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Can U.S. strategic petroleum reserves calm a tight market exacerbated by the Russia–Ukraine conflict?

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ABSTRACT

Recent changes in global petroleum markets have driven the debate regarding the use of strategic petroleum reserves (SPRs) as a price management tool during periods marked by extreme price volatility. We examine the price management role of the U.S. SPR under typical market conditions and in extreme emergencies. Furthermore, we discuss the White House's hypotheses that (a) boosted Organization of the Petroleum Exporting Countries' (OPEC) production and releases from the U.S. SPR result in a negative pressure on U.S. gasoline inflation, and (b) crude oil releases from the U.S. SPR helps balance the global oil market. The threshold cointegration results indicate that U.S. SPR releases impact neither OPEC production nor imported input prices. We apply a hybrid open-economy Phillips curve to model gasoline inflation, accounting for backward- and forward-looking price settings, domestic and global slackness, and energy security. We distinguish between normal-, super-, and hyper-backwardation and -contango oil markets using threshold cointegration and regression techniques. Our results demonstrate that SPR releases and OPEC output increases generally decrease inflation, with a crucial exception being the hyper-backwardation market, as seen in 2021–2022. This period was characterized by severely constrained global supply buffers, including OPEC's spare capacity, exacerbated by the Russia–Ukraine conflict. For this period, we conclude that (1) the impact of OPEC production changes on gasoline inflation would be negligible, (2) excess domestic demand relative to domestic supply raises concerns about domestic energy security, and (3) the unprecedentedly large SPR drawdowns are likely to have caused the market to panic and contributed to gasoline price increases, contrary to arguments suggesting that the 2022 releases eased domestic gasoline prices. We conclude that the SPR is an ineffective price control mechanism during crises and may not have the strategic value previously thought in an extremely tight oil market.

1. Introduction

The fear of petroleum supply disruptions or shortfalls sends a shiver down our spines. Markets feed off the uncertainty, and prices start to escalate. Can a government step in and throw its weight behind to actually try to solve a petroleum supply crisis? Could potential shortfalls be addressed simply by breaking out savings from a piggy bank? This scenario sounds like dipping into your retirement savings funds just because you need to come up with a down-payment for a new car—which any financial advisor will tell you is an unwise thing to do!

In this study, we examine the impact of U.S. SPR drawdowns on gasoline inflation in the U.S. and the reserve's role in the global oil market, both under typical market conditions and in the extreme scenarios brought about by the 2020 COVID-19 pandemic and the 2022 Russia–Ukraine conflict. Our empirical analysis covers the period from January 2002 to October 2022, which enables us to focus on the 'new

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energy age' associated with an increased U.S. interest in energy transition coupled with Russia's emergence as an energy power and China becoming a major energy consumer (Considine et al., 2022; Poussenkova, 2010; Hill, 2002). The sample period also extends the timeframe beyond that used in previous studies, enabling us to examine the implications of the Russia–Ukraine conflict.

The role of government strategic crude oil stockpiles is integral for alleviating the economic impacts of petroleum market stability. Immediate physical availability and energy price volatility (which are closely linked, due to the intertwined relationship between markets for physical barrels on one hand, and oil futures, on the other) influence petroleum market instability and result in adverse macroeconomic consequences, including welfare costs and energy poverty. Strategic reserves are held to ensure energy supply security and, as of late, as a price management tool.[5] The energy security function of SPRs is intuitive: by tapping on reserves, the government can provide refineries with time to adjust to unexpected supply conditions as well as prevent consumers and operators from hoarding and speculators from taking long positions—both being activities which could create shortages that might not have existed in the first place. In contrast, the price-management role of an SPR is more controversial, as it involves government intervention in market dynamics. National welfare is maximized when markets operate freely, and only market failure warrants government intervention. The effectiveness of strategic reserves as a price management tool is historically poor, and has not been tested during crises (Ramsay, 2009; Hubbard and Weiner, 1985) until recently.

The creation of the U.S. SPR in 1975 came about as a response to the 1973–74 OPEC oil embargo, which highlighted the U.S. economy's dependence on imports. The narrative motivating the establishment of the U.S. SPR focused on strengthening domestic energy security and economic welfare while decreasing vulnerability to global oil price shocks. Specifically, the SPR was designed to decrease reliance on imports during emergencies and, thus, to offset severe physical crude oil supply disruptions. The stated goal of the SPR was to mitigate the domestic economic impact of petroleum supply shortages—possibly due to natural disasters and geopolitical events—by maintaining the uninterrupted operation of the domestic refining industry and ensuring a continuous flow of petroleum products needed by consumers into the domestic market. The focus was on emergencies with significant supply reductions and severe price spikes that could adversely affect the domestic economy. Historically, SPR releases aimed to balance short-term supply disruptions and provide temporary psychological market support to stabilize oil and petroleum product prices. The SPR also yielded political benefits as a deterrence tool, potentially moderating the severity of disruptions caused by blockages. Thus, at least from a historical perspective, the SPR's characterizing features were that of a hedging tool against misalignment in political intents between the U.S. and oil-supplying countries. Over the years, the perceived nature of the SPR has evolved beyond its use as an emergency backup oil supply. Recent changes in global petroleum markets and the role of the U.S. have driven a debate on the opportunity of using SPR drawdowns and purchases as a price management tool during episodes of extreme oil price volatility; however, it should be noted that Congress did not design the SPR for price support (Jamali, 2022; R. B. Stevens and Zhang, 2021; Greenley, 2020; U.S. DOE, 2017; P. Stevens, 2009; Murphy et al., 1987; Hubbard and Weiner, 1985; Balas, 1981).

In this study, we provide a brief historical overview of the reasons behind the creation of the U.S. SPR and describe cases when drawdowns were effective and ineffective in countering gasoline and crude oil price inflation. We conduct stylized fact analysis to compare the SPRs of the U.S. and other OECD countries to the OPEC's spare capacity and Russia's production, explain the limited ability of the U.S. to act as a swing producer, and examine the impact of SPR on domestic gasoline prices. Motivated by insights obtained from this analysis, we contribute to the literature on U.S. SPR and gasoline prices by building a model to examine the determinants of gasoline inflation, accounting for the roles of energy security and refineries. Further, we discuss the White House's hypothesis that boosted OPEC production and releases from the U.S. SPR result in a negative pressure on gasoline inflation.

The theoretical underpinning of the empirical analysis is based on a hybrid open-economy Phillips curve model as an approach that we use to identify the drivers of gasoline price changes. Consistent with the theoretical framework of the Phillips curve, the gasoline price model in this study accounts for backward- and forward-looking gasoline price settings as well as domestic and global slackness. We use the U.S. refinery utilization rates to capture the domestic output gap and U.S. domestic petroleum demand to reflect energy security and the domestic output gap. We contribute to the literature on the hybrid open-economy Phillips curve by taking OPEC production as an observable measure of the global output gap, as supported by the findings of Pierru et al. (2018) and Razek and Michieka (2019). Including OPEC production in the model also enables us to examine the White House hypothesis regarding the impact of the latter on domestic gasoline prices. We incorporate the level of the U.S. SPR in the model, unlike Kilian and Zhou (2020) and Newell and Prest (2017), who included SPR changes and indirectly modeled SPR. We account for gasoline and crude oil price market expectations—which are linked to inventory dynamics and supply shocks—by use of the gasoline futures basis and the long-run West Texas Intermediate (WTI) futures basis. Considering that the price expectations align with the theoretical framework underpinning the Philips curve, we rely on storage theory (Ahmadi et al., 2020; Working, 1949; Kaldor, 1939) to interpret these expectations across oil market regimes.

From a methodological standpoint, we contribute to the literature on the role of strategic reserves in energy markets by applying threshold cointegration and open-loop threshold autoregressive (TAR) distributed lagged modeling to examine the impact of U.S. SPR releases on domestic gasoline prices in contango and backwardation oil markets.[6] This approach alleviates concerns that ignoring non-linearity and cyclicality or using an incorrect non-linear specification could result in misleading results in general (Enders, 2023), and with regard to oil markets in particular (Jiang et al., 2020, 2022). These techniques also enable us to be the first to test the U.S. SPR's controversial role as a price management tool during severe emergencies, such as the 2020 COVID-19 pandemic and the 2022 Russia–Ukraine conflict. Our choice of applying threshold cointegration and regression techniques is consistent with the approaches utilized in previous studies in the literature on the hybrid open-economy New Keynesian Philips curve (Rumler, 2007), on capacity utilization as a measure of the output gap (Chang and Emery, 1997), and on the theory of storage (Considine et al., 2022; Considine and Aldayel, 2020; Koy, 2017; Fattouh, 2009; Larson & DEC, 1994).

Our empirical analysis builds on previous research on the U.S. SPR and global crude oil and U.S. domestic gasoline prices. Kilian and Zhou (2020) concluded that SPR releases have a limited impact on gasoline prices. The authors used a vector autoregressive (VAR) model to examine policymakers' beliefs that SPR releases alleviate global oil market fluctuations, stabilize global oil prices, and reduce U.S. federal deficit and inflation-adjusted gasoline prices. Their 4 × 4 VAR model examined data from 1977M10–2018M10 for real oil prices, global crude oil production, global business cycle, global crude oil inventories, and changes in U.S. SPR. Kilian and Zhou (2020) modeled U.S. SPR as a component of total global inventories as well as included U.S. SPR changes in their VAR estimation. However, they did not examine variations in the impact of SPR releases for contango and backwardation oil market regimes.

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[5] A stream of literature also discusses whether SPR accumulation and releases have a potential positive welfare effect (see, for example, Yang et al., 2022).

[6] The "3.3. Oil Market regimes" section discusses the characteristics of contango and backwardation markets.

Newell and Prest (2017) relied on a VAR model to analyze how futures prices and inventory dynamics affect U.S. SPR policies to help policymakers make SPR-related decisions that are informed by market prices. Newell and Prest (2017) modeled SPR as an unexpected increase in commercial inventories. Their analysis relied on data from 1988M12–2016M06, including the real crude oil prompt-month price, crude oil 12-month spread, OECD petroleum consumption, OECD commercial crude oil inventories, and OPEC crude oil production. In their empirical evaluation, the SPR was modeled as an unexpected increase in commercial inventories. Newell and Prest (2017) concluded that the slope of the futures term structure curve, which is a gauge of market contango and backwardation, provides guidance about whether an SPR drawdown or buildup is most appropriate. More pertinent to the focus of our analysis, they also concluded that SPR releases might be effective in moderating oil price increases caused by short-rather than long-term shocks to oil supply. The empirical approach of the U.S. Treasury (2022) built on Newell and Prest (2017) and explicitly modeled domestic gasoline prices. Their study concluded that SPR drawdowns have a meaningful moderating impact on gasoline prices. However, the U.S. Treasury (2022) acknowledged that their model's assumptions are restrictive. For example, they assumed that prices do not respond to speculative and geopolitical influences and a one-to-one pass-through from crude oil prices to gasoline prices. Their framework also accounted for neither changes in commercial inventories nor the fact that the effect of SPR announcements is short-lived. It is unclear whether the U.S. Treasury (2022) accounted for the difference in the relationship between the variables in contango and backwardation regimes.

In this study, we examine whether the effectiveness of SPR releases depends on the oil market regime. Other studies in this line of research have taken into consideration market regimes, usually defined by the sign of the slope of the oil futures term structure. Bouchouev (2022) took a storage theory perspective to provide a qualitative analysis of the U.S. government's likely gains and losses from SPR releases in contango and backwardation markets. Although Bouchouev (2022) and Newell and Prest (2017) accounted for contango and backwardation regimes, they did not examine refined oil production. To the best of our knowledge, our study is the first in this line of research to apply threshold analysis to test the relationship between the U.S. SPR and OPEC production and their joint effect, along with energy security and refinery utilization, on domestic gasoline inflation across different oil market regimes. A distinctive advantage of threshold analysis is that oil market regimes are endogenously identified, rather than being exogenously assumed based on the sign of the basis.

This study provides several insights regarding the impact of U.S. SPR releases on the global oil market. Our stylized fact analysis suggests that the U.S. SPR is no more than a drop in the ocean and highlights the obvious: the U.S. is an oil price taker, rather than a price maker. This claim is confirmed by our results of Granger causality and threshold cointegration tests. Further, our results reveal that the SPR does not impact OPEC production (which is instrumental in affecting global oil prices) and has a limited effect on the price of imported intermediate inputs of gasoline production. We find evidence supporting the view that OPEC production increases generally have a deflationary effect on gasoline prices and that U.S. SPR releases counter gasoline inflation in tight markets, consistent with the White House hypotheses; however, periods of extreme shortage and oversupply show deviations from these expectations. For instance, SPR releases have negligible effects on gasoline inflation in periods of extreme oversupply—a scenario that emerged during the 2020 COVID-19 pandemic.

From an energy security standpoint, it is only of moderate interest that SPR drawdowns do not affect gasoline prices in periods of extreme oil abundance. In contrast, from the same standpoint, it is crucial to understand whether SPR releases and OPEC production increases are effective in moderating gasoline inflation in periods of extreme shortage characterized by low supply buffers. This scenario emerged in 2022, when the oil market was in a hyper-backwardation condition characterized by severely constrained global supply buffers—including OPEC's spare capacity—which was at the time exacerbated by the Russia–Ukraine conflict. Our analysis for the latter scenario indicates that OPEC production increases did not moderate the upward trend of U.S. gasoline prices. Furthermore, we show that SPR release fueled gasoline inflation, rather than countering it—an equally important insight from the perspective of U.S. energy security. Both of these findings contradict the White House hypothesis. We propose that the inflationary pressure exerted by SPR releases in hyper-backwardation markets might be the outcome of the releases acting as an expectation coordination mechanism for oil prices and concerns about the effectiveness of global oil supply buffers to manage future oil price spikes and volatility. However, regardless of the explanation, our findings raise concerns about U.S. domestic energy security, as they reflect a situation of excess domestic demand relative to domestic supply. We conclude that the SPR may not have the strategic value it was previously thought to have in case of an extremely tight oil market.

2. Background and literature review

2.1. Impact on global oil prices

2.1.1. Historical overview

"Congress authorized the creation of the SPR in the Energy Policy and Conservation Act (EPCA) of 1975 in the wake of the 1970s Arab Oil Embargo as a way to insulate the United States from future petroleum supply disruptions" (Bordoff, 2015). In 1973, in retaliation to the U.S. decision to continue military supply to the Israelis, and to gain leverage in post-war peace negotiations, OPEC had suspended crude supplies from the Middle East to the U.S. and other Western nations, which resulted in a fuel crisis; gasoline prices skyrocketed as supplies ran out, gasoline stations ran out of fuel, and long lines of cars were stranded trying to fill their tanks. Since 1977, the United States has utilized the SPR to stabilize the oil market in the face of challenges due to unexpected shortfalls of oil supplied to the U.S. refining industry and U.S. crude oil imports or due to geopolitically driven global oil market disruptions. In a Federal Reserve Bank of Dallas research paper, Kilian and Zhou (2020) empirically examined policymakers' beliefs that SPR releases alleviate global oil market fluctuations and stabilize oil prices. Their empirical results demonstrated that previous U.S. SPR releases did not prevent oil price increases during Operation Desert Storm in 1991 and only modestly impacted oil prices after Hurricane Katrina in 2005. Likewise, Clinton's 30 million-barrel SPR release in the 2000s was unimpactful, a result also confirmed by other researchers (Freitas, 2021; Horsnell, 2000). In contrast, the SPR release coordinated by the International Energy Agency (IEA) in response to the 2011 Libyan oil supply disruption successfully moderated oil prices (Kilian and Zhou, 2020).

2.1.2. U.S. Spare capacity and 2021/2022 SPR releases versus OPEC+ spare capacity

Goldman Sachs analysts have concluded that the November 2021 SPR release was a temporary fix that was fully factored into the current market price (Cho, 2021). On March 31, 2022, oil prices decreased by approximately USD 5 per barrel in anticipation of the White House's announcement that the U.S. would release another 180 million barrels (Brower and Politi, 2022; Nardelli et al., 2022). However, the latter SPR release effect is likely to be short-lived (Kilian, 2009b).

The size and dynamics of U.S. shale production and its SPR (Fig. 1) do not enable the U.S. to dictate oil prices or function as a swing producer (Kilian and Zhou, 2020; Webster, 2016). Although Fig. 1 shows that the U.S. SPR surpasses that of all OECD countries, Fig. 2 indicates that the U.S. SPR and spare capacity are small compared to OPEC's spare capacity.

Spare capacity reflects a swing producer's ability to respond to oil supply disruptions and shortages in global oil markets and influence

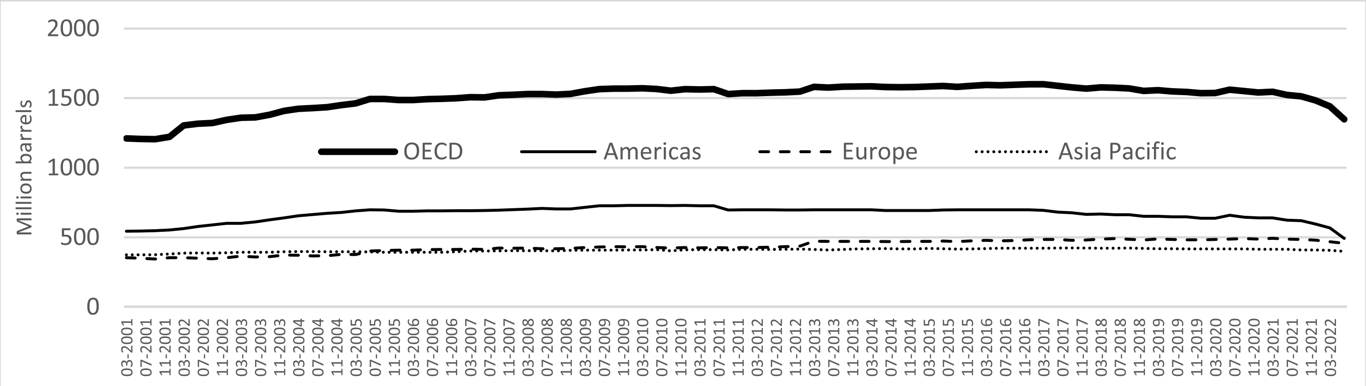

Fig. 1. OECD SPR closing stock (2001:M03–2022:M06).
Source: OPEC, CEIC.

