of oil producers.

5.3. Funding shocks of PMMFs, the price of crude oil, and the dollar exchange rate channel

We further analyze the impact of our funding shock of interest on the real crude oil spot price by introducing the *NEER* to the augmented model (1). The results are presented in Fig. 7. Fig. 7 indicates that our negative funding shock of interest leads to a persistent decline in the *Real crude oil spot price*, and a persistant increase in *Oil inventories*, *Oil production*, *NEER*. As expected, the *Real activity* and *PMMFs* see a decline in response to a negative funding shock. The reduction in *Real activity* is persistent throughout the observed period, while the reduction in *PMMFs* is mostly reversed within 10 months. Noteworthy, the decline in the *Real crude oil spot price* becomes persistant when *NEER* is introduced to the augmented model (1).[37]

This result indicates that the *NEER* could be a complementary transmission channel of funding shocks to the *Real crude oil spot price*. The rationale behind the transmission of our funding shock of interest to the *Real crude oil spot price* is that the 2016 reform has raised the dollar funding costs, driving the US *NEER* higher. A higher US dollar exchange rate negatively affects real price of oil through its effect on oil supply, oil demand and financial markets (Breitenfellner and Cuaresma, 2008).

We then proceed to introduce the *CPI* and *VIX*, alongside the *NEER*, to the augmented model (1).[38] The impulse response estimates are depicted in Fig. 8. Fig. 8 indicates that our negative funding shock of interest is associated with a temporary decline in the *Real crude oil spot price*, from month 16 to month 44, and a temporary increase in *Oil production*, from month 10 to month 34.[39] This result further emphasizes the role of the *NEER* in the transmission of funding shocks to the real price of oil and is in line with the predictions of Yousefi and Wirjanto (2004) and Fratzscher et al. (2014), discussed in Beckmann et al. (2020), which indicate that in the case of a partial or full-exchange rate pass-through, foreign oil producers could increase the oil production or reduce the oil price, if there is an appreciation in the US dollar.

37 Results are qualitatively similar when the 3-months sign restriction imposed on *PMMFs* is relaxed. These results are available upon request.

38 For completeness, we introduce the *CPI* to augmented model (1) for the period 2011:2– 2021:10 and find no statistically significant effect of the negative funding shock on the *Real crude oil spot price*. The estimation results are available upon request.

39 Results are very similar when the 3-months sign restriction imposed on *PMMFs* is relaxed. These results are available upon request.