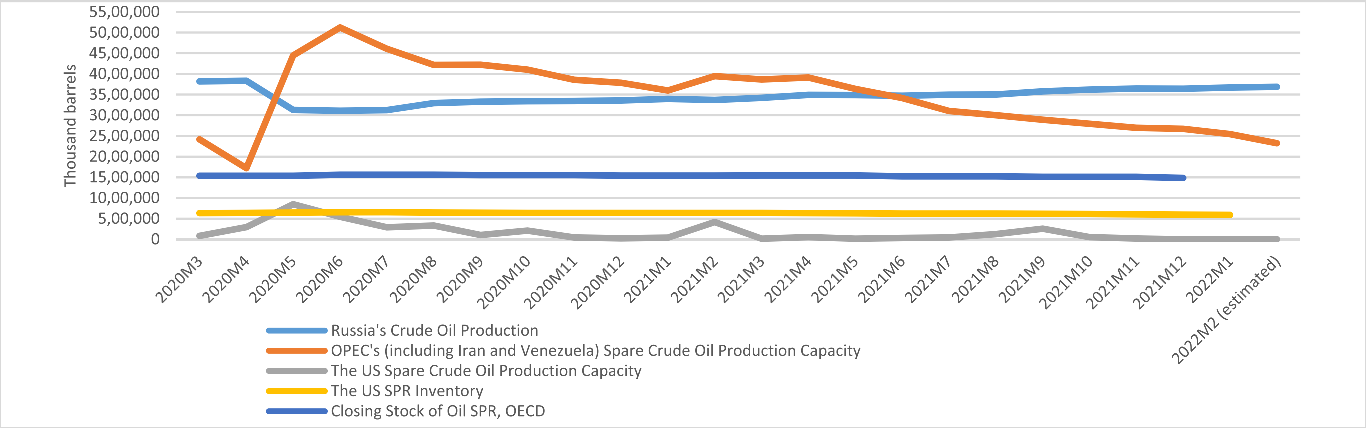

Fig. 2. Russia's crude oil production versus U.S. and OECD SPR and U.S. and OPEC (including Iran and Venezuela) spare capacity.[7]
Source: U.S. DOE, CEIC and authors' calculations: Rystad Energy, Bloomberg.

global oil prices (Razek and Michieka, 2019; U.S. EIA, 2022b). Notably, non-OPEC producers typically produce at or near full production capacity and, even if their production levels could influence oil prices, they are ultimately price-takers, not price-makers (Razek and Michieka, 2019; U.S. EIA, 2022b). In January 2022, OPEC's spare capacity represented approximately 9% (10% including Russia) of the total global production of crude oil, whereas the U.S. SPR represented 2%. As of January 2022, Saudi Arabia had the largest share of OPEC's spare crude oil production capacity (29.36%), followed by the UAE (17.6%), Iran (16.4%), and Iraq (15.32%). The 50 million-barrel U.S. SPR release in November 2021 represented approximately 8% of the total U.S. SPR inventory and 0.2% of global crude oil production.[8] The March 2022 U. S. release, combined with other IEA member releases, amounted to approximately 1.4 million barrels/day from April to October, representing approximately 9% of the total emergency reserves (IEA, 2022; Saadi, 2022).

2.1.3. *The U.S. as a swing producer of oil*

Over 70% of U.S. oil production comes from shale ("tight rock") or unconventional sources, as opposed to conventional porous rock reservoirs. One significant difference between the two is that production from conventional reservoirs often can be increased or decreased simply by turning valves on the wells, or by increasing the rate of water or gas pumped in at the edges to push out oil faster. In unconventional reservoirs, however, there are no such quick controls. Increasing production requires the creation of more producing wells. Between an investment decision and resulting production growth, there is a minimum six-to nine-month lag, requiring unavoidable steps such as planning and drilling a fresh well, completing the hydraulic fracturing process, and connecting the well to the logistics network by pipelines or trucks.

In contrast, production growth response from most OPEC+ members can be implemented within weeks, if not days, given that the majority of their oil production comes from conventional sources. The months-long lag between any desired production growth and the actual response from U.S. unconventional wells makes it fairly impossible to seriously consider the U.S. as a "swing" producer, even though its total production volume is reasonably significant; for more details, we refer the reader to Webster (2016).

2.1.4. *Ability of U.S. And OECD members to offset Russia's production disruptions*

The White House claimed that the 2022 SPR drawdown would decrease Europe's dependence on Russia while easing energy prices and associated inflationary pressure (Saadi, 2022). Fig. 2 depicts the OPEC+ spare capacity (including that of Venezuela and Iran), U.S. spare capacity, and total global SPR. The figure illustrates that neither the OPEC+ and U.S. spare capacities nor the U.S. SPR is sufficient to offset a potential disruption to Russia's crude oil production. Although a global coordinated SPR release combined with OPEC+ and U.S. spare capacity

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[7] The data on OECD SPR are available on quarterly basis. The series has been interpolated to generate a monthly data series, assuming that the value is constant within a year.

[8] Authors' calculations using Rystad Energy (n.d.a, n.d.b) data retrieved from Bloomberg.

and U.S. SPR could potentially offset a disruption to Russia's crude oil production temporarily, the global oil market would be left without a supply buffer to calm oil markets and manage oil price spikes and volatility (Courvalin et al., 2022; Finley and Krane, 2022). Courvalin et al. (2022) have warned about a range of potential outcomes from such a strategy, suggesting a severe oil spike with disruptive consequences for the global economy.

2.1.5. *Concerns with attributing oil price decreases to SPR releases*

Although some analysts have attributed the decrease in gasoline and crude oil prices in early August 2022 to SPR releases, these price changes were predominantly due to market fundamentals, geopolitics, and expectations. For instance, the price decrease followed the August 3, 2022, OPEC+ meeting when members announced a slight production increase because crude oil commercial inventories had increased and average gasoline demand was lower than in 2020 due to concerns of a possible recession in the U.S., lockdowns in China, and global economic slowdown that would limit demand. Simultaneously, efforts have been undertaken to revive the Iran nuclear deal. Although an improvement in the prospects of the deal could generate expectations that more Iranian crude would reach the market and increase the global supply, this effect had already been factored into the market and reflected in crude oil prices (Fanzeres, 2022).

Moreover, by early March, the process of self-sanctioning followed by Western government sanctions on Russia's oil sector limited access to insurance and tankers, rendering most of Russia's supply off limits and enormously increasing oil price estimates (Courvalin et al., 2022; Smith, 2022). As the dust settled in the following months, trading firms and banks had been looking into ways to continue Russian oil purchases without breaching sanctions, while friendly countries were importing discounted Russian oil (Cahill, 2022; Fattouh et al., 2022; Payne, 2022; Tan, 2022). Sanctions and self-sanctions on Russian oil imports resulted in a complete logistical overhaul of the global oil market (Finley and Krane, 2022). In other words, the Russia–Ukraine geopolitical factor had already been factored into the market and, accordingly, prices had started to decline. In summary, SPR releases have a trivial effect when all of these factors are simultaneously taken into consideration. Crude oil trades in a global market, where the implications of SPR drawdowns on oil prices are to be judged in terms of global dynamics, rather than solely on domestic consumption (Kilian, 2009b; Hubbard and Weiner, 1985).

2.2. *Impact on U.S. Gasoline prices*

2.2.1. *U.S. Gasoline prices and Days of Oil Consumption Covered by SPR*

Kilian and Zhou's (2020) model indicated that a U.S. SPR release would reduce inflation-adjusted U.S. gasoline prices by just USD 0.13/gallon, which is too small of a change to stimulate the U.S. economy. Indeed, U.S. gasoline prices were negligibly affected by the November 2021 SPR release announcement (Fig. 3). As of March 31, 2022, U.S. gasoline prices remained high, even as the markets anticipated an unprecedented U.S. SPR release (Nardelli et al., 2022; U.S. EIA, 2022a). Gasoline prices spiked in June 2022 before they trended downward; however, as of August 2022, prices were higher than in 2021 (Fig. 3). The U.S. government acknowledged that gasoline prices had only slightly decreased and remained high (Melvin, 2022b). Fig. 3 suggests that the impact of SPR release announcements is short-lived (if at all) and that other factors determine gasoline prices, as discussed in the following subsection.

In September 2021, before the November 2021 and March 2022 release announcements, the U.S. SPR would have covered approximately 25 days of U.S. total crude oil consumption (Fig. 4). Furthermore, according to U.S. EIA (2022c) data, a 50 million barrel release would have covered U.S. petroleum consumption for just 2.4–2.7 days, while a 180 million barrel release would have covered U.S. petroleum consumption for approximately 9 days. Note that, by June 2022 (after a series of notices of SPR sales), the U.S. SPR would have covered approximately 19 days of U.S. total crude oil consumption (see Fig. 4).[9]

2.2.2. *The relationship between crude oil and gasoline prices*

The White House (2022) referred to a U.S. Treasury (2022) report, which builds on Newell and Prest's (2017) work, in support of the view that SPR releases are effective in decreasing domestic gasoline prices. Newell and Prest (2017) used futures and inventory dynamics to analyze U.S. SPR policies; however, they did not account for refined petroleum. The U.S. Treasury (2022) report expanded on Newell and Prest's (2017) analysis to account for the impact of SPR releases on U.S. retail gasoline prices. The U.S. Treasury (2022) acknowledged that their model focused on short-term analysis and assumed that the supply is unresponsive to price changes, that transportation prices and differences in crude quality and blends have a limited impact, and that prices respond to supply and demand but not to speculative and geopolitical factors. Naturally, this latter assumption is limiting when analyzing the impact of the 2022 SPR release. Furthermore, the U.S. Treasury (2022) report accounted for neither changes in commercial inventories nor the notion that SPR announcements might affect market expectations, and that expected SPR releases might be factored into prices in advance. Additionally, the U.S. Treasury (2022) stated that, as the amount of the pass-through from crude oil price changes to retail diesel and gasoline prices was unclear, a one-to-one pass-through was assumed. Accordingly, their results suggested that a USD 1 per barrel crude oil price decrease would result in a USD 1 per barrel (i.e., USD 0.024 per gallon) gasoline price decrease.

The U.S. Treasury (2022) acknowledged that the aforementioned assumptions are very restrictive. For instance, in the same report, the U.S. Treasury (2022) stated that "refining markets have been very tight, and it's possible that a $1 change in crude oil would not lead to an equal decline in the retail price of gasoline." It should be emphasized that, according to Golding and Kilian (2022), the crude oil price (which is determined by global supply and demand beyond the control of the U.S. oil industry) represented only 59% of the retail gasoline price in March 2022. The final gasoline price for end-users is also impacted by domestic gasoline market circumstances and competition as well as local conditions. Retail prices at gas stations are based on several factors, including "expected acquisition cost for the next delivery of fuel from the local distributor, federal and state tax rates, and a markup that covers operating expenses, such as rent, delivery changes" (Golding and Kilian, 2022).

2.2.3. *U.S. Petroleum product reserves*

It is worth engaging in further analysis to examine why the U.S. government did not utilize its gasoline inventory (Fig. 5) and emergency reserves of 1 million barrels each of gasoline and heating oil (Bordoff, 2015) to directly address the domestic spike in gasoline prices. The heating oil reserve—an ultra-low-sulfur distillate that can be utilized as diesel fuel or home heating oil—was tapped in 2012 after Hurricane Sandy; however, the gasoline reserve has never been used (Melvin, 2022a).

While we cannot provide a direct reason for the U.S. government's decision not to tap these reserves to decrease gasoline prices, we note a disagreement between the U.S. Government Accountability Office (GAO) and the Department of Energy (DOE) that predates the 2021/2022 gasoline price spikes. The following is a quote from a U.S. GAO (2018) report:

"Regarding our recommendation that U.S. DOE conduct or complete studies on the costs and benefits of regional petroleum product reserves, the agency disagreed. U.S. DOE stated that it is the agency's position that government owned and operated regional petroleum product reserves are an inefficient and expensive solution to respond to regional fuel supply disruptions. U.S. DOE further stated, based on studies done in 2015 that U.S. DOE officials told us were pre-decisional and therefore

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[9] June 2022 was the most up-to-date data as of August 2022.

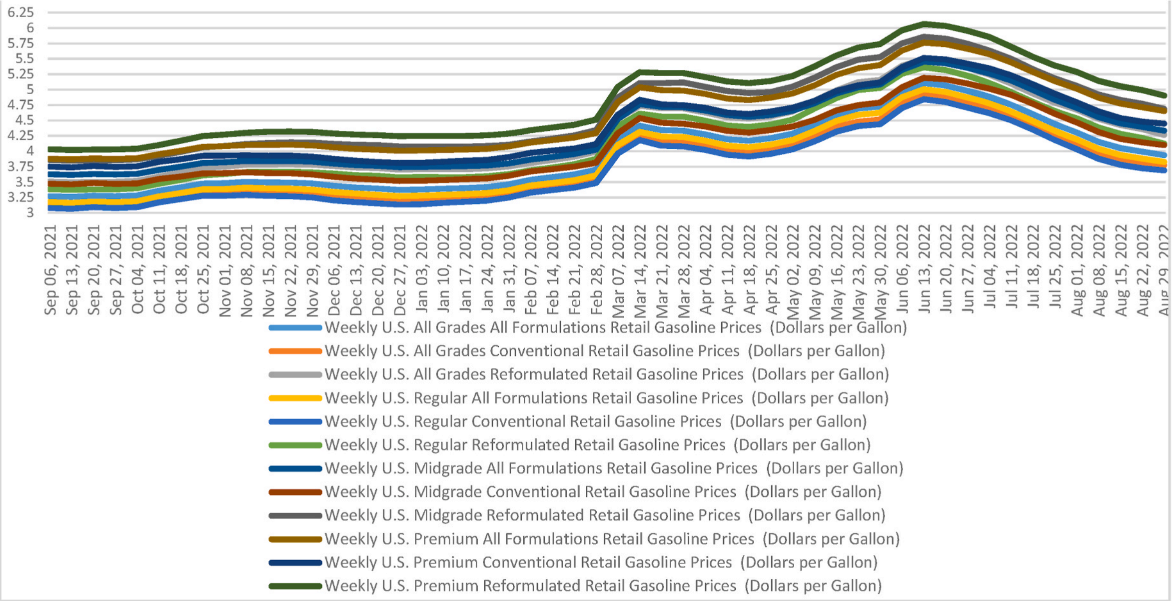

Fig. 3. U.S. Weekly gasoline prices (September 6, 2021, to August 29, 2022).
Source: U.S. EIA (2022a).

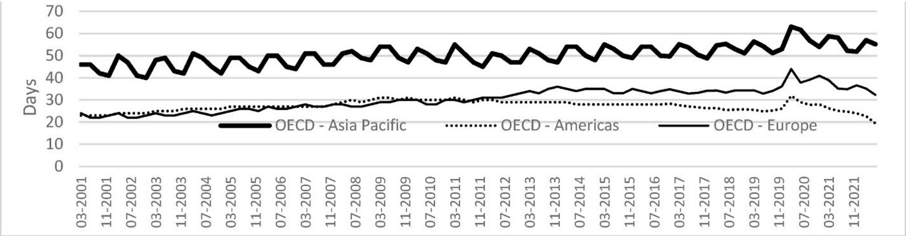

Fig. 4. Days of oil consumption covered by SPR (2001:M03–2022:M06).
Source: OPEC, CEIC.

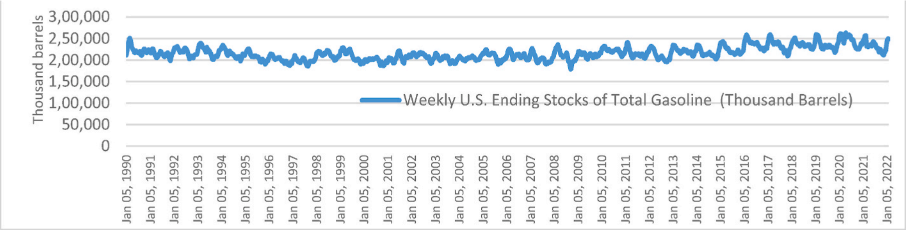

Fig. 5. Weekly U.S. Stocks of gasoline (1990-01-05 to 2022-02-04).
Source: U.S. EIA (2022c).

could not be reported, that there are additional concerns associated with government-owned and operated regional refined petroleum product reserves, including little to no storage capacity for lease in commercial terminals and high costs for government owned and operated regional product reserves. However, these same studies took these concerns into account, and concluded that a product reserve in the Southeast would provide significant net economic benefits (benefits minus costs) to the region and the United States in the event of a major hurricane. These studies also concluded that additional analyses are required to inform decisions regarding the potential benefits of a similar reserve on the West Coast. Further, the Quadrennial Energy Review of 2015 recommended that similar analyses be completed for other areas deemed by U. S. DOE to be vulnerable to fuel supply disruptions. Therefore, we continue to believe that conducting these analyses, as recommended in the Quadrennial Energy Review of 2015, will provide Congress with information needed to make decisions about regional product reserves."

According to Melvin (2022a), the U.S. GAO has reiterated the recommendation to look into alternative mechanisms and policies to increase the responsiveness of the petroleum product reserve in emergencies as well as alternative measures to diversify reserve sizes and ownership, geographic locations, and fuel composition to alleviate the impact of energy price shocks, particularly on vulnerable regions. For further insights into the views of different U.S. government entities on establishing petroleum product reserves instead of relying only on crude oil reserves, we refer the reader to Greenley (2020) and U.S. DOE (2017).

2.2.4. U.S. Crude oil and petroleum product imports from Russia

Sanctions on Venezuela's crude oil since 2018 have driven the increase in Russian exports to the U.S. (Finley and Krane, 2022; Razek et al., 2021). According to Finley and Krane (2022), before the 2022 sanctions, the U.S. was the second-largest export market for Russia's refined products (representing approximately 20% of trade volume in the category); however, even though U.S. crude oil imports from Russia doubled in 2021, the U.S. remained a small market for Russia relative to other countries. Figs. 6 and 7 show Russia's total proceeds from exports of crude oil and refined products from 2005 to 2021, with exports to the U.S. accounting for 1.32% and 4% on average, respectively. The latter began to increase in 2019, making the U.S. Russia's second-largest export market for refined products, reaching a maximum of approximately 11% in September 2020. Approximately 10% of U.S. West Coast imports of crude oil and approximately 10% of East Coast gasoline imports were from Russia at that time (Finley and Krane, 2022).

The U.S. produces light oil but consumes heavy oil (Nilsen, 2022). U. S. imports of Russia's crude are mostly Mazut, an "unfinished," low-quality, heavy fuel oil which U.S. refineries are designed to upgrade into gasoline and diesel (Finley and Krane, 2022; Meyer, 2022; Nilsen, 2022). Hence, in terms of the efficiency of the match between oil quality and refinery configurations, the U.S. depends on imported heavy fuels. However, even abstracting from crude oil quality and refinery configurations, U.S. oil production is still insufficient to meet domestic demand. Accordingly, the U.S. is not entirely energy independent (Bordoff and O'Sullivan, 2022; Nilsen, 2022).

2.3. U.S. SPR release in relation to the U.S. Government budget deficit, refinery production, and oil exports

2.3.1. The November 2021 U.S. SPR release

The 50 million-barrel SPR release in November 2021 had two components. The first component involved the direct sale of 18 million barrels of crude oil, authorized in 2018 (Knight, 2021; The White House, 2021; Wood, 2021). Direct sales are typically used to finance the federal budget deficit (Bouchouev, 2022; Kilian and Zhou, 2020), which increased significantly in 2021 (Fig. 8).[10] The second component involved issuing long-term loans to companies in the first quarter of 2022 totaling 32 million barrels of oil, on the condition that those companies would return the crude oil plus a premium between 2022 and 2024 (Knight, 2021; The White House, 2021; Wood, 2021). For a more detailed analysis of the likely gains and losses to the government from a storage theory perspective in contango and backwardation markets, we refer the reader to Bouchouev (2022).

Kilian and Zhou (2020) noted that the exchange approach (i.e., oil loans) is commonly applied during temporary oil supply disruptions due to ship channel closures, hurricanes, and pipeline obstructions (see, for example, Endress, 2021). As noted by Melvin (2022b), the 2021 releases were intended as a "supply lifeline for oil and refining companies." Consistent with this view, we find that U.S. DOE (n.d.a) data show that the U.S. DOE released sour rather than sweet crude, where the former quality of crude oil matches U.S. refinery configurations more than the latter; however, Tobben and Kumar (2021) reported that the amount released was not necessarily restricted to domestic consumption. In an email to Bloomberg, the U.S. DOE stated:

"The SPR does not have authority or control over exports of crude oil exchanged or sold from the SPR. There are no restrictions on the export of U.S. crude oil," …. Foreign companies will also be permitted to participate in the two offers, "except countries that are not allowed to do business with the United States" (Tobben & Kumar, 2021).

The implication is that, while the 2021 drawdown was meant to support the domestic refining industry, the release could have been diverted to oil exports and, therefore, be less effective than anticipated in moderating gasoline price inflation.

2.3.2. The March 2022 U.S. SPR release

The retail price of gasoline (all grades, all formulations) in March 2022 was 0.83 USD/gallon higher than the price in November 2021. Given that the November 2021 high prices triggered alarm in the White House and prompted an SPR release, an analogous, even stronger response to the March 2022 price spike came as no surprise.

Broadly speaking, there are two approaches to SPR management. In the first approach, oil is loaned out with a fixed time horizon for its return. The commodity's own interest rate, by virtue of lower future prices relative to current spot prices, would translate into an assured return (profit) on the barrels loaned out. In the second approach, barrels are sold outright under the speculative expectation of lower prices at the time of replenishment. This risky approach suffers from exposure to market volatility and is vulnerable to negative returns if future prices continue to rise (Bouchouev, 2022). According to Brower and Politi (2022), the March 2022 release was initially planned as an exchange involving long-term loans to companies that would have to return the crude later at a set price of USD 80 per barrel. However, the U.S. DOE opted to pursue the direct sale of 180 million barrels from the SPR through competitive auctions. The average sales prices for the first three SPR releases (in March, April, and May) were approximately 95.8 USD/barrel, 105.67 USD/barrel, and 108.64 USD/barrel, respectively. The U.S. DOE's intention was to re-purchase the barrels after the 2023 fiscal year end at a lower competitive fixed forward-price, rather than a market-linked price at the time of the delivery (Bouchouev, 2022; Finely, 2022; T. Gardner et al., 2022; Melvin, 2022b; The White House, 2022). These transactions entail net losses for the U.S. government, unless the re-purchase price is lower than the original sales price (Bouchouev, 2022).

Supporters of releasing oil into the market by sales rather than oil exchanges argue that this approach provides more flexibility to the U.S. DOE, given the scale of the release, as it ensures that barrels are returned at a fair price to minimize government losses, incentivizes production and investment in the sector, and alleviates market uncertainty due to firmer expectations of the future oil purchases by the government. Proponents also claim that, although an exchange would have guaranteed a return over a specific period of time, it would have taken the government a longer time to negotiate contracts with companies on a case-by-case basis. A concern with the direct-sale approach is that replenishing the reserve may take a long time, as it requires authorization from Congress. It is also unclear whether a fixed forward price can effectively stimulate investment and reduce uncertainty, given that oil producers already utilize crude oil futures to hedge price risk.

Opponents of the direct-sale strategy warn that oil sales are speculative in nature because future oil prices are unknown. Furthermore, SPR releases not only decrease the market buffer—potentially leading to longer-term market risks and oil price volatility—but also create logistical complexities in the Gulf Coast region, crowd out shale production, and may eventually burden taxpayers if barrels are re-stocked when spot oil prices are high (Bouchouev, 2022; Finely, 2022; T. Gardner et al., 2022; Melvin, 2022b; The White House, 2022).

In the classical sense, commodity storage provides options with regard to availability. In times of commodity surplus, some quantities are shifted into a stockpile to counteract potential short-term deficits. In principle, the stockpile acts as a buffer, where its effectiveness is constrained by its size. To apply storage as a price management mechanism, an inverse relationship must exist between inventory levels and price. Specifically, a release from storage could help to restore the balance between low supply and high demand, thus easing price escalation and inventory depletion. The assumption underpinning the effectiveness of storage as a price management mechanism is that there is an efficient

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[10] Kilian and Zhou (2020) estimated that a White House proposition to sell half of the SPR over 10 years would yield USD 13.6–18.9 billion. Bordoff (2015) warned that the decision to draw down the SPR is too complicated to be solely driven by the purpose of financing the government budget deficit.

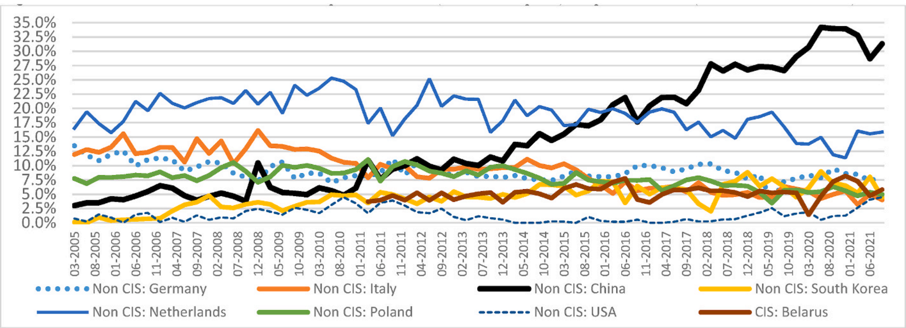

Fig. 6. Share of Russia's total crude oil exports proceeds (Value of exports): Top 8 countries (2005:M03–2021:M09).
Source: Russia's Federal Customs Service; retrieved from CEIC.

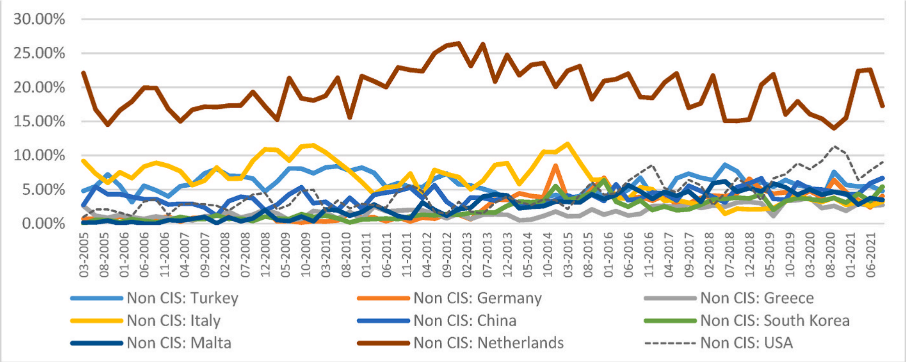

Fig. 7. Share of Russia's total refined products exports proceeds (Value of exports): Top 9 countries (2005:M03–2021:M09).
Source: Russia's Federal Customs Service; retrieved from CEIC.

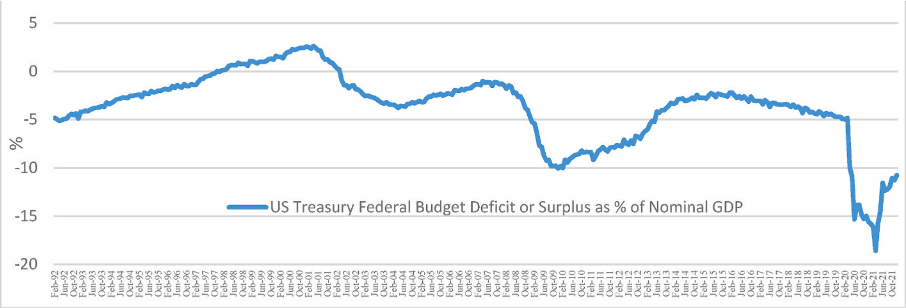

Fig. 8. U.S. Treasury federal budget deficit or surplus as % of nominal GDP (February 1992–December 2021).
Source: U.S. Treasury data retrieved from Bloomberg.

and elastic price response to the supply and demand equilibrium. In oil markets, however, both demand and supply are very inelastic (Bouchouev, 2022). In 2022, the oil market was extremely tight as global inventories were limited, global supply buffers were severely restrained, and OPEC members could not meet their quotas. Meanwhile, domestic petroleum demand had not shown strong shifts in response to exceptionally high price levels. Against this backdrop, beliefs about the effectiveness of the 2022 SPR release in reducing gasoline prices must be carefully scrutinized.

Another aspect of the March 2022 release that should be taken into consideration is the difference between crude oil produced in the U.S. which could be used to replenish the SPR, and the quality of crude oil best suited for U.S. refineries (Finely, 2022). The SPR inventory is composed of light-sweet crude and medium-sour crude. Although sweet crude is of higher quality and trades at a premium, refineries on the U.S. Gulf Coast are optimized for sour crude (Bouchouev, 2022). The SPR release was expected to be sour crude in order to replace imports of Russian crude processed by U.S. refineries with the purpose of offsetting supply shortages until U.S. shale production had recovered (Brower and Politi, 2022; Hari, 2022). Although the March, April, and May 2022 sales were predominantly of sour crude, the July release shifted to mostly sweet crude. This begs the question of whether the release was well-suited for U.S. refineries—and, ultimately, for the production of gasoline—or whether these releases were intended to support oil export. The latter scenario is likely to be politically controversial (Bouchouev, 2022; Finely, 2022; IEA, 2022; Melvin, 2022b; Saadi, 2022).

2.4. *Recent crises and the U.S. SPR role as a price management tool*

The function of strategic reserves as a price management tool had not been tested in the case of extreme crises (Hubbard and Weiner, 1985; Ramsay, 2009) until recently, considering the market turbulences associated with the COVID-19 pandemic and the 2022 Russia–Ukraine conflict. This section provides an overview of discussions on the viability of the U.S. SPR during these two crises.

2.4.1. The 2020 COVID-19 low-price environment

When oil prices collapsed and global commercial storage capacity got exhausted as a consequence of the COVID-19 pandemic and the market share tussle between Saudi Arabia and Russia, the discussion shifted from selling SPR (during the prior high oil price environment) to buying oil to fill the SPR to its full capacity (Greenley, 2020; JPT, 2020). According to JPT (2020), utilizing the full capacity of the SPR would have generated a revenue of approximately USD 2.6 billion. To allow domestic producers to temporarily store crude oil in SPR sites and to provide them with financial relief, Congress sanctioned that the U.S. SPR store up to 1 billion barrels, and the U.S. DOE solicited the storage of 30 million barrels of crude oil in return for a future fixed premium of barrels. Despite the Federal government's efforts and measures to provide SPR capacity, the Cushing storage capacity is a fundamental determinant of WTI prices. Furthermore, the U.S. SPR capacity is limited and, hence, its impact on an over-supplied crude oil market is marginal and uncertain, as it depends on the volume and duration of the excess supply and undefined threshold value of prices (Greenley, 2020). In this paper, we attempt to estimate those threshold values.

2.4.2. The 2022 Russia–Ukraine conflict high-price environment

High crude oil prices are associated with an actual or expected tight market (Greenley, 2020). In a congressional report, Greenley (2020) acknowledged that, although the SPR is recognized as a valid tool to temporarily relieve increasing prices, oil price management was not among the functions for which the SPR was designed by the U.S. Congress. Greenley (2020) also noted that, although releases could temporarily decrease prices, it is difficult to foresee their long-term quantitative impact. As Greenley (2020, p. 16) reported, some scholars "do not support use of the SPR to mitigate high crude oil prices. These observers prefer allowing the market to resolve itself and for government not to intervene. Further, observers may contend that market conditions and current and anticipated geopolitical events are affecting prices more than short-term physical supply concerns or that speculative bidding in the oil commodity futures market has driven price volatility more than the current supply-demand balance. In this context, using the SPR would have limited impact on market conditions." Kilian (2009b) recommended that the reserves be used to offset temporary supply disruptions (likely caused by geopolitical or weather disturbances), as originally intended, instead of as a price management tool. The same study also emphasized that it might be unfeasible for SPR releases to re-balance a tight market driven by rising global demand or to offset global economic cycles and structural global economy changes.

In light of the Russia–Ukraine conflict and supply shortfalls arising from global sanctions on Russian imports, U.S. gasoline prices rose to an average of 4.321 USD/gallon (all grades and formulations) for the month of March 2022 (U.S. EIA, 2022a). In 2022, OPEC members disregarded appeals from the U.S. government and IEA to leverage their spare capacity and boost supply in an attempt to combat skyrocketing energy prices exacerbated by the Russia–Ukraine conflict. As a recourse, the U.S. and IEA members announced coordinated reserve releases to re-balance the global oil market and alleviate domestic gasoline inflation. Although some scholars have argued that this move constitutes a positive evolution in the use of the SPR, others argue against using the SPR as a short-term fix, given that it is a vital national strategic asset.

SPR releases typically coincide with supply disruptions[11]; however, the White House March 2022 move seems to have targeted price, rather than supply (Croft, 2022). On one hand, Croft (2022) stated, "that's a new evolution in the use of the SPR, at least the justification for the use. And … it did send a signal to these OPEC countries that kind of, either you or me situation." On the other hand, warning that the SPR should not be used as "an ATM," Bordoff (2015, 2019) explained that SPR releases only temporarily address price spikes, arguing that higher fuel economy standards would better protect U.S. consumers from global oil market fluctuations. Bordoff (2015) emphasized that, despite increased crude oil production and decreased reliance on oil imports in the U.S., the SPR remains a vital national security asset—an assessment that this study's results call into question.

Despite the unprecedented 180-million-barrel SPR release by the White House in March 2022, in June/July of the same year, concerns about surging gasoline prices worldwide were still growing. As a response, the U.S. then embarked on a diplomatic campaign to persuade oil producers to increase their output. In July 2022, U.S. President Joe Biden made his first trip to the Middle East since being elected, visiting Israel and Saudi Arabia (Baker and Sanger, 2022). The visit was overshadowed by a U.S. policy of divestment and retrenchment from the Middle East, both politically and militarily (Lynch and Jamal, 2019). The trip was especially awkward for U.S. President Biden, as his administration had previously criticized Saudi Arabia (Gardner, 2021). Nevertheless, rising inflation in the U.S. and Russia's invasion of Ukraine prompted the Biden administration to change its priorities. First among them was the effort to lower domestic gasoline prices in the U.S. and shore up support for sanctions against Russia. The U.S. diplomatic mission to the Middle East followed earlier efforts to increase the quantity of oil supplied by Venezuela and Iran (Wallace, 2022; Schmidt et al., 2022).

Biden's diplomatic visit failed to achieve any major diplomatic breakthroughs or an immediate pledge from Saudi Arabia to increase oil production, which led to increased oil prices in the days following the trip (Lawson, 2022). U.S. officials claimed that Saudi Arabia agreed to gradual increases, which was confirmed in OPEC's August 3, 2022, announcement of a slight increase in oil production (El Wardany et al., 2022). Nonetheless, in previous months, the production of OPEC+ members had been below target (Argus, 2022). Moreover, OPEC+ countries, which continued to monitor the global demand amid global recessionary fears, tight monetary policies, rising inflation, and increased uncertainty, indicated on August 31, 2022, that the decision to increase production could be reversed (Astakhova and Ghaddar, 2022; Reuters, 2022). Indeed, during the OPEC meeting on September 5, 2022, the group asserted that the 0.1 million barrel/day increase in production announced in August would only be in effect for September 2022. At the September 2022 meeting, the group reassessed market conditions and decided to revert to August 2022 production levels in an attempt to stabilize market conditions (OPEC, 2022b).