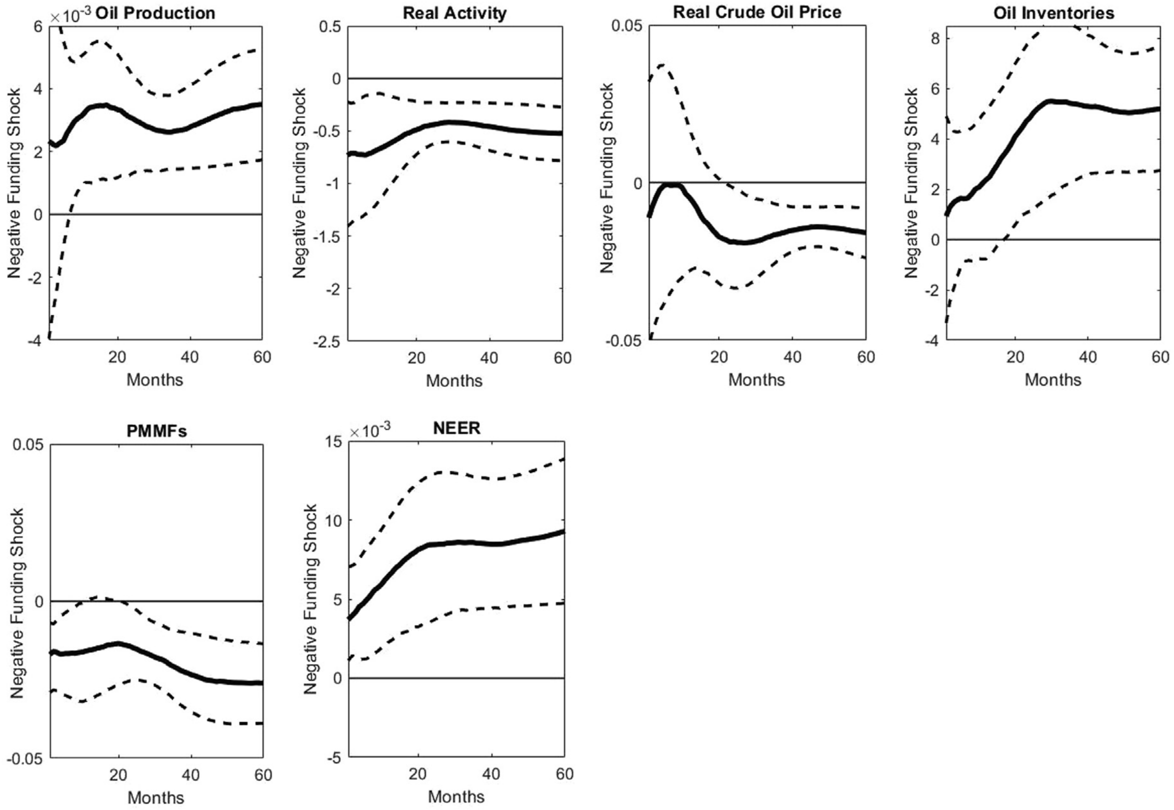

Fig. 7. Structural impulse responses to negative funding shocks, 2011:2–2021:10. Further analysis: the NEER channel. *Notes:* Solid lines indicate the impulse response estimates for the model to a one-standard deviation shock in PMMFs funding. *NEER* is measured in cumulative percentage changes. The *Real crude oil spot price* is measured in logs and presented in decimals.

6. Robustness tests

6.1. Alternative measures of the price of crude oil

We further analyse the impact of the funding shock driven by the US PMMFs reform on crude oil prices by proxying the real price of oil through the *Brent crude oil spot price* and the *WTI crude oil spot price*. The impulse response estimates are presented in Fig. 9 and Fig. 10, respectively. The results are in line with our findings from the augmented model (1), which introduces to the global crude oil market model of KM (2014) our funding variable *PMMFs* and measures the real crude oil price as the US refiners' acquisition cost for imported crude oil, deflated by the US CPI.

More specifically, we find that the negative funding shock increases *Oil production* 8 months from the impact and decreases the real *Brent Crude Oil spot price* and the real *WTI Crude Oil spot price* 19 months from the impact.[40]

6.2. VIX as an alternative measure of global liquidity

We further analyze the impact of our funding shock of interest on the *Real crude oil spot price* by introducing *VIX* to the augmented model (1). *VIX* is a widely used price-based measure of global private liquidity, capturing investor risk perception and tolerance, while US PMMFs is a quantity-based measure of global private liquidity, which captures short-term debt securities as a component of international credit (see Cesa-Bianchi et al., 2015; Cerutti et al., 2017). The results are presented in Fig. 11.

The response of the *Real crude oil spot price* is lagged, negative and persistent. While the timing of the response of the *Real crude oil spot price* remains unchanged with the introduction of *VIX*, its magnitude changes from temporary to persistent. This result confirms the negative effect of tighter dollar funding conditions driven by the 2016 US PMMFs regulatory reform on

[40] Results are qualitatively similar when the 3-months sign restriction imposed on *PMMFs* is relaxed. These results are available upon request.