2.5. Summary

Given the stylized fact analysis, background, and literature review discussed in this section, in what follows, we empirically examine the relationship between OPEC production and the U.S. SPR. Moreover, we contribute to the literature on U.S. SPR and gasoline prices by building a model to study the determinants of gasoline inflation. Our analysis provides insights into the validity of the White House hypotheses concerning the impact of U.S. SPR releases and OPEC production changes on U.S. domestic gasoline prices, on the role of refineries in determining

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[11] For historical coverage of the US SPR emergency and non-emergency sales and exchanges, refer to U.S DOE (n.d.b).

gasoline prices trends, and on U.S. energy security.[12] In the following section, we describe our model, which is aimed at testing the role of the U.S. SPR as a price management tool under both typical market conditions and in extreme emergencies.

3. Theoretical background

In this study, we rely on a hybrid open-economy New Keynesian Philips curve approach to model gasoline price inflation and to examine the impact of OPEC production and SPR releases on U.S. domestic gasoline price inflation. We first review the theoretical framework underpinning the New Keynesian Philips curve and then adapt it to model gasoline inflation. Afterward, we discuss the normal and extreme contango and backwardation oil market regimes.

3.1. The hybrid open-economy New Keynesian Philips curve

The New Keynesian Phillips curve is derived from economic fundamentals in a dynamic optimization setting and has been widely used as a standard specification to model inflationary processes. In this framework, the determinants of inflation include expected inflation and excess demand or marginal costs, where excess demand can be captured by the output gap, unemployment rate, or capacity utilization, while marginal costs can be captured by the wage share (Dur and Martínez García, 2020; Jansen, 2004).

Previous research has suggested enriching this baseline inflation model to adjust for information expectations and imported inflation. Specifically, previous empirical studies have shown that inflation models incorporating only forward-expected inflation cannot adequately capture inflation dynamics (Jansen, 2004). In contrast, by incorporating both expected and lagged inflation, the hybrid New Keynesian Phillips curve accounts for both forward- and backward-looking price-setting behaviors (Clarida et al., 1999; Galı and Gertler, 1999). Particularly, including lagged inflation in the model allows price rigidity and the backward-looking behavior of agents to be captured (Jansen, 2004).

Furthermore, empirical research has shown that the closed New Keynesian Philips curve does not adequately capture globalization-altered inflation processes and that, when an economy is globally integrated, global slackness plays a role in determining domestic inflation (Dur and Martínez García, 2020; Engel, 2013; Wynne and Martínez-García, 2010). The open New Keynesian Philips curve was developed to allow for trade linkages between an economy and the rest of the world (Duncan and Martínez-García, 2023). The global economy affects domestic inflation through two channels: the foreign output gap and exchange rate misalignments. The more open an economy is, the larger the impact of foreign-related variables on domestic inflation (Engel, 2013). Rumler (2007) found that price stickiness is systematically lower in an open-than a closed-economy specification. From the perspective of this study, given that oil is a global commodity, the implication is that both domestic price stickiness and foreign inflation determinants should be taken into account in the assessment of inflation dynamics.

Building on the insights of previous research, this study relies on a hybrid open-economy New Keynesian Philips curve to model gasoline inflation. Accordingly, the following equation provides a log-linearized representation of the determinants of the inflation rate:

$$\pi_t = \beta E_t(\pi_{t+1}) + \gamma \pi_{t-1} + \theta X_t + \mu Z_t + \varnothing v_t + \in_t, \tag{1}$$

where π_{t-1} is lagged inflation, $E_t(\pi_{t+1})$ is expected inflation, v_t is a supply shock, and X_t and Z_t are sets of domestic and foreign variables, respectively (Duncan and Martínez-García, 2023; Dur and Martínez García, 2020; Engel, 2013; Rumler, 2007; Jansen, 2004).

The term $E_t(\pi_{t+1})$ captures the impact of expected inflation (developed in the previous period and influenced by past inflation and wage, and price-setting decisions) on current price decisions. The variable v_t reflects the domestic cost-push shocks that impact domestic producers' marginal costs, which may be correlated with foreign cost-push shocks (Duncan and Martínez-García, 2023).

The set of variables summarized by X_t reflects local slackness, including the domestic output gap and change in interest rate. A productivity shock will affect an economy's dynamics through its impact on output potential and, accordingly, is encompassed by the output gap variable. A positive output gap would indicate excess demand and put upward pressure on inflation, while a negative output gap would indicate excess supply and put downward pressure on inflation (Bank of Canada, 2021). Changes in the policy interest rate could constitute an alternative to the output gap to control for local slackness. However, while the policy rate is intrinsically a good predictor of U.S. inflation because it is controlled by the Federal Reserve, quantity-based variables are preferred over variables based on policy decisions to gauge local slackness (Dur and Martínez García, 2020). Chang and Emery (1997) discussed capacity utilization as a measure of the output gap.

Finally, the set of variables Z_t captures global slackness and features of the international monetary system (Dur and Martínez García, 2020). The global and domestic output gaps affect inflation in the same way: an increasing domestic output gap would indicate rising excess demand, which would put upward pressure on prices. A rising foreign output gap raises demand for domestic products, generating upward pressure on domestic wages and inflation (Engel, 2013). As finding reliable measures for an unobservable foreign output gap variable is not straightforward, Dur and Martínez García (2020) used data on G7 countries to construct nominal measures of the global money gap and global credit gap as proxies. Wynne and Martínez-García (2010) suggested using the real exchange rate gap (i.e., the deviation of the real exchange rate from its long-term equilibrium value) as a proxy for foreign slack. We contribute to this line of research by using a global oil market measure as a proxy for foreign slack.

3.2. The model for gasoline inflation

3.2.1. Determinants of the U.S. domestic gasoline inflation

We adopt the open-economy hybrid New Keynesian Phillips curve, formalized in Equation (1), to model domestic U.S. gasoline inflation. To compute the inflation rate (*gas_infl*), we use the U.S. domestic gasoline price.

We rely on the lagged domestic gasoline inflation to account for backward-looking price setting (i.e., price stickiness). As an alternative, we experiment with the lagged value of the inflation rate of relevant imported intermediate goods. The motivation for this choice stems from the results of Engel (2013), who modeled inflation as a function of domestic goods price inflation (which depends on domestic real wages, the marginal product of labor, and future expected inflation) and home currency inflation of imported goods. Rumler (2007) decomposed prices of factors of production into domestic and imported intermediate input prices and domestic wages and accounted for the shares of domestically produced and imported intermediate goods in domestic GDP and the relative prices of domestically produced and imported intermediate goods. Taken together, these results suggest that lagged inflation of

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[12] The impact of domestic U.S. partisan conflict on the price of crude oil strategic reserves, which was studied by Jiang et al. (2020), is beyond the scope of our paper. In this study, we examine petroleum releases from the U.S. SPR, adopted as a tactical measure to combat escalating consumer prices for refined products. Such measures have been implemented by administrations across the political spectrum and, as such, the level of bipartisan conflict in U.S. politics is likely to be immaterial to our analysis. We focus on the White House hypothesis regarding the impact of U.S. SPR releases on domestic gasoline prices, and do not distinguish whether the releases were supported by a conservative or liberal U.S. administration.

imported domestic goods could provide a viable gauge of backward-looking pricing setting behaviors.

In this study, we qualify the effect of SPR releases under different long-term regimes of expectations on the oil future output, which are captured by the spread of the 12-month WTI futures and the spot price (the 12-month futures basis), denoted by (WTI_sprd_12m_spot). This spread captures the intertwined domestic and global supply shocks in the crude oil market, a crucial input for gasoline production (Golding and Kilian, 2022). As noted by Cheng and Xiong (2014), this basis has several determinants, including market structure and related information asymmetries, risk-sharing incentives, and storage costs. The basis is also affected by geopolitical and macroeconomic shocks and financial instability (see, for example, Nazlioglu et al., 2015; Morana, 2013).[13] The relationships between physical inventories, storage, and price spreads reflect the relationship between financial and crude oil markets (Razek and Michieka, 2019). By using the 12-month futures basis, we allow market prices to summarize the effect of these multi-faceted forces forming market expectations for the crucial input of gasoline production. Oil market cost-push shocks affect the marginal costs of gasoline producers (Duncan and Martínez-García, 2023) and, accordingly, gasoline prices.[14]

We interpret the relationship between gasoline inflation and the 12-month WTI futures basis in light of the theory of storage. As noted by Ahmadi et al. (2020), one of the key predictions of the theory of storage is that price fluctuations are more marked in the spot than in the futures market, as market participants expect that production will adjust to re-balance the market in the long run. The implication here is that changes in the basis are variations in current spot market conditions after adjusting for expectations of long-term trends in the oil market. Keeping this interpretation of the basis in mind, we expect a negative relationship between gasoline inflation and the 12-month WTI basis. As per the conventional theory of storage, in tight markets, the spot price rises more than the futures price, as market participants expect that higher prices will induce higher production levels in the future. In such a case, inventories could be at minimal or just-in-time levels, and suppliers attempt to increase production to satisfy growing demand, as has been reported by Considine and Aldayel (2020) and Tran and Turvey (2022). Accordingly, spot prices are likely to exceed futures prices, the spread is negative, and the market is in backwardation. Hence, in the backwardation case, when spot crude prices are higher than futures prices (i.e., $WTI\_sprd\_12m\_spot < 0$), gasoline inflation is expected to increase. Under normal market circumstances, when the market is balanced, futures prices typically exceed spot prices to offset storage costs and foregone interest income. However, when there is excess supply, storage becomes more expensive (given its limited flexibility), placing downward pressure on the spot price. As market participants expect producers to rein in oversupply in the long-term, futures prices drop less markedly than spot prices and the spread widens from normal market levels—a situation termed contango.

We note that part of the literature has identified an alternative oil market benchmark in the Brent. Fig. 9 illustrates the 12-month futures and spot price differential for WTI and Brent. The graph shows that the variables are highly correlated. As this study focuses on gasoline inflation in the U.S., our analysis relies on the WTI.

Our New Keynesian Phillips curve model for gasoline inflation takes into account expectations and forward-looking price-setting in the gasoline market by including the spread between the 6-month futures and spot prices for gasoline ($gas\_sprd\_6m\_spot$) in the gasoline inflation model.[15] According to the theory of storage, we should expect the spread fluctuations to be dominated by those of the spot price, with an almost mechanically determined negative relationship emerging as a result between the contemporaneous gasoline spread and gasoline inflation.

We include the U.S. refinery utilization rate (ref_utlz) in the model as a measure of the domestic slackness relevant to crude oil and gasoline markets. Chang and Emery (1997) have shown that the impact of capacity utilization on inflation is regime-dependent and sensitive to data frequency. For instance, they found that a positive relationship holds when the industrial capacity utilization exceeds a threshold of approximately 82% and is more evident at the quarterly frequency. Low capacity utilization (Chang and Emery, 1997) indicates insufficient demand (i.e., a negative output gap; see, for example, Bank of Canada, 2021) and an increase in inventories. Accordingly, low utilization should be associated with inventory increases and eventual price decreases. By extension, we predict a positive relationship between refinery utilization and gasoline prices under contango oil market regimes. However, as gasoline is storable, increases in utilization during contango might have muted effects on gasoline prices, given that gasoline might be stored in expectation of future higher prices. In contrast, under an extreme backwardation oil market, demand exceeds supply and there is a positive output gap. In this scenario, a decrease in refinery utilization would exacerbate scarcity and add further concerns about future oil market uncertainty and supply disruptions, putting upward pressure on prices. Hence, a negative relationship between refinery utilization and gasoline prices is likely to emerge under backwardation oil market regimes.

We control for domestic slackness and energy security using the U.S. domestic petroleum consumption ($pet\_consump$).[16] Following the same line of reasoning linking the output gap to inflation, an increase in demand for petroleum will lead to upward pressure on prices. Furthermore, the more dependent the economy is on petroleum products, the more likely that petroleum demand by consumers and the industry will increase as the economy expands.

The inclusion of OPEC crude oil production ($opec\_prod$) in the proposed New Keynesian Phillips curve for gasoline is motivated by two lines of reasoning. One is that this variable allows us to examine the White House and IEA hypothesis that an increase in OPEC production decreases domestic gasoline prices, while the second is to capture global output slackness. Global oil demand and the financialization of oil are the primary drivers of OPEC's production (Razek and Michieka, 2019). Global crude oil supply disruptions are associated with global GDP losses. OPEC uses its spare production capacity to maintain a reliable global crude oil supply and offset the adverse effect of supply disruptions on global economic activity (Pierru et al., 2018).[17]

We incorporate the U.S. SPR in the model to examine the White House hypothesis that U.S. SPR releases decrease domestic gasoline prices. If this hypothesis holds, the SPR variable will positively impact gasoline inflation; that is, when the government releases SPR and, accordingly, the size of the SPR decreases, so will inflation. Given the relatively small quantities typically associated with SPR releases, the releases are likely to affect prices more substantially in normal market conditions, when the crude oil market is balanced and prices are in a state of mild contango, compared to extreme cases of excess supply or

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[13] The effects of these factors are also non-linearly related to each other. For example, the storage cost is known to import interest rate risk into commodity markets (Fama and French, 1987) by affecting the financing costs of the carry trade. However, storage costs also increase measures of financial instability (Ahmadi et al., 2020) which, in turn, are linked to interest rate dynamics.

[14] Razek and Michieka (2019) found that the role of oil as a financial asset is an important determinant of oil price movements. The WTI spread variable captures this latter effect, as well as the sentiments of global investors referred to by Jiang et al. (2021).

[15] We rely on 6-month gasoline futures contract because it is more liquid (i.e., in terms of trading volume) than the corresponding 12-month contract.

[16] For more details on energy security indicators, we refer the reader to Global Energy Institute (2020).

[17] According to Razek and Michieka (2019), China's demand for crude oil is an important driver of OPEC production. Hence, China is indirectly included in our analysis.

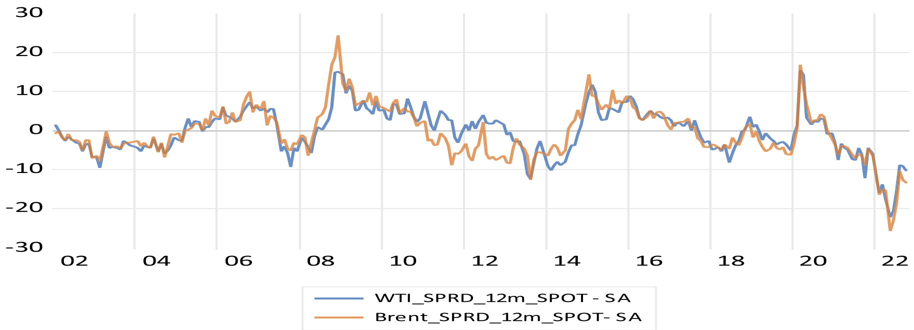

Fig. 9. 12-Month future and spot price differentials for WTI and Brent.
Source: Refinitiv.

demand.

The U.S. DOE is more likely to sell or loan out SPR in backwardation oil market regimes (when spot prices exceed futures prices) and buy back crude oil to replenish the SPR in contango oil market regimes (when spot prices drop relative to futures prices). Hence, SPR releases are more likely to have a relatively more significant impact on the supply side of the crude oil market in backwardation oil market regimes and a relatively more significant impact on the demand side of the crude oil market in contango oil market regimes. According to Kilian (2009b), the ultimate purpose of SPR releases is to lower the price of refined products, not crude oil prices, and the releases would lower retail refined products prices only if the spare capacity of refineries is sufficient to process the supplementary crude oil feedstock—a condition that might be violated in contango regimes.

3.3. Summary

In summary, we model the relationship between U.S. gasoline inflation and the abovementioned determinants as illustrated by Equation (2), which accounts for the U.S. SPR, energy security, refinery utilization rates, WTI and gasoline price spreads, and OPEC production.

$$gas_{infl_t} = \gamma gas_{infl_{t-i}} + \beta_1 \left(gas_{sprd_{6m_{spot}}\, t} \right) + \beta_2 \left(WTI_{sprd_{12m_{spot}}\, t} \right) + \theta_1 pet_{consump_t} + \theta_2 ref_{utlz_t} + \mu opec_{prod_t} + \alpha SPR_t + \in_t \tag{2}$$

We estimate this model allowing for different regimes, identified based on the WTI 12-month futures and spot spread. This approach enables us to identify differences in the nature of the relationship between gasoline prices and the variables of interest, including the SPR, across different regimes under contango and backwardation oil market states.

3.4. Oil market regimes

In a contango market, traders expect typical bullish market conditions (i.e., higher future prices and demand). A market in backwardation, which signifies a bearish market, is characterized by investors expecting weaker demand and lower prices in the future. As market conditions tend to be self-perpetuating, a contango or backwardation market is likely to persist (Johnson, 2011). The degree of contango or backwardation in crude oil markets reveals the extent of supply shock persistence.

Considine et al. (2022), Tran and Turvey (2022), Considine and Aldayel (2020), Koy (2017), Fattouh (2009), and Larson and DEC (1994) identified five oil market statuses: normal-contango, super-contango, hyper-contango, normal-backwardation, and extreme backwardation. Larson and DEC (1994) have suggested a non-linear approach to analyze the basis, also referred to as the shadow price of inventories, according to the theory of storage (Considine and Aldayel, 2020). Fattouh (2009), Koy (2017), Considine et al. (2022), and Considine and Aldayel (2020) adopted a Markov switching approach to determine the different oil market regimes.

Considine et al. (2022) defined the oil market regime as contango when crude oil inventories are rising, extreme contango when inventories are rapidly increasing, backwardation when inventories are falling, and extreme backwardation when inventories are rapidly decreasing. Fattouh (2009) distinguished a contango oil market regime with low oil price volatility from a backwardation oil market regime with high oil price volatility. Koy (2017) identified three regimes: sharp backwardation and slight backwardation (both with high price volatility), as well as slight contango (with low price volatility). Furthermore, Considine et al. (2022) and Considine and Aldayel (2020) identified three oil market regimes: (1) contango with an average oil price volatility, (2) backwardation with low oil price volatility, and (3) extreme backwardation with high oil price volatility. Although oil price volatility is relatively mild in a normal-backwardation market, it is markedly high in an extreme backwardation market. Falling and inadequate inventories in the latter regime increase the vulnerability of the market to economic and geopolitical developments and shocks, causing extreme oil price volatility (Considine et al., 2022; Considine and Aldayel, 2020).