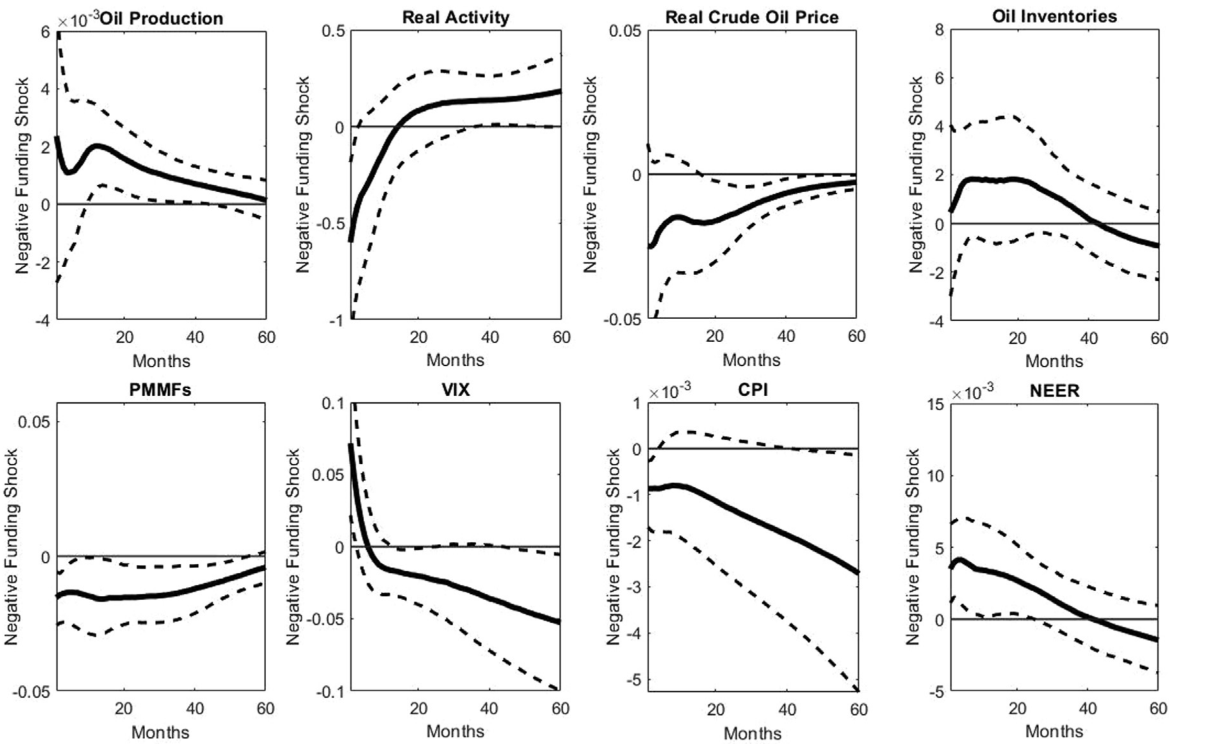

Fig. 8. Structural impulse responses to negative funding shocks, 2011:2–2021:10. Further analysis. *Notes:* Solid lines indicate the impulse response estimates for the model to a one-standard deviation shock in PMMFs funding. *CPI* and *VIX* are measured in cumulative percentage changes. The *Real crude oil spot price* is measured in logs and presented in decimals.

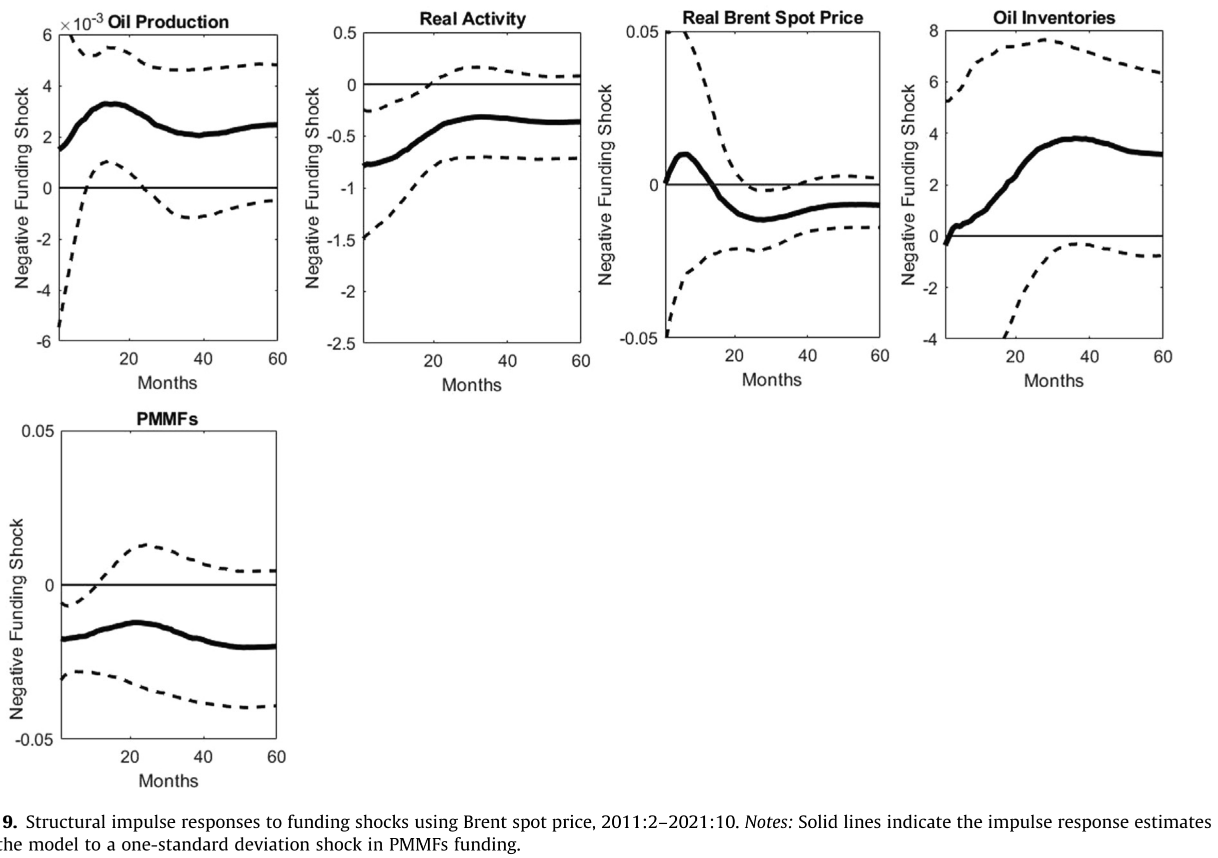

Fig. 9. Structural impulse responses to funding shocks using Brent spot price, 2011:2–2021:10. *Notes:* Solid lines indicate the impulse response estimates for the model to a one-standard deviation shock in PMMFs funding.

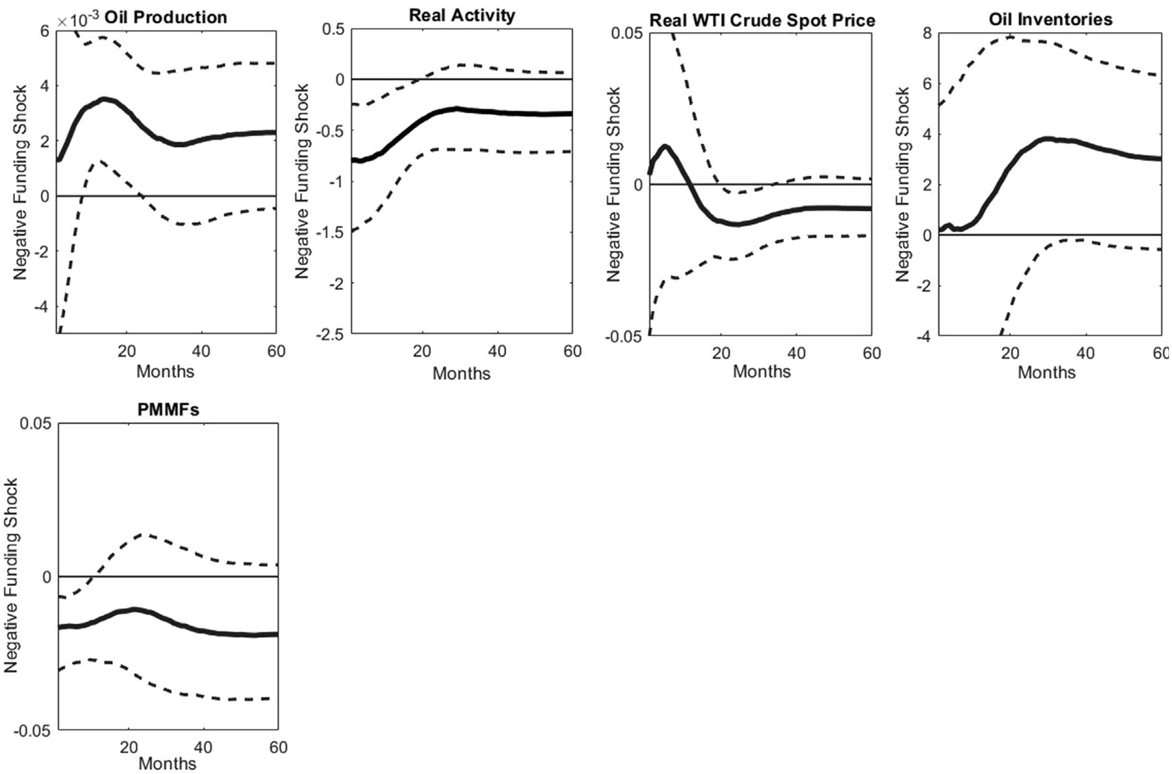

Fig. 10. Structural impulse responses to funding shocks using WTI spot price, 2011:2–2021:10. *Notes:* Solid lines indicate the impulse response estimates for the model to a one-standard deviation shock in PMMFs funding.