Tran and Turvey (2022) differentiated between normal-contango, super-contango, and hyper-contango based on how small the spot price value is relative to the near-month futures price and whether the latter has a positive or negative value. Typically, investors expect higher future prices because of storage costs and foregone interest income. Accordingly, a normal-contango regime is more likely to occur when the market is relatively balanced (Nasdaq, 2023; Considine and Aldayel, 2020). However, super- and hyper-contango oil markets will likely occur under extreme conditions. A super-contango market is characterized by severe excess supply, which results in an erosion of storage capacity, causes the cost of carry to spike and the spot price to drop dramatically relative to the futures price, and increases the basis. This situation would persist if neither inventories are utilized, nor storage space capacity is increased (IG, n.d.; Razek and McQuinn, 2021; Tran and Turvey, 2022). The corresponding underlying economic fundamentals apply to the hyper-contango scenario. However, because storage availability is highly inelastic in the latter scenario, the cost of storage dramatically increases and the spot price or the near-month futures price can even turn negative (Tran and Turvey, 2022).

4. Data

4.1. Time period

We study the period from 2002M1–2022M10. At the time of writing, the earliest available data for the U.S. refinery utilization rate and OPEC production were from 2001M12 to 2002M1, respectively, and the latest observations for the same variables were from 2022M10. In economic terms, this period is informative for four reasons. First, Ha et al. (2023) have noted that the importance of global demand shocks and oil prices in explaining domestic inflation in advanced economies increased starting in 2001 relative to previous decades. Second, the year 2000 signifies the beginning of the 'new energy age,' characterized by high demand; for instance, in 2001, China joined the World Trade Organization (WTO), and the year 2005 saw the beginning of the so-called U.S. shale revolution (Considine et al., 2022). Third, the high oil prices in the early 2000s financed subsidies and investments into energy efficiency and limited carbon emissions policies in the U.S. (Economou, 2015), signifying the increasing importance of energy security and transition in the country. Fourth, this sample enables us to focus on the period when Russia became an emergent energy power (Hill, 2002). Although Russia's oil industry struggled during the economic crisis of the 1990s, Russia's interest in globally expanding its oil industry to regain world power through geopolitical influence on energy markets became a priority in the 2000s (Poussenkova, 2010).

4.2. *Data characteristics*

The gasoline inflation rate is computed as the contemporaneous (month-to-month) log difference of the U.S. retail gasoline price. The latter is the average price of all grades and all formulations (measured in USD per gallon). The retail gasoline price data are from the U.S. EIA (2022a). The data source for U.S. petroleum consumption is the U.S. EIA, and the variable was retrieved from CEIC (series SR123619047). The data source for the U.S. SPR is the U.S. EIA, and the variable was retrieved from CEIC (series SR636062). The data source for OPEC production is OPEC and the variable was retrieved from CEIC (series SR981331). The U.S. refinery utilization rate data source is OPEC, and the variable is from CEIC (series SR444748). The U.S. refinery utilization rate is reported as the share of the total capacity, whereas U.S. petroleum consumption, SPR, and OPEC production variables are in log terms.

We rely on the spot price and 6-month futures price on New York Harbor conventional gasoline regular spot price free on board (dollars per gallon). The spread is computed as the spot price subtracted from the futures price. The 12-month WTI spread is calculated analogously using the WTI spot price and the 12-month futures price (with prices in USD per barrel). Futures and spot prices refer to the last trading day (in NYMEX) of the month. All spot and futures prices were obtained from Refinitiv-DataStream.

All variables are adjusted for seasonality using the U.S. Census Bureau's X-13 seasonal adjustment and Cleveland et al.'s (1990) seasonal-trend decomposition methodology. Fig. 10 displays the plots of the (seasonally adjusted) variables employed in our estimation of gasoline inflation. While these plots do not raise concerns regarding multicollinearity or linear and quadratic trends, they suggest the existence of outliers. For unit root testing, we employed the augmented Dickey–Fuller (ADF), Phillips–Perron (PP), and Kwiatkowski–-Phillips–Schmidt–Shin (KPSS) tests. The unit root test results, as reported in Table 1, support the stationarity of the variables. Following the approach suggested by Enders (2023), we conducted the Broock–Deschert–Scheinkman (BDS) test, which uses a general alternative hypothesis to detect non-linearity, parameter instability, serial correlation, and structural breaks. The results of the BDS test (given in Table 2) indicate that the null hypothesis can be rejected. Hence, the graphical analysis and BDS test results suggest that the variables are non-linear.

Table 3 presents the Enders and Siklos (2001) threshold cointegration results for the variables of interest, when each variable is considered as the endogenous variable. These results enabled us to test for threshold cointegration and weak exogeneity. Testing for threshold cointegration enables us to determine the appropriateness of applying threshold techniques, while testing for weak exogeneity is adequate to determine the presence of a feedback effect between the variables (Enders, 2023), which could warrant applying a threshold vector autoregressive (TVAR) model instead of a single-equation threshold autoregressive (TAR) model. According to the results reported in Table 3, the null hypothesis of no threshold cointegration is rejected (i.e., the results suggest a non-linear cointegration relationship only when gasoline inflation is the endogenous variable). This result implies that gasoline inflation is not weakly exogenous to the variables of interest, and the opposite is true for the rest of the variables. In other words, the variables of interest are explanatory variables for gasoline inflation. Furthermore, the threshold cointegration test applies the Schwarz criterion for the lag length selection. The results in Table 3 show that the appropriate lag length is 2. Accordingly, we employ a 2-lag TAR model.

5. Empirical methodology

The possibility that the drivers of inflation are regime-dependent has been considered in previous estimations of hybrid open-economy New Keynesian Philips curves. For instance, Rumler (2007) employed Newey–West standard errors to deal with likely autocorrelation and heteroskedasticity issues associated with regime switching that arise due to changes in the exchange rate and monetary policies. Regarding capacity utilization, as a measure of the output gap, Chang and Emery (1997) stated that its impact is sensitive to changes in economic regimes. According to the theory of storage, the spread exhibits different dynamics in contango and backwardation regimes (Considine et al., 2022; Considine and Aldayel, 2020; Koy, 2017; Fattouh, 2009; Larson & DEC, 1994). In terms of the impact of geopolitical threats and actions on the role of oil as a financial asset (which is captured in our model by the WTI spread variable), Jiang et al. (2022) emphasized that major geopolitical events non-linearly affect crude oil markets. In the context of this study, applying a threshold empirical approach is consistent with examining the relationship between gasoline price inflation and the variables of interest across different oil market regimes under contango and backwardation statuses. From a statistical perspective, a threshold-based empirical approach is appropriate, given the data characteristics.

In view of these considerations, we employ a single equation threshold model to evaluate the impact of the U.S. SPR, refinery utilization rates, petroleum consumption, WTI and gasoline spread variables, and OPEC production on U.S. domestic gasoline inflation. We use the WTI spread as the threshold variable.

5.1. *Why a threshold autoregressive model?*

A distinctive feature of oil markets is market regimes; that is, periods of different degrees of misalignment between current and expected oil prices. From this standpoint, it is intuitive to consider the relationship

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[18] An ADF test is represented as follows: $\Delta y_t = \alpha + \beta y_t + \delta t + \gamma_1 \Delta y_{t-1} + \gamma_2 \Delta y_{t-2} + \bullet\bullet\bullet + \gamma_k \Delta y_{t-k} + \varepsilon_t$, where t is the time trend and α is a constant. "With a constant and without a time trend" is the case of a random walk without a drift (α is included). "With a constant, time trend not in regression" is the case of a random walk with a drift but without a time trend. "Unrestricted constant, time trend in regression" is the case when y_t follows a random walk with or without a drift; that is, α is unrestricted and t is included (Stata, 2019).

[19] The BDS does not perform well in small samples if the critical values are not bootstrapped (Enders, 2023).

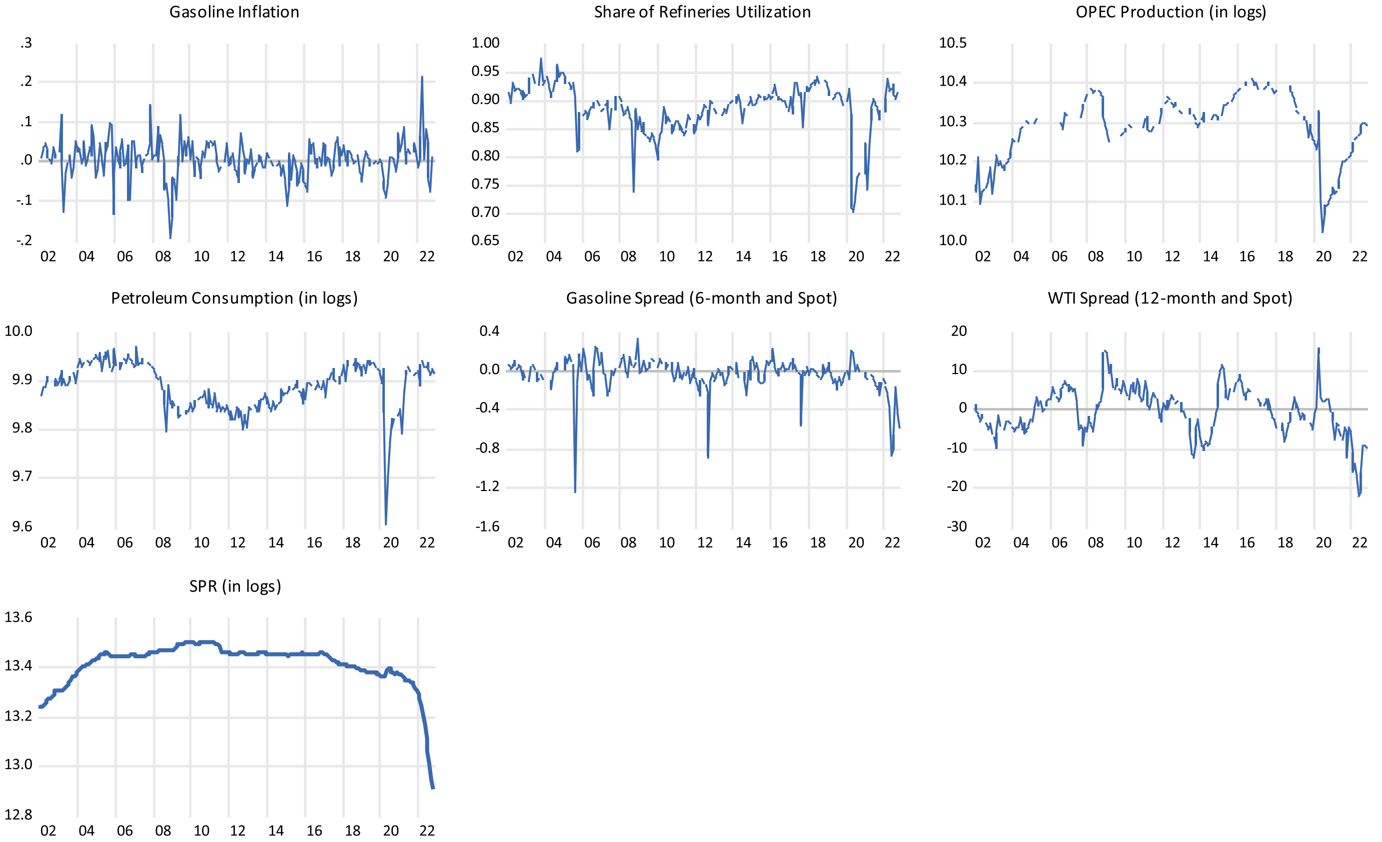

Fig. 10. Data.
Source: U.S. EIA; OPEC; CEIC; Refinitiv

Table 1
Unit Root Tests: Variables in levels.

Test	Null hypothesis			Gasoline inflation	Refinery Utilization Rate	OPEC Production	Petroleum consumption	Gasoline Spread (6m-spot)	WTI Spread (12m-spot)	SPR
ADF[18]	Null hypothesis: unit root	RW without a drift	Z(t)	***[0.000***]***	[0.6514]	[0.7774]	[0.7106]	***[0.000***]***	***[0.000***]***	[0.281]
		RW with a drift	Z(t)	***[0.000***]***	***[0.000***]***	[0.2583]	***[0.000***]***	***[0.000***]***	***[0.0126**]***	[0.999]
		RW with an unrestricted constant, time trend in regression	Z(t)	***[0.000***]***	***[0.000***]***	[0.5967]	***[0.002***]***	***[0.000***]***	***[0.0435**]***	[1.000]
GLS	Null hypothesis: unit root	Test statistic		***−10.316****	***−4.6617****	−1.4183	***−4.288****	***−8.44****	***−3.5****	0.216
		Minimum SIC		0	0	2	0	0	0	0
PP	Null hypothesis: unit root	RW with a constant and without a time trend	Z(t)	***[0.000***]***	***[0.003***]***	***[0.0968*]***	***[0.002***]***	***[0.000***]***	***[0.0136**]***	[0.999]
		RW with an unrestricted constant, time trend in regression	Z(t)	***[0.000***]***	***[0.000***]***	[0.3351]	***[0.008***]***	***[0.000***]***	***[0.046**]***	[1.000]
KPSS	Null hypothesis: level stationary	With a constant	LM-statistic	***0.129853****	***0.2228****	***0.27754****	***0.3238****	***0.452****	***0.264****	***0.526****
	Null hypothesis: trend stationary	With a constant and a linear trend	LM-statistic	***0.105829****	***0.153****	0.23697	0.226578	***0.1374***	***0.1822****	0.4295

P-values are reported in square brackets. Values not reported in square brackets are the t-statistic and LM-statistic values. Stationary variables are in bold italics. *, ** and *** indicate that a series is stationary at the 10%, 5%, and 1% significance levels, respectively. ADF: augmented Dickey–Fuller; GLS: generalized least squares; PP: Phillips–Peron; KPSS: Kwiatkowski, Phillips, Schmidt, and Shin; RW: random walk.

Table 2
BDS test (bootstrap probabilities[19]).

Dimensions	p-value						
	Gasoline inflation rate	Refinery Utilization Rate	OPEC production	Petroleum Consumption	Gasoline Spread (6m-spot)	WTI Spread (12m-spot)	SPR
2	***0.0000******	***0.0000******	***0.0000******	*0.1704*	***0.0000******	***0.0000******	***0.0000******
3	***0.0000******	***0.0000******	***0.0000******	***0.0960****	***0.0000******	***0.0000******	***0.0000******
4	***0.0000******	***0.0000******	***0.0000******	***0.0600****	***0.0000******	***0.0000******	***0.0000******
5	***0.0000******	***0.0000******	***0.0000******	***0.0264****	***0.0000******	***0.0000******	***0.0000******
6	***0.0000******	***0.0000******	***0.0000******	***0.0152****	***0.0000******	***0.0000******	***0.0000******

The null hypothesis indicates that the series is linear. Values in bold italics indicate rejection of the null hypothesis.
*, **, and *** indicate 10%, 5%, and 1% significance levels, respectively.

Table 3
Threshold Cointegration. Lags (determined by data): 2.

Variable	Gasoline inflation rate	Refinery Utilization Rate	OPEC production	Petroleum Consumption	Gasoline Spread (6m-spot)	WTI Spread (12m-spot)	SPR
T-max value:	***−4.875331***** ***(−3.150589)***	−1.86 (−3.164031)	−1.082 (−3.142267)	−1.189 (−3.154885)	−2.934508 (−3.150819)	−2.9967 (−3.1532)	1.932058 (−3.158106)
Threshold value (tau):	***0.036557***						
Coefficient							
Above Threshold	−0.8938	−0.14457	−0.055	−0.069	−0.369	−0.356	−0.2867
Below Threshold	−0.51829	−0.220	−0.130	−0.1899	−0.7013	−0.176	0.1207

The null hypothesis indicates no cointegration. The alternative hypothesis indicates threshold cointegration. The null hypothesis is rejected if the T-max value is more negative than the relevant critical value. A necessary condition for convergence is for both threshold coefficients to be negative (Enders and Siklos, 2001). Values in bold italics indicate rejection of the null hypothesis at the 5% significance level. Simulated critical values for a 5% significance level are in brackets. Number of simulations: 10,000.

between the SPR and gasoline inflation to be regime-dependent. Abstracting from the effects of regimes on the relationship is equivalent to ignoring non-linearity or using an incorrect non-linear specification, which could lead to poor estimation results (Enders, 2023).

The three main empirical approaches in the literature that take regimes into consideration are threshold autoregressive (TAR), smooth transition autoregressive (STAR), and Markov switching.[20] In the first two, the observed past values of the threshold variable define the regimes. If the lagged dependent variable is the threshold variable, the TAR model becomes a self-exciting TAR (SETAR) model (Tong, 1983). On one hand, if a smooth transition function is used in the latter model, it becomes a STAR model (Enders, 2023; Zivot and Wang, 2006); on the other hand, in the Markov switching approach, the threshold variable is unobservable (Potter, 1999).

In the framework of this study, storage theory identifies the crude oil futures and spot prices spread as an ideal threshold variable to separate oil market regimes. Therefore, we neither use the Markov switching approach nor a SETAR model because the threshold variable is neither unobservable nor the lagged dependent variable. A distinctive advantage of the TAR approach is that the switching variable is identified and observable and is not restricted to be the lagged dependent variable.

TAR techniques allow for abrupt breaks to be captured, whereas the STAR model assumes a smooth transition function across regimes. Considine and Aldayel (2020) found that the extent of volatility differs from one oil market structure to another and that the path from one regime to another is too complex to be described as stable. They explained that, when the market is in backwardation status, there is a higher probability of the status shifting from backwardation to extreme backwardation (characterized by extreme oil price volatility). Furthermore, the short duration of the extreme backwardation status suggests that the transition to this oil market regime is highly volatile. The abruptness of oil regime switches might become more marked in future years. Bordoff and O'Sullivan (2022) have raised concerns that the decrease in oil sector investments coupled with unabated and increasing demand will further exacerbate oil supply shortages and price volatility.