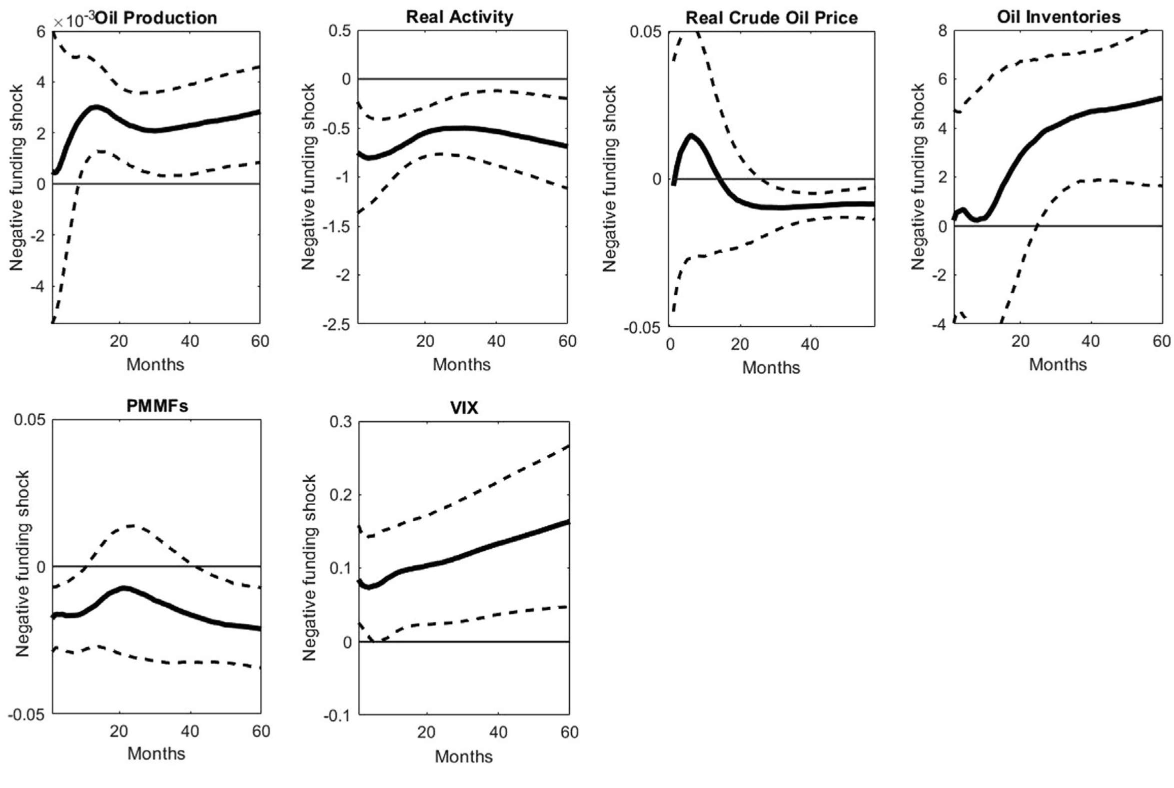

Fig. 11. Structural impulse responses to negative funding shocks, 2011:2–2021:10. Further analysis: the VIX channel. *Notes:* Solid lines indicate the impulse response estimates for the model to a one-standard deviation shock in PMMFs funding.

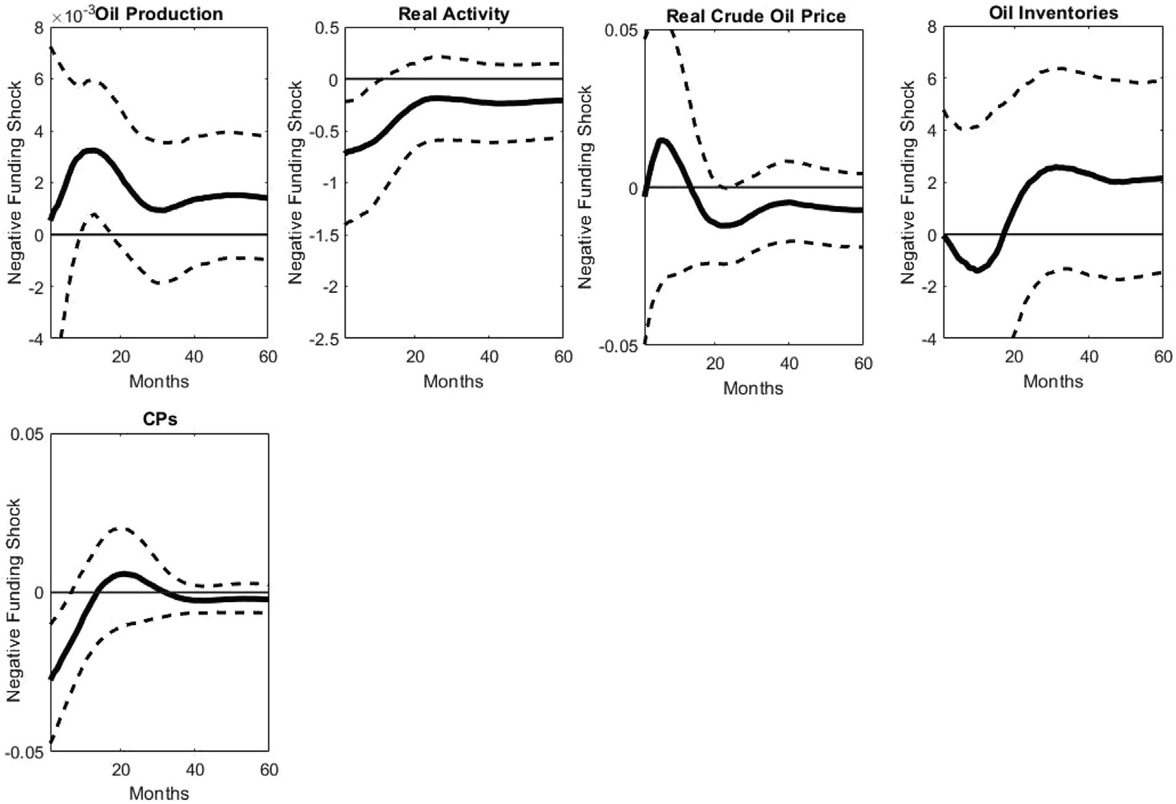

Fig. 12. Structural impulse responses to funding shocks using CPs, 2011:2–2021:10. *Notes:* Solid lines indicate the impulse response estimates for the model to a one-standard deviation shock in *CPs* funding.

the *Real crude oil spot price*, and its positive effect on *Oil production* and *Oil inventories* as well as the validity of our main proxy for global liquidity, *PMMFs*.[41]

6.3. CPs as an alternative measure of PMMFs investment holdings by instrument

We investigate the direct link between *PMMFs* and the oil companies by introducing *CPs* as our funding variable (i.e., an alternative to the aggregate PMMFs investment holdings by global issuance) to the baseline model (1) for the period 2011:2 – 2021:10. As previously noted, *CPs* represent the primary short-term funding source of oil companies and thus allows us to capture the impact of funding shocks on the oil market via the direct channel of direct oil company borrowings. The impulse response estimates are presented in Fig. 12. The response of *Oil inventories* and *Real crude oil price* is not statistically significant for the period 2011:2 – 2021:10. *Oil production* sees a lagged and positive response, however, low in magnitude. The responses of *Real activity* and *CPs* are negative on impact, as imposed through our identification approach. These results indicate that funding shocks are not transmitted directly from *PMMFs* to oil companies, through *CPs* and reinforce our finding of a cross-border bank transmission channel of funding shocks from *PMMFs* to the oil market via *CDs*.[42]

7. Conclusion

PMMFs represent a vital source of US dollar funding for non-US borrowers, especially during crisis episodes. In 2016, a set of regulatory reforms for US PMMFs were introduced to address the susceptibilities which emerged during the GFC, which led to higher short-term dollar borrowing costs. The expansion of debt in the oil sector in the post-GFC period at a faster pace compared to other commodity sectors, makes oil companies particularly vulnerable to this sudden disruption in the short-term dollar funding market.