To further illustrate the abruptness of oil price movements, we note that, in 2022, the WTI oil price was approximately 83 USD/barrel in January (U.S. EIA, 2023). The February 2022 Russia–Ukraine conflict intensified geopolitical uncertainty regarding the global oil market and the associated natural gas market spillover effect (Fattouh et al., 2022; Reed, 2021). By early March 2022, the process of self-sanctioning followed by Western government sanctions on Russia's oil sector limited access to insurance and tankers, pushing the lion's share of Russia's supplies off limits and pulling the WTI oil price to 124 USD/barrel (U.S. EIA, 2023) in March (Courvalin et al., 2022; Smith, 2022). As the dust settled toward the end of the month, trading firms and banks had been looking into ways to continue Russian oil purchases without breaching sanctions, while friendly countries were accepting discounted Russian oil (Cahill, 2022; Fattouh et al., 2022; Payne, 2022; Tan, 2022). By September 2022, the WTI oil price was 84 USD/barrel (U.S. EIA, 2023). Even if supplies were relatively unaffected, the geopolitical and speculative risk premium due to increased uncertainty drove prices upward (Fattouh et al., 2022) and contributed to oil price volatility.

In view of these considerations, we employ a TAR model in this study because oil prices are volatile and the shift between oil market regimes could be abrupt (rather than smooth).

5.2. Estimation of a TAR model

Stigler (2012) argued that including the instrumental threshold variable as a regressor is essential for the TAR estimation. Accordingly, we apply a TAR-distributed lagged model which includes the WTI spread variable in the double role of regressor and threshold-defining variable. This type of TAR estimation technique is called an open-loop TAR system (Tong and Lim, 1980).

Threshold regression techniques capture data asymmetries and

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[20] According to Potter (1999), using Bayesian techniques for the marginal inference of coefficients would result in uncertainty about the threshold and affect the inferred coefficients. In view of these considerations, we implement the classical approach in this study.

abrupt breaks and extend linear regressions to allow for different regimes to have differing coefficients. A threshold variable separates multiple distinct regimes in a single model. While the entire sequence of each series in a model is non-linear, each series is linear in individual regimes (Enders, 2023).

Considering an observed threshold variable ω_t and associated value θ, a two-regime threshold regression can be represented, without loss of generality, by either of the following equations:

$$y_t = x_t\beta + z_t\alpha_1 I(\omega_t \leq \theta) + z_t\alpha_2 I(\theta < \omega_t) + \varepsilon_t, \tag{3}$$

or

$$y_t = C + x_t\beta + z_t\alpha_1 + \varepsilon_t \quad \text{if} \quad \omega_{t-d} \leq \theta, \tag{4}$$

$$y_t = C + x_t\beta + z_t\alpha_2 + \varepsilon_t \quad \text{if} \quad \theta > \omega_{t-d,}$$

where y_t is the dependent variable; C is a $k \times 1$ vector of constant terms; x_t is a $1 \times k$ vector of regime in-variant regressors, where β is a $k\times$ 1 vector of the associated parameters; z_t is a vector of regime-specific explanatory variables, where α_1 and α_2 are the relevant coefficients; and ω_t may be one of the regime-specific or regime in-variant variables, and must be pre-determined relative to ε_t. The shock ε_t is normally distributed with mean 0 and variance σ^2. As it may take time for the model to switch from one regime to another, the regression includes a delay parameter d, where $d = 1,2, \ldots$, which affects the threshold value ω_{t-d} and the time of the regime switch (Enders, 2023; Stata, 2019; Bai and Perron, 2003; Potter, 1999; Tong and Lim, 1980). In this study, we apply a pure threshold model, where the term $x_t\,\beta$ is excluded, whereas regime-specific variables are included. We do not include seasonal dummy variables in the model—which would have been included in x_t—because we use seasonally adjusted variables, as discussed in the Data Characteristics section. Regime 1 includes the subset of observations with $\omega_{t-d} \leq \theta$, and Regime 2 includes the subset of observations when $\omega_{t-d} > \theta$.

Equation (3) represents the case when the variance of ε_t is the same across regimes, while Equation (4) illustrates the case when the variances are heterogeneous. The error distribution may be heterogeneous across regimes, provided that breaks in ε_t and the parameters occur on the same dates (Bai and Perron, 2003), implying that each regime's ε_t is independent (Tong and Lim, 1980). In our estimation, we consider both the case when the error distribution is similar and when it is heterogeneous across regimes.

Estimating the threshold value is complex, due to its non-standard asymptotic distribution. The threshold value, delay parameter, and order of autoregression are unknown. Conditional least squares estimation is repeatedly conducted for each of those discrete parameters. To ensure sufficient observations in individual regimes, we exclude the top and bottom 15% of the total T observations, rendering T_1 observations. Least-squares regressions of the two-regime model illustrated in Equations (3) and (4) are conducted for a succession of T_1 values of the threshold variable ω_t. The appropriate estimated threshold value, the associated appropriate delay parameter, and lag length are derived from the least-squares estimation with the smallest SSR, as the regression with the minimum SSR has been shown to provide a consistent threshold estimate (Enders, 2023; IHS Markit, 2019; Stata, 2019; Potter, 1999; Hansen, 1997).

A threshold regression model with j threshold values has $j+$ 1 regimes, where j indexes potential threshold values. To identify the number of regimes, we conduct the Bai–Perron test (Bai and Perron, 1998, 2003; Stata, 2019) and estimate a two-regime model and the associated threshold value that minimizes the SSR. Then, we utilize that threshold to successively search for additional threshold values that minimize the SSR and point to the existence of other regimes. The process is repeated until the potential small SRR values are not significantly different and the appropriate number of thresholds is reached.

6. Results

6.1. Results and robustness checks

6.1.1. TAR model

The threshold cointegration results presented in Table 3 suggest that allowing for a lag length of 2 in the TAR model is appropriate. Although the variables in Fig. 10 do not display evidence of multicollinearity, evaluating the gasoline inflation model (i.e., Equation (2)) with the variables of interest in levels and accounting for two lags introduces multicollinearity. We then compute the correlation values between the variables in level and lags and conduct variance inflation factor (VIF) tests to identify the problematic variables. Next, following a general-to-specific approach, we apply the Wald test for various variable combinations and a series of coefficient restrictions to establish the appropriate number of lags for each variable in the model and reach specifications that pass all diagnostic tests and do not suffer from multicollinearity.[21]

These steps suggest including petroleum consumption, the WTI spread, and the SPR variable (all in levels); the second lag of the refinery and petroleum consumption variables; the first lag of OPEC production; and the first and second lags of the gasoline inflation and gasoline spread in the model. Using these variables, the model (denoted Model B) passes all diagnostic tests except for heteroscedasticity, which is marginally significant at the 10% significance level. When estimating the model replacing the first lag of OPEC with its second lag (denoted Model A), we do not find evidence of multicollinearity, the model passes all diagnostic tests, and there is no evidence of heteroscedasticity in errors for all significance levels.[22] We note that the SSR value is about 12% lower for Model A than for Model B. The results for the model that passes all diagnostic tests and has the smaller SSR (Model A) are reported in Panel A of Table 4. Henceforth, we refer to Model A as the benchmark model. The results for Model B are shown in Panel B of the same table. In the untabulated findings, we note virtually no changes in the results for Models A and B when we allow the error distribution to be heterogeneous across breaks. For the sake of brevity, only the results obtained under the assumption that the error distribution is the same across regimes are reported.[23]

In Panel C of Table 4, we report the results for a variation of Model A using the first lag of gasoline inflation, instead of the first and second lags (denoted Model C). Following Rumler (2007), we gauge the price inflation of intermediate goods by using the import price index for mineral fuels, oil, and residuals. The inflation rates for gasoline and the relevant intermediate goods are plotted in Fig. 11. Comparison of the curves shows that the two variables tend to move in tandem. In Panel D of Table 4, we report the results for a variation of Model C obtained by replacing the first and second lags of gasoline inflation with the first lag of intermediate goods inflation (denoted Model D). Model D passed the diagnostic tests when replacing the second lag of OPEC with the first lag of the variable. Models C and D (reported in Panels C and D, respectively) pass all diagnostic tests when the error distribution is the same across breaks, but not in the case of heterogeneous error distribution across breaks.

The selection of the number of lags for the variables employed in Models A-D aligns with the previously mentioned Wald test results. The four models passed all diagnostic tests. The CUSUM of squares test results, depicted in Fig. 12, indicate that all presented models are stable.

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[21] The correlation, VIF, and Wald test results are available from the authors upon request.

[22] Using the second lag of the OPEC production and U.S. refinery utilization rates could raise concerns about multicollinearity. However, the correlation between the two variables was not excessive, at 0.369.

[23] The case when errors are heterogeneous across breaks is available from the authors upon request.

Table 4
TAR results.

Panel A

	Extreme backwardation		Normal-backwardation	Normal-contango	Extreme contango	
	Hyper-backwardation	Super-backwardation			Super-contango	Hyper-contango
Threshold value for $WTI\_sprd\_12m\_spot_t$	Spread < −5.264278	−5.264278 ≤ spread < −3.241551	−3.241551 ≤ spread < −0.725622	−0.725622 ≤ spread <2.441339	2.441339 ≤ spread <5.411762	5.411762 ≤ spread
Variables/Number of observations	39	38	37	42	53	38
gas_infl_{t-1}	***−0.142***	0.096	0.137	***0.446***	***0.309***	0.133
	[0.087]*	[0.2514]	[0.3655]	[0.000]***	[0.000]***	[0.51]
gas_infl_{t-2}	0.175	0.1315	−0.313	***−0.65***	−0.067	−0.003
	[0.2544]	[0.3045]	[0.1482]	[0.001]***	[0.543]	[0.9836]
ref_utlz_{t-2}	***−0.5057***	***−0.293***	***−0.487***	0.3768	0.022	***0.453***
	[0.0238]**	[0.0146]**	[0.000]***	[0.1405]	[0.929]	[0.033]**
$opec\_prod_{t-2}$	−0.112	***−0.3256***	***0.117***	***−0.29***	−0.038	***−0.625***
	[0.1855]	[0.000]***	[0.07]*	[0.000]***	[0.6825]	[0.000]***
$pet\_consump_t$	***1.636***	0.0108	***0.7789***	0.1975	***0.25***	−0.09
	[0.0315]**	[0.9708]	[0.0822]*	[0.1819]	[0.0508]*	[0.5974]
$pet\_consump_{t-2}$	−1.377	***0.7697***	−0.349	−0.332	−0.009	−0.168
	[0.1102]	[0.0013]***	[0.2619]	[0.112]	[0.967]	[0.646]
$gas\_sprd\_6m\_spot_{t-1}$	***0.062***	0.0296	***0.159***	***−0.059***	0.0008	0.0115
	[0.0051]***	[0.6159]	[0.0101]**	[0.000]***	[0.9724]	[0.9042]
$gas\_sprd\_6m\_spot_{t-2}$	***0.095***	***0.2796***	0.086	−0.018	−0.013	***0.225***
	[0.000]***	[0.000]***	[0.1249]	[0.5368]	[0.787]	[0.024]**
$WTI\_sprd\_12m\_spot_t$	***−0.005***	0.0014	−0.0045	−0.0143	***−0.012***	***−0.0115***
	[0.000]***	[0.848]	[0.4716]	[0.0315]	[0.003]***	[0.06]*
SPR_t	***−0.098***	***0.483***	−0.05	***0.49***	0.195	0.35
	[0.0562]*	[0.000]***	[0.6582]	[0.005]***	[0.225]	[0.425]
LM test; H_0: no serial autocorrelation - 12 lags	[0.644]	**Normality test (Jarque Bera)**	[0.2871528]	**SSR**	0.17006	
White test (H_0: homoskedasticity)	[0.1905]	**H_0: No ARCH**	[0.4376]	**AIC**	−3.908698	
Threshold significance level	0.05	**Delay parameter**	0	**BIC**	−2.97096	
Coefficient covariance matrix	HAC (Newy–West): same errors across breaks			**HQIC**	−3.53116	

Panel B

Threshold value for $WTI\_sprd\_12m\_spot_t$	spread < −5.228414	−5.228414 ≤ spread< −0.8127654	−0.8127654 ≤ spread< 2.441339	2.441339 ≤ spread <5.411762	5.411762 ≤ spread
Variables/Number of observations	41	72	43	53	38
gas_infl_{t-1}	−0.10123	***0.3613***	***0.4378***	***0.31***	0.176
	[0.224]	[0.000]***	[0.000]***	[0.000]***	[0.404]
gas_infl_{t-2}	0.1917	−0.1373	***−0.563***	−0.066	0.029
	[0.1997]	[0.308]	[0.002]***	[0.542]	[0.85]
ref_utlz_{t-2}	***−0.5238***	***−0.227***	***0.462***	0.009	***0.432***
	[0.007]***	[0.029]**	[0.09]*	[0.971]	[0.046]**
$opec\_prod_{t-1}$	−0.0839	−0.036	***−0.336***	−0.029	***−0.49***
	[0.2567]	[0.6818]	[0.002]***	[0.767]	[0.019]**
$pet\_consump_t$	***1.624***	0.034	−0.022	***0.244***	−0.186
	[0.024]**	[0.912]	[0.888]	[0.056]*	[0.294]
$pet\_consump_{t-2}$	***−1.39***	0.289	−0.128	0.003	−0.107
	[0.099]*	[0.2488]	[0.445]	[0.989]	[0.778]
$gas\_sprd\_6m\_spot_{t-1}$	***0.0618***	***0.0779***	***−0.058***	0.002	0.03
	[0.008]***	[0.054]*	[0.000]***	[0.945]	[0.75]
$gas\_sprd\_6m\_spot_{t-2}$	***0.095***	***0.1105***	−0.015	−0.013	***0.23***
	[0.0016]***	[0.0379]**	[0.519]	[0.7819]	[0.027]**
$WTI\_sprd\_12m\_spot_t$	***−0.0044***	***−0.011***	***−0.013***	***−0.012***	***−0.013***
	[0.001]***	[0.0045]***	[0.03]**	[0.003]***	[0.07]*
SPR_t	***−0.1138***	0.135	***0.46***	0.19	0.3
	[0.039]**	[0.326]	[0.0102]**	[0.22]	[0.549]
LM test; H_0: no serial autocorrelation - 12 lags	[0.5933]	**Normality test (Jarque Bera)**	[0.416528]	**SSR**	0.19304
White test (H_0: homoskedasticity)	[0.099]*	**H_0: No ARCH**	[0.5658]	**AIC**	−3.87099
Threshold significance level	0.05	**Delay parameter**	0	**BIC**	−3.089557
Coefficient covariance matrix	HAC (Newy–West): same errors across breaks			**HQIC**	−3.55638

Panel C

Threshold value for $WTI\_sprd\_12m\_spot_t$	spread < −5.228414	−5.228414 ≤ spread < −0.8127654	−0.8127654 ≤ spread <2.450591	2.450591 ≤ spread <5.411762	5.411762 ≤ spread
Variables/Number of observations	42	72	44	52	38
gas_infl_{t-1}	−0.074	***0.342***	***0.388***	***0.3***	0.173
	[0.456]	[0.000]***	[0.0046]***	[0.000]***	[0.3973]
ref_utlz_{t-2}	***−0.47***	***−0.19***	***0.817***	0.0365	***0.42***
	[0.0107]**	[0.047]**	[0.0175]**	[0.8695]	[0.0292]**

(continued on next page)

Table 4 (*continued*)

Panel C					
$opec\_prod_{t-1}$	***−0.123***	−0.03	***−0.413***	−0.0323	***−0.507***
	[0.04]**	[0.715]	***[0.0044]******	[0.7385]	***[0.0167]*****
$pet\_consump_{t}$	***1.47***	−0.039	−0.073	0.1878	−0.184
	[0.013]**	[0.887]	[0.6468]	[0.2414]	[0.3024]
$pet\_consump_{t-2}$	***−1.165***	0.29	***−0.351***	0.0638	−0.1205
	[0.08]*	[0.224]	***[0.0244]*****	[0.8042]	[0.7358]
$gas\_sprd\_6m\_spot_{t-1}$	***0.07***	***0.075***	***−0.058***	0.0064	0.0315
	[0.000]***	***[0.0506]****	***[0.000]******	[0.7861]	[0.7461]
$gas\_sprd\_6m\_spot_{t-2}$	***0.076***	***0.1115***	−0.0025	−0.0187	***0.224***
	[0.000]***	***[0.0189]*****	[0.919]	[0.6978]	***[0.0438]*****
$WTI\_sprd\_12m\_spot_{t}$	***−0.005***	***−0.011***	***−0.012***	***−0.0115***	***−0.013***
	[0.000]***	***[0.0108]*****	***[0.0238]*****	***[0.003]******	***[0.0237]*****
SPR_{t}	***−0.076***	0.102	0.252	0.1957	0.279
	[0.017]**	[0.4739]	[0.1463]	[0.1981]	[0.5373]
LM test; H$_0$: no serial autocorrelation - 12 lags	[0.8884]	**Normality test (Jarque Bera)**	[0.17304]	**SSR**	0.20718
White test (H$_0$: homoskedasticity)	[0.2589]	**H$_0$: No ARCH**	[0.5744]	**AIC**	−3.8465
Threshold significance level	0.05	**Delay parameter**	0	**BIC**	−3.13815
Coefficient covariance matrix	HAC (Newy–West): same errors across breaks			**HQIC**	−3.56135

Panel D				
Threshold value for $WTI\_sprd\_12m\_spot_{t}$	Spread < −5.220912	−5.220912 ≤ spread < −0.6409345	−0.6409345 ≤ spread <5.411762	5.411762 ≤ spread
Variables/Number of observations	42	74	94	38
$intermdiate\_goods\_infl_{t-1}$	0.004	***0.2798***	***0.188***	***0.25***
	[0.9665]	***[0.000]******	***[0.000]******	***[0.019]*****
ref_utlz_{t-2}	***−0.394***	***−0.21***	***0.335***	0.395
	[0.0589]*	***[0.087]****	***[0.0307]*****	[0.1243]
$opec\_prod_{t-2}$	***−0.153***	−0.09	***−0.124***	***−0.394***
	[0.0358]**	[0.1978]	***[0.0891]****	***[0.0691]****
$pet\_consump_{t}$	***1.43***	−0.062	−0.071	0.226
	[0.000]***	[0.7859]	[0.5978]	[0.2093]
$pet\_consump_{t-2}$	***−1.215***	0.34	−0144	0.094
	[0.000]***	[0.1086]	[0.3275]	[0.755]
$gas\_sprd\_6m\_spot_{t-1}$	***0.075***	***0.089***	***−0.048***	0.065
	[0.086]*	***[0.0718]****	***[0.011]*****	[0.3409]
$gas\_sprd\_6m\_spot_{t-2}$	***0.068***	***0.102***	−0.0076	***0.238***
	[0.0938]*	***[0.0126]*****	[0.6835]	***[0.000]******
$WTI\_sprd\_12m\_spot_{t}$	***−0.005***	***−0.01***	−0.002	***−0.009***
	[0.000]***	***[0.0008]******	[0.4453]	***[0.006]******
SPR_{t}	−0.079	***0.194***	***0.21***	0.118
	[0.692]	***[0.066]****	***[0.0754]****	[0.7631]
LM test; H$_0$: no serial autocorrelation - 12 lags	[0.4426]	**Normality test (Jarque Bera)**	[0.1355]	**SSR** 0.2049
White test (H$_0$: homoskedasticity)	[0.1206]	**H$_0$: No ARCH**	[0.112]	**AIC** −3.938
Threshold significance level	0.05	**Delay parameter**	0	**BIC** −3.3715
Coefficient covariance matrix	Ordinary: heterogeneous errors across breaks			**HQIC** −3.71006

Values in bold italics indicate the significance of the variable and rejection of the null hypothesis, with *, **, and *** indicating 10%, 5%, and 1% significance levels, respectively. P-values are reported in square brackets.

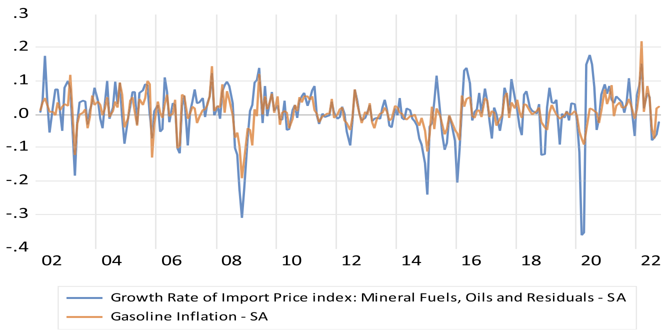

Fig. 11. Gasoline and intermediate goods inflation rates (SA).
Source: U.S. EIA (2022a), U.S. Bureau of Labor Statistics retrieved from CEIC (series SR679777).

Model A (i.e., the benchmark model) exhibited the smallest SSR value of the four models. The test results for selecting the number of regimes and thresholds in the benchmark model are reported in Tables 5 and 6.

We repeat the estimation of the benchmark model after substituting the price of the front-month futures for the spot price in the spreads of the WTI and gasoline; that is, replacing the spreads (WTI_sprd_12m_spot) and (gas_sprd_6m_spot) with the spreads (WTI_sprd_12m_1m) and (gas_sprd_6m_1m), respectively. The results are robust to such a change, but the SSR increases relative to the benchmark model. Furthermore, using the front-month futures to calculate the spreads in Models B–D support the robustness of the results for the benchmark model. For the sake of space, the results obtained using the front-month futures instead of the spot prices are not included here (available from the authors upon request).

All the models reported in Table 4 show a break that differentiates backwardation from contango oil market regimes. This break takes place when the threshold variable, $WTI\_sprd\_12m\_spot_{t}$, is very close to zero, approximately equal to −0.72 (Panel A), −0.8 (Panels B and C), or −0.64 (Panel D).

Models B–D (Panels B–D) indicate two regimes within the backwardation oil market, whereas Model A in Panel A shows three. In Models B–D, one regime occurs when the WTI spread variable is smaller than −5.2, and the other occurs when the threshold variable is between −5.2 and −0.8 (Panel B and C) or between −5.2 and −0.6 (Panel D). This latter regime is broken down into two regimes in Panel A, such that one regime depicts the status when the threshold variable is between −5.2 and −3.2 and the other between −3.2 and −0.7. The results

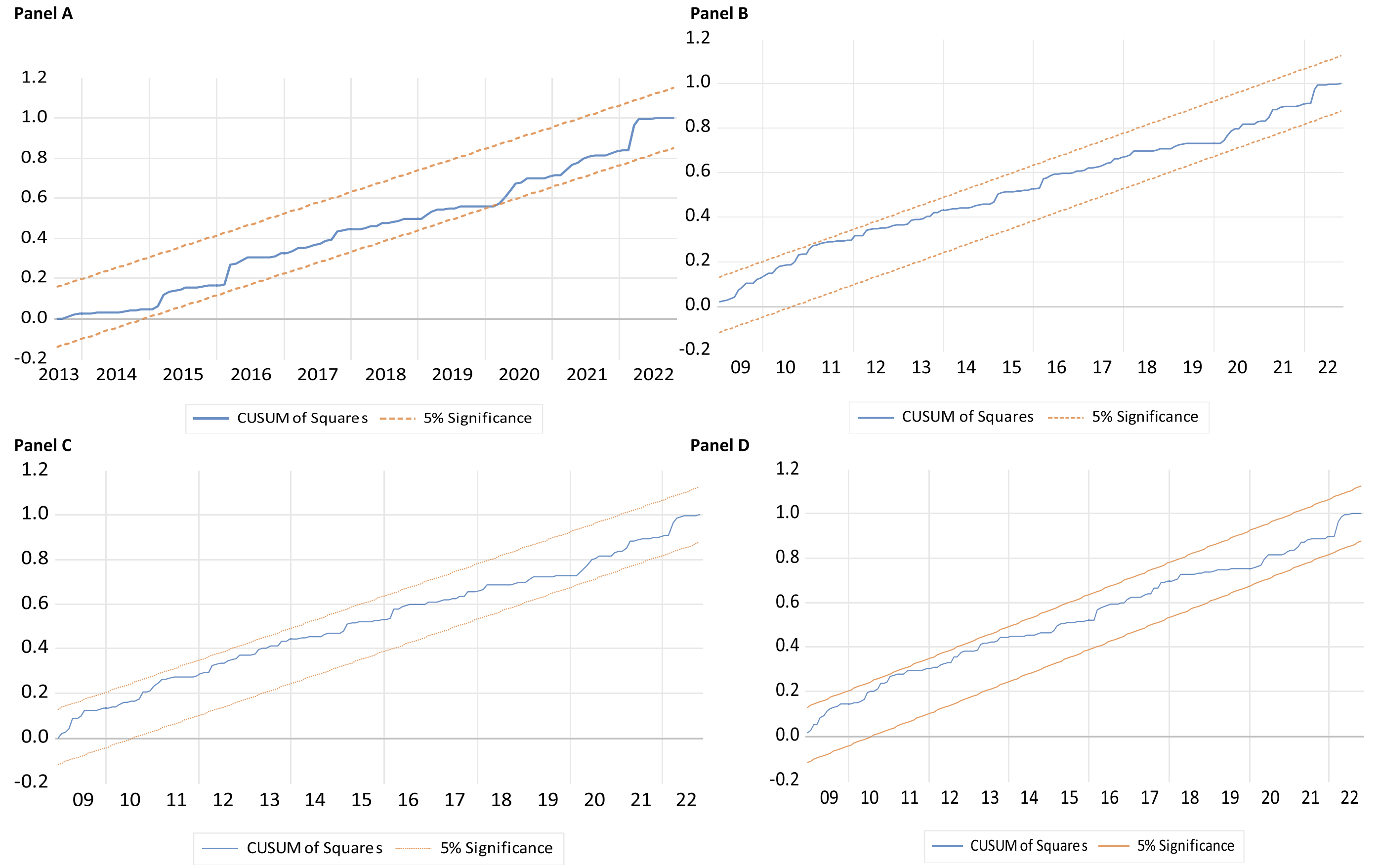

Fig. 12. Cusum of squares test results.[24].

Table 5
Model selection criteria for benchmark model.

Model	SSR	Regimes
WTI_SPRD_12_SPOT_SA	0.170061	6
WTI_SPRD_12_SPOT_SA(-1)	0.227528	4
WTI_SPRD_12_SPOT_SA(-4)	0.242337	4
WTI_SPRD_12_SPOT_SA(-3)	0.256198	3
WTI_SPRD_12_SPOT_SA(-6)	0.263658	3
WTI_SPRD_12_SPOT_SA(-2)	0.266830	3
WTI_SPRD_12_SPOT_SA(-5)	0.305030	2

Table 6
Multiple threshold tests: Bai–Perron tests of L+1 vs. L sequentially determined thresholds for Benchmark Model.

Sequential F-statistic determined thresholds: 5

Threshold Test	Scaled F-statistic	Critical Value**
0 vs. 1 *	71.88898	27.03
1 vs. 2 *	106.3383	29.24
2 vs. 3 *	64.03186	30.45
3 vs. 4 *	59.65461	31.45
4 vs. 5 *	39.28630	32.12

reported in Panels A–C of Table 4 suggest that, when the two regimes are combined in Models B and C, the effects of some variables across the separated regimes offset each other and accordingly appear insignificant in the combined regime. Also, combining the two regimes amplifies the effect of other variables.[25]

Based on the results of the benchmark model, we hereafter refer to the regime as hyper-backwardation when the spread is lower than −5.2, super-backwardation when the spread is between −5.2 and −3.2, and normal backwardation when the spread is between the values −3.2 and 0.7. The same applies to the equivalent regimes in Panels B–D.

Regarding the contango oil market, Panels A–C show three regimes, while Panel D identifies two regimes. The three regimes in the benchmark model (Panel A) are defined such that the thresholds take the following values: −0.7, 2.4, and 5.4. These threshold values are approximately the same in Panels B and C. In Panel D, however, the first two regimes of a contango market are combined, with the thresholds taking the values of −0.6 and 5.4. However, the differences between contango regimes across the models did not seem to affect the stability of the results.

Based on the results of the benchmark model, henceforth, the regime when the spread is above 5.4 is referred to as hyper-contango, the regime when the spread is between 2.4 and 5.4 is termed super-contango, and the regime when the spread is between −0.7 and 2.4 is identified as the normal-contango regime. The same applies to the equivalent regimes in Panels B–D. Apart from variations driven by differences in the number of regimes, the results of Models A–D are substantially consistent in terms of the sign and significance of the

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[24] The cumulative sum of squares is within the 5% significance lines, implying the residual variance is stable.

[25] For instance, the SPR variable is insignificant in the second regime in Panels B–C, marginally significant in Panel D, and significant in Panel A when the threshold variable is between −5.2 and −3.2. Furthermore, although the lagged inflation rate and the WTI spread variables are significant in the second regime in Panels B–D, they become insignificant when the regime is separated into two regimes in Panel A. The opposite is true for OPEC production and petroleum consumption, which are insignificant in the second regime of Panels B–D and significant when the regime is broken down into two regimes in Panel A. The results for the gasoline spread variables remain unaffected.

coefficients. As all models pass the diagnostic tests, we take these results as evidence that the benchmark model (Model A) provides more nuanced insights into the drivers of gasoline inflation than Models B–D.

The results in the benchmark model are symmetric, with three regimes for each of the contango and backwardation statuses. The threshold value identifying hyper from super oil market regimes is approximately equal to 5 in absolute value for both the contango and backwardation statuses. Furthermore, the threshold values (in absolute value) that distinguish normal from extreme cases in the contango and backwardation statuses are also relatively close. In line with the theory, the number of total observations in all three contango regimes is higher than that for the three backwardation regimes. Relying on the literature, we present a loose matching (by year) between the oil market regimes identified by the benchmark model and the associated events in Table 7.

6.1.2. *Granger causality*

The Granger causality test indicates whether a variable provides statistically significant information to forecast another variable. When used along with the weak exogeneity test (in Table 3), it indicates whether a variable is strongly exogenous. We use these tests in combination to provide additional evidence of the appropriateness of estimating a single-equation model.

The results shown in Table 3 suggest that all variables are weakly exogenous, except for gasoline inflation. Accordingly, utilizing a single-equation TAR model with gasoline inflation as the endogenous variable is considered appropriate. The results also show that the SPR is weakly exogenous to OPEC production, implying that the former does not affect the latter.

Having identified the number of regimes and the associated threshold values in the benchmark model (Table 4, Panel A), we conduct Granger causality tests (reported in Table 8) in order to further examine the strong exogeneity (weak exogeneity and Granger non-causality) of the variables of interest to gasoline inflation, as well as the strong exogeneity of the SPR to OPEC production. Regarding the relationship between gasoline inflation and the variables of interest, the results in Tables 3 and 8 demonstrate that most variables are strongly exogenous, further supporting the use of a single-equation TAR estimation technique.

According to Razek and Michieka (2019), OPEC balances the global oil market, OPEC production is primarily driven by global demand (which is impacted by U.S. production) and, although OPEC production could explain a larger portion of oil price variations than U.S. production at longer horizons, the reverse is true at shorter horizons. Following the same line of thought, we test the Granger causality regarding whether SPR affects OPEC production and the price of imported intermediate input prices. Table 8 also clearly supports the strong exogeneity of U.S. SPR with respect to OPEC production. Table 8 also shows that SPR only Granger causes price inflation of intermediate goods when the market is relatively balanced (i.e., under normal rather than extreme regimes).

6.2. *Interpretation of the results*

In this sub-section, we comment on the benchmark model results reported in Table 4, Panel A, in the context of the new Keynesian hybrid open-economy Philips curve and the theory of storage. Our discussion focuses on highly significant variables (i.e., those at the 5% and 1% significance levels).

The threshold regression approach utilized in this study allows for the identification of normal regimes as well as extreme oil market regimes (including, hyper-backwardation and hyper-contango). Before providing a detailed interpretation of the TAR analysis results, we briefly summarize our findings by stating that the empirical analysis provides broad support for the White House hypothesis, with the crucial exception of hyper-backwardation and hyper-contango regimes.

For the hyper-contango regime, we link the results in this sub-section to the 2020 COVID-19 crisis, when applicable. From the perspective of

Table 7
Extreme backwardation and contango markets (benchmark model) and relevant events.

	Extreme-backwardation		Extreme-contango		Remarks
	Super	Hyper	Super	Hyper	
2002	✓	✓			The oil market was in backwardation status from 1994 to 2005 (Chincarini and Moneta, 2021). The early 2000s marked the start of the 'new energy age,' characterized by high demand (Considine et al., 2022) and the emergence of Russia as a global energy power (Hill, 2002). In 2001, China joined the WTO (Considine et al., 2022). The increase in global crude oil demand was coupled with geopolitical instability created by the September 11, 2001 attacks and the consequent "war on terror," which included the U.S. military invasion of Afghanistan (2002) and Iraq (2003) (Hinnebusch, 2007; Sinno, 2010). Furthermore, in December 2002 and January 2003, Venezuela's oil exports plunged due to a general strike (Parraga, 2020; Billig, 2004).
2003	✓	✓			
2004	✓	✓			
2005	✓		✓		The 2005 spike in crude oil prices prompted U.S. legislators to approve the Energy Policy Act (Kemp, 2015), which incentivizes energy production. For an overview on the 2005 Energy Policy Act, refer to IEA (2021). Moreover, Hurricane Katrina occurred in 2005 (Bamberger and Kumins, 2005).
2006			✓	✓	The oil market was in contango status for most of the period from 2006 to 2017, due to pressure from speculators in the futures market when the oil market was exposed to equity market changes (Chincarini and Moneta, 2021). In 2005, the U.S. shale revolution started (Considine et al., 2022). According to Goldman Sachs, as Kaminska (2008) reported, limited spare storage capacity was a concern in 2006.
2007	✓	✓	✓	✓	Sharp changes in speculative behavior, reflecting changing conditions in financial markets in the post-2004 period characterized by the financialization of commodity markets (Prokopczuk et al., 2019).
2008	✓	✓	✓	✓	The Great Financial Crisis was a period of extreme instability for the oil market (Joo et al., 2020; Prokopczuk et al., 2019), as actual and expected oil prices mirrored surging levels of economic and financial uncertainty.
2009			✓	✓	The oil market was in super-contango status in late 2008 and early 2009. The demand had dropped—relative to supply—due to the financial crisis (Tran and Turvey, 2022; Longley and Blas, 2020). During this crisis, limited spare storage capacity was not an issue. However, the liquidity
2010			✓	✓	

(continued on next page)

Table 7 (*continued*)

	Extreme-backwardation		Extreme-contango		Remarks
	Super	Hyper	Super	Hyper	
					preference and restricted access to credit prompted economic agents to expect a premium to sell oil in the future (Kaminska, 2008). Between 2008 and 2010, risk appetites changed fundamentally and, consequently, the relative returns and risk for oil investments became relatively similar to those for stocks (Razek and Michieka, 2019).
2011	✓		✓		The Arab Spring, Libya civil unrest, and geopolitical tensions due to the Iranian nuclear program increased oil market uncertainty (Ebrahim et al., 2014; Darbouche and Fattouh, 2011; Stevens, 2011).
2012			✓		Ample non-OPEC supplies into the market were coupled with the sluggish global petroleum demand intensified by the Euro-zone sovereign debt and concerns about likely associated consequences on the global economy. Meantime, OPEC maintained its production levels (Economou, 2015).
2013	✓	✓			Between November 2013 and March 2015, OPEC's strategy was to defend its market share (Fattouh and Economou, 2018) by maintaining its production levels.
2014	✓	✓		✓	Persistent volatility in oil markets and rapid expansion of oil supply from unconventional sources were accompanied by strong price drops since mid-2014 due to OPEC abandoning its price support policy (Kilian, 2016; Baffes et al., 2015). The price of oil went through a full cycle between 2014 and 2017, shifting from backwardation in early 2014 to contango in the second half then back to backwardation in the second half of 2017 (Jesse, 2018).
2015			✓	✓	The market was in a super-contango state in 2015 (Longley and Blas, 2020). Amid the unprecedented boom in U.S. tight oil production, the U.S. added 2.16 million barrels per day to an already saturated global market between 2013 and 2014. The U.S. production increase was associated with weak growth in global petroleum demand (Economou, 2015). OPEC followed a high-production low-price approach in 2014–2015 to drive high-cost producers out of the market (Fattouh and Economou, 2018; Economou, 2015). In 2016, oil prices collapsed. By the end of 2016, Saudi Arabia signed the Declaration of Cooperation with non-OPEC producers, in order to stabilize the market (OPEC, 2021b).
2016			✓	✓	
2017	✓		✓		OPEC+ extended production cuts to support prices (Jesse, 2018; OPEC, 2017).
2018	✓	✓	✓		The escalation of the U.S.–China Trade war raised concerns about a decrease in global petroleum demand (Perkins, 2018).
2019	✓				Saudi Arabia's vital oil infrastructure was attacked with drones and missiles (Razek and McQuinn, 2021).
2020			✓	✓	Razek and McQuinn (2021) and Longley and Blas (2020) documented the occurrence of extreme-contango markets in 2020. Amid the 2020 oil supply shock and the COVID-19-induced demand shock, the crude oil market was over-satisfied and the spare storage capacity plunged, causing spot prices to drop and storage costs to skyrocket. This extreme situation prompted contract holders—who wanted to avoid physical delivery—to exit before the expiration of their positions. Those who could not find buyers paid counterparties to take oil delivery. Unprecedentedly, on April 20, 2020, WTI near-month futures prices traded below 0, reaching −40.32 USD/barrel (U.S. EIA, 2020).
2021	✓	✓			Amid the COVID-19 recovery, the increase in international crude oil demand was not coupled with a similar increase in global crude oil production and investments. The global oil market was already tight in late 2021 and early 2022. The Russia–Ukraine Conflict intensified shortages and exacerbated uncertainties (Razek and McQuinn, 2022).
2022		✓			

understanding the potential role of the SPR in moderating gasoline inflation, the hyper-backwardation regime is obviously more relevant than the hyper-contango regime and, thus, hyper-backwardation warrants the focus of a separate final discussion presented in the following section. Insights on such market conditions are offered by the recent 2022 geopolitical shocks, a period during which the oil market structure has been referred to by several scholars as in strong, super, extreme, and severe backwardation (Currie, 2022; Lewis et al., 2022; Salzman, 2022).