Using the global crude oil market SVAR model of KM (2014), we show that tighter short-term dollar funding conditions driven by the 2016 US PMMFs reform affect the crude oil market. More specifically, we find compelling evidence of a lagged

[41] Results are qualitatively similar when the 3-months sign restriction imposed on *PMMFs* is relaxed. These results are available upon request.

[42] Results are very similar when the 3-months sign restriction imposed on *CPs* is relaxed. These results are available upon request.

negative effect of tighter funding conditions on the real crude oil spot price, and of a lagged positive effect on oil production and oil inventories. We suggest that the positive response of the oil production to tighter short-term dollar funding conditions can be explained by oil companies increasing output levels to raise short-term cash flows, which will enable them to remain liquid and meet dividend payments or to stabilize the purchasing power value of their export revenues in dollars. Moreover, we argue that disruptions in PMMFs funding provision can lead to a lagged decline in real crude oil spot price via its effect on oil production, oil demand or on the hedging activity of oil producers.

Importantly, we find that the effect of the PMMFs funding disruption on the crude oil market is driven by a fall in CDs, which constitute the most important unsecured wholesale funding for global banks. Hence, the US dollar funding disruption triggered by the PMMFs reform is transmitted indirectly from PMMFs to the crude oil market, through cross-border bank flows. Further, we show that if our negative funding shock of interest results in an US dollar appreciation, the US nominal effective exchange rate acts as a transmission channel of US short-term dollar funding shocks to the real crude oil spot price, through a fall in oil demand or a reduction in the cross-border lending of non-US banks.

As we find cross-border bank lending to be a key driver of US PMMFs funding shocks to the crude oil market, our findings stress the importance of a number of mechanisms recently discussed in literature in mitigating the adverse effects of US dollar funding constraints on the US dollar cross-border bank flows, namely, central bank swap lines, central banks' international reserve holdings, central banks' backstop liquidity vis asset purchases and special lending facilities, and the monitoring of the US dollar funding fragility. Firstly, dollar swap lines allow central banks to obtain dollar liquidity from the Federal Reserve to meet underlying demand from banks in their jurisdictions for a fixed period of time at a pre-specified interest rate. These injections of liquidity flow across borders and show up in the form of a rise in cross-border interbank claims, which help to stabilise global dollar liquidity conditions. Secondly, by identifying a fall in the CDs to be a primary driver of the PMMFs funding disruption, our findings support the purchase of CDs via special lending facilities by central banks. Thirdly, stronger global financial safety nets such as the international reserves of central banks, largely denominated in US dollars, can play a stabilizing role in the event of stress in US funding markets such as PMMFs, by providing US dollar liquidity to the non-US financial system.

Moreover, we support the strong need for monitoring the US dollar funding fragility of recipient banks and for strengthening currency-specific liquidity risk frameworks, stress tests, emergency funding strategies and resolution planning (IMF, 2019). Lastly, in the light of the persistent disruptions of the US PMMFs during the GFC, the European debt crisis, the disruptions following the 2016 US PMMFs reform and the Covid-19 outbreak, by showing that PMMFs funding shocks affect the crude oil market, our findings highlight the need for reassessing the resilience of the US PMMFs sector and support the call for a global approach to monitoring these markets (Eren et al., 2020a; IMF, 2021).

We propose the following avenue for future research. Given the growing interconnectedness between banks and non-financial institutions and the structural vulnerabilities in the NBFI sector, exposed by the COVID-19 market turmoil, it would be interesting to explore how liquidity shocks are transmitted between non-bank financial institutions (NBFI), and subsequently to the bank sector and the oil market (see Aldasoro, Huang and Kemp, 2020, for a discussion on cross-border links between banks and non-bank financial institutions). A first step in this direction would be to investigate how systematic differences in the balance sheet structure of banks and non-banks affect the liquidity transmission across the financial sector. The substantially different regulatory frameworks of NBFI as compared to banks, and their limited access to central bank liquidity facilities pose financial stability risks and call for an effective global monitoring exercise on non-bank financial intermediation.

Appendix A

See Table 1A and Figs. 1A and 2A.

Table 1A
Description of the variables included in the analysis.

Variable	Source	Construction
PMMFs	Federal Reserve	
CDs	Federal Reserve	
CPs	Federal Reserve	
CPI	BIS	
Real activity	Kilian (2009) index	Dry cargo shipping rate index
Oil production	EIA	
Real crude oil spot price	EIA	US refiners' acquisition cost for imported crude oil deflated by US CPI
Oil inventories	EIA	US crude oil inventories, scaled by the ratio of OECD petroleum stocks over US petroleum stocks
NEER	BIS	
VIX	CBOE	
BRENT spot price	EIA	deflated by US CPI
WTI spot price	EIA	deflated by US CPI

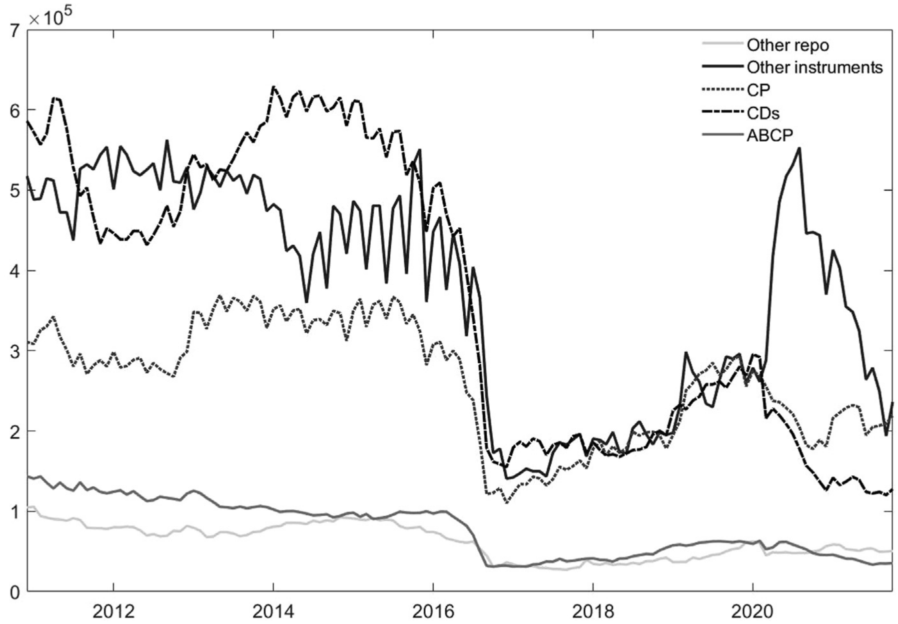

Fig. 1A. PMMFs Investment Holdings by Instrument, 2011–2020. *Source:* Board of Governors of the Federal Reserve System. *CPs* stand for commercial papers, *CDs* for certificates of deposit, and *ABCP* for asset-backed commercial paper.

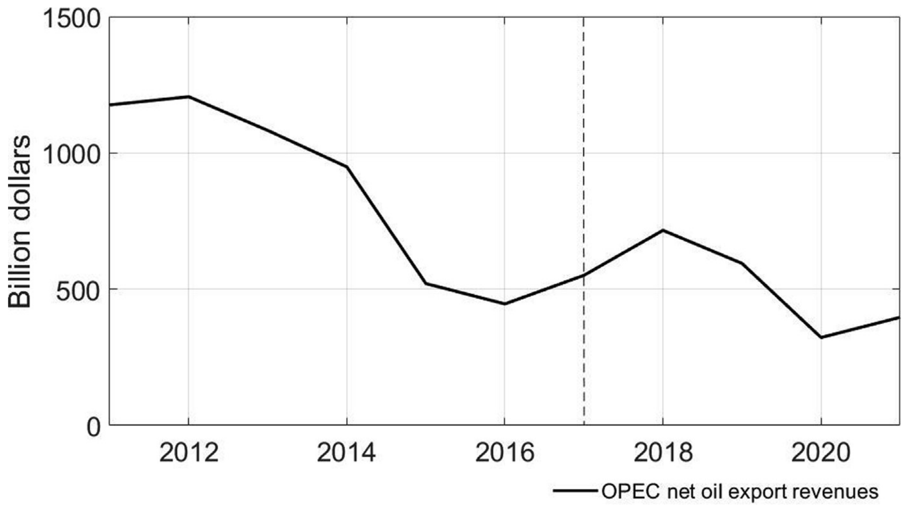

Fig. 2A. OPEC net oil export revenues, 2011–2021. *Source:* U.S. Energy Information Administration, derived from data published in the October 2020 *Short-Term Energy Outlook*, OPEC stands for the Organization of the Petroleum Exporting Countries.

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