6.2.1. *WTI spread*

Changes in the WTI spread appear not to affect gasoline inflation in normal markets, possibly reflecting the ability of investors to hedge business-as-usual oil price fluctuations. When the spread is significant, its coefficient is negative—a result that is consistent with our predictions. One can interpret this result in terms of the link between the spread and the cost of storage. For instance, during backwardation oil market regimes (characterized by excess demand), a premium is paid to discourage storage, which drives WTI spot prices upward and contributes to gasoline inflation. Meanwhile, the increase in spot price (relative to the futures price) causes the value of the WTI spread to decrease. An analogous line of thought applies to contango regimes.

6.2.2. *Gasoline spread*

The spread between the 6-month gasoline futures and the gasoline spot is included in the empirical specification with two lags. Both lagged

Table 8
Granger causality results.

		Extreme backwardation		Normal-backwardation	Normal-contango	Extreme contango	
		Hyper-backwardation	Super-backwardation			Super-contango	Hyper-contango
First: ***H0: The following variables do not Granger cause Gasoline inflation***							
Refinery Utilization Rate	2 lags	[0.939]	[0.783]	[0.667]	[0.817]	[0.884]	***[0.037]*****
OPEC Production	2 lags	[0.740]	***[0.008]******	***[0.037]*****	[0.958]	[0.959]	[0.140]
Petroleum Consumption	2 lags	[0.468]	[0.608]	[0.583]	[0.615]	[0.963]	***[0.001]******
Gasoline price Spread	2 lags	***[0.002]******	[0.880]	[0.869]	[0.826]	[0.897]	***[0.047]*****
WTI price Spread	2 lags	[0.358]	[0.295]	***[0.048]*****	***[0.096]****	***[0.064]****	***[0.000]******
SPR	2 lags	***[0.005]******	***[0.004]******	***[0.009]******	***[0.095]****	[0.861]	[0.847]
Second: ***H0: SPR does not Granger cause OPEC Production***							
	2 lags	[0.167]	[0.509]	[0.539]	[0.439]	[0.394]	[0.890]
Third: ***H0: SPR does not Granger cause mineral fuels, oil, and residuals import price inflation***							
	2 lags	[0.130]	[0.199]	***[0.012]*****	***[0.045]*****	[0.1358]	[0.362]

P-values are reported in square brackets. Values in bold italics signify a rejection of the null hypothesis, with *, **, and *** indicating 10%, 5%, and 1% significance levels, respectively. The number of lags is based on the Newey–West rule of thumb, where lag length = $0.75T^{1/3}$.

spreads rely on a futures contract with an expiration that is closer to the period for which gasoline inflation is examined than for the 12-month WTI basis. Considering the extent to which the market is correctly predicting gasoline prices over the next few months, the expectation side of the lagged gasoline spread (i.e., the futures side) should play a larger role when interpreting the results for gasoline inflation than for the WTI spreads. Specifically, the predictive power of the gasoline spreads should be concentrated in the futures, with a positive coefficient. This prediction is confirmed by the empirical results, as all of the coefficients for the lagged gasoline spreads are either insignificant or positive.

The exception is the negative coefficient for the lag-1 gasoline spread under normal-contango. We interpret this result as indicating that normal-contango is the regime for which the direction of gasoline price expectations are the most uncertain, as the effect of the gasoline spot price dominates the effect of the spread on gasoline inflation. The gasoline spot price has a positive predictive power for gasoline inflation in contango as a contango market generates a self-perpetuating cycle that tends to persist for some time (Johnson, 2011). Hence, when the crude oil market eases from normal-backwardation to normal-contango, the market shifts from moderate excess demand to moderate supply status, and crude oil price volatility decreases. Accordingly, the (positive) predictability of gasoline spot prices increases, which implies a negative coefficient for the gasoline spread.

A complementary explanation of the negative sign on the one-lag gasoline spread is linked to a decrease in volatility as the market eases to a low-price regime. Specifically, when the crude oil market shifts from backwardation to contango, the market shifts from a situation of excess demand to one of excess supply and crude oil price volatility transitions from high to average and low levels. Lower volatility increases the predictive power of the gasoline spot price, which then dominates the dynamics of the spread. As prices decline when entering contango, gasoline inflation is likely to decelerate. Hence, the adjustment in expectations regarding the volatility of petroleum prices and market status justifies the shift in the effect of the gasoline expectations variable from positive to negative when the oil market regime changes from backwardation into contango. As a contango market generates a self-perpetuating cycle, it persists for some time (Johnson, 2011). Thus, once the market expectations have adjusted to the low gasoline prices outlook, low prices will likely persist as long as the contango regime continues to prevail.

6.2.3. *Lagged gasoline inflation*

The coefficient of lagged inflation informs us about price stability. We find that, in normal- and super-contango regimes, previous-month gasoline inflation is a good predictor of current gasoline inflation, consistent with contango being a regime in which prices are more stable and predictable (Johnson, 2011). Conversely, in normal- and super-backwardation, lagged gasoline does not predict future inflation. Hence, gasoline price inflation becomes more unpredictable when oil prices are highly volatile, as is typical of backwardation regimes. Comparison of the coefficients of the gasoline spread across the regimes suggests that the forward-looking price setting plays a more significant role than backward-looking price setting under all backwardation-related regimes.

6.2.4. *U.S. petroleum consumption and U.S. refinery utilization rate*

The results indicate that domestic petroleum consumption—a proxy for demand changes—is positively significant in backwardation regimes and generally insignificant in contango. Hence, domestic petroleum consumption increases exert upward pressure on domestic gasoline prices only in tight markets. In contrast, when the market is saturated or over-saturated in a contango oil status, demand is satisfied and, accordingly, petroleum consumption is not a driving factor for gasoline prices. This result raises energy security concerns for the U.S., as rising domestic consumption increases gasoline inflation precisely during periods of scarcity.

Applying the same line of reasoning to the refinery utilization rate—as a proxy of supply shifts in the gasoline market—yields generally consistent results. In tight markets, refineries produce less relative to demand, which increases gasoline prices. The inelasticity of gasoline demand encourages refineries to pass the price increase onto consumers.

The results also indicate that, in abundant times, refinery utilization rates are not a driving factor in gasoline prices, as the associated coefficients are generally insignificant. The exception is the hyper-contango oil market regime, during which the utilization rate is positively related to gasoline inflation. We believe that this result reflects the COVID-19 emergency period in 2020, during which gasoline demand dropped dramatically at a time when the oil market was over-saturated. Extremely high storage costs and high uncertainty levels caused refiners to decrease production rates at a time when gasoline demand had dramatically declined, explaining the positive coefficient for utilization rate under the hyper-contango regime.

6.2.5. *OPEC production*

The lagged OPEC production variable is generally negative when significant (except in the normal-backwardation, when it is weakly positive significant). Accordingly, an increase in OPEC production causes U.S. domestic gasoline prices to decrease. This result is consistent with Engel's (2013) argument that an increase in the foreign output gap (i.e., a shortage in international supply relative to domestic demand) increases domestic demand for domestic products, generating upward pressure on domestic inflation.

These results are consistent with Considine and Aldayel's (2020) findings that emphasize the significant role of OPEC in balancing the global oil market. By increasing production when global inventories are low, OPEC can push spot prices downward, bringing the market into contango and preventing the extreme oil price volatility that characterizes backwardation. These results support the White House and IEA hypothesis that an increase in OPEC production decreases domestic gasoline prices; however, it also reflects excess domestic demand relative to domestic supply and, thus, raises concerns regarding U.S. domestic energy security. Should the U.S. be a fully autarkical energy unit, OPEC production changes should be neutral to gasoline prices.

6.2.6. SPR

From a cost- and impact-optimizing perspective, the U.S. DOE has incentives to initiate a replenishment schedule when oil prices are expected to be low.[26] In contrast, as SPR releases have the intended goal of alleviating the effect of severe oil supply shocks on gasoline prices, they should occur when oil prices are high. The varying size of the SPR in the six regimes identified by our TAR estimation (Model A), as reported in Table 9, supports this view. The table indicates a monotonic relationship between the average size of the SPR and the oil market regimes, with the reserve being at its highest under the hyper-contango oil market regime and at its lowest under hyper-backwardation. In view of these considerations, we interpret the coefficient of the SPR variable reported in Table 4 in terms of the effect of releases for backwardation regimes and replenishment purchases for contango regimes.

The benchmark model (in Panel A) indicates that, under normal-contango (i.e., in a balanced market), SPR replenishments increase gasoline prices. This result indicates that, when demand and supply are relatively balanced, the SPR acts as a marginal buyer, with its long positions increasing the equilibrium price of oil and, eventually, of gasoline. Hence, we note that the SPR purchases can exert inflationary pressure on gasoline prices; however, this effect is limited to balanced market conditions.

The coefficient of SPR is insignificant in the extreme contango case. The interpretation of this is that the more saturated the market and the larger the excess supply of crude oil and refined products, the less likely it is that SPR purchases will affect gasoline prices. In an overly saturated oil market, the scope of SPR purchases is too limited and, therefore, those purchases are likely to be ineffective. Indeed, Greenley (2020) has commented that the storage availability in Cushing – rather than the SPR capacity –plays a key role for WTI prices in absorbing excess supply.

Recent SPR releases had the intended goal of balancing oil and gasoline price inflations. Whether this goal is actually achieved for the gasoline market is highlighted by the coefficient of the SPR variable for backwardation regimes. Specifically, if releases are effective in countering gasoline inflation, this coefficient should be positive and significant. In normal-backwardation, there is no evidence of a significant relationship between gasoline inflation and SPR releases. We find that the months included in this regime show an extremely low variation in SPR levels, indicating that the SPR is relatively inactive under normal-backwardation compared to hyper-backwardation. During a normal-backwardation oil market, the market is relatively balanced. Thus, the upward pressure on prices is not as intense as in the extreme backwardation cases and, so, the SPR releases will likely have a trivial effect, as illustrated by the insignificant coefficient under the normal-backwardation regime. In a super-backwardation oil market, excess demand and, accordingly, the upward pressure on prices are likely to intensify. Thus, SPR releases are likely to partially contribute to the decreasing inflationary pressure on gasoline prices, as represented by the positively significant coefficient under the super-backwardation regime. As noted above, Models B and C do not separate the normal- and super-backwardation regimes and, thus, do not demonstrate that SPR releases might counter gasoline inflation in super-backwardation. Instead, these models present an insignificant coefficient for the SPR variable (in Panels B and C), which Model A attributes to normal-backwardation.

These results indicate that SPR releases successfully meet the intended goal of countering gasoline inflation, or are at least neutral, under super- and normal-backwardation regimes. However, as we shall discuss in the next section, SPR releases exert upward pressure on gasoline prices when the market is in hyper-backwardation. From Panel A, we can see that SPR releases exert a weakly significant upward pressure on gasoline prices. This finding is confirmed, with stronger significance, by the results in Panels B and C.[27]

6.3. Discussion: extremely tight oil markets and the U.S. SPR—The hyper-backwardation regime amid the 2022 Russia-Ukraine conflict

Economic activity rebounded in the wake of a diminished threat from COVID-19 in 2021, causing an imbalance in energy demand versus supply, which had shrunk due to constrained production activity during pandemic shutdowns. In an attempt to alleviate surging gasoline prices, in November 2021, the Biden administration asked OPEC+ to release additional crude supplies to the market. When OPEC+ refused (Reed, 2021),[28] the administration pledged to use all available tools to deal with the global crude oil shortage to decrease gasoline and heating oil prices, with the goal of supporting U.S. residents and businesses. Accordingly, the White House announced the release of 50 million barrels of oil from the SPR[29] as part of a coordinated effort with China, India, Japan, South Korea, and the U.K. (Knight, 2021; Paraskova, 2021; The White House, 2021). However, the process and timing of the other countries' SPR releases remained unclear,[30] and the SPR releases from the U.K. and India were small (15 mbbl and 5 mbbl, respectively), weakening the impact of this coordinated move (Wood, 2021). The SPR release announced by the White House in November 2021 had a negligible effect on domestic gasoline prices, as demonstrated by our stylized fact analysis.

Hence, on the eve of the Russia–Ukraine conflict, the market was already in shortage as supply could not keep up with increasing demand at a time in which economies were bouncing back from the pandemic. Expectations of further oil shortages kept prices rising as refineries competed for oil barrels to profit from the predicted increasing demand (Salzman, 2022).

Against this background, the shock of the conflict and the consequent re-configuration of petroleum trade flows in response to uncertainty about sanctions on Russia and possible retaliation actions from the latter—as well as supply disruptions in the North Sea, Kazakhstan, and Libya—resulted in a supply freeze. Fattouh et al. (2022) described the 2022 oil market condition as a market structure, rather than a supply crisis. Fears of failed deliveries caused oil buyers to pay hefty premiums

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[26] We note that, in 2022, replenishments also became a tool for guiding domestic oil production, as the U.S. DOE steered part of the oil procurement toward domestic producers with the intended purpose of supporting the domestic oil industry.

[27] The SPR coefficient is insignificant in Panel D in the extreme backwardation case. Model D does not pass model specification tests when errors have a heterogeneous error distribution across breaks. In extreme scenarios like backwardation, such heterogeneity is potentially very relevant to the analysis, which makes us inclined to disregard the lack of significance of the SPR coefficient in Panel D under the extreme scenario of extreme backwardation.

[28] OPEC producers set their production in accordance with long-term demand trends and do not adjust their production in response to short-term demand fluctuations (Kilian, 2009a).

[29] Other tools could include banning U.S. domestic crude oil exports, investigating anti-competitive practices that may prevent gasoline prices at the pump from responding to falling crude oil prices (Knight, 2021; Paraskova, 2021; The White House, 2021), mobilizing "the threat of antitrust legislation to pressure OPEC" (Gordon, 2022), and/or invoking the 1950 Defense Production Act to promote the production of critical minerals (Nardelli et al., 2022).

[30] Additional measures taken by Japan, India, and South Korea to relieve the effect of high prices on consumers included fuel subsidies and reductions in fuel taxes (Mohanty and Vahn, 2022).

Table 9

Size of the SPR under different Oil Market Regimes (Thousand Barrels), 2022M01 to 2022M10.

	AVERAGE	MAXIMUM	MINIMUM	STANDARD DEVIATION
HYPER-BACKWARDATION	622,583.43	699,594.66	401,723.86	85,583.24
SUPER-BACKWARDATION	646,756.04	700,280.31	586,280.58	32,818.27
NORMAL-BACKWARDATION	653,154.87	701,803.28	562,099.78	43,776.75
NORMAL-CONTANGO	678,707.56	728,372.07	555,050.33	35,235.15
SUPER-CONTANGO	696,587.11	728,838.14	640,837.29	22,200.92
HYPER-CONTANGO	700,368.16	728,294.28	632,696.26	21,711.01

Source: Authors' calculations; U.S. DOE, retrieved from CEIC (series SR636062)

to acquire prompt shipments, resulting in a surge in spot and near-month futures prices and driving the market into an extreme backwardation status (Lewis et al., 2022; Salzman, 2022). The high degree of backwardation was determined by a strong discrepancy between long- and short-term oil price forecasts, as traders expected those initial panicking dynamics to be temporary as, eventually, the conflict would end or the market would adjust (Salzman, 2022).

In 2022, the crude oil market was extremely tight. Despite skyrocketing petroleum prices, U.S. demand did not show signs of abating. Meanwhile, domestic and global production did not increase. Domestically, U.S. shale producers—which had been hit hard by a sharp decrease in investments during the pandemic—struggled to regain the financial backing needed for further expansions (Norouzi, 2021). Internationally, the shortage was associated with limited OPEC spare production capacity. Inventories were also low as refiners, globally, maintained low inventories to avoid punitive storage costs during extreme backwardation (Lewis et al., 2022). With OPEC hitting capacity, OPEC and Russia unable to meet their quotas, limited crude oil inventories, and thin production buffer, an extreme backwardation market was manifested (Currie, 2022).

Consistent with the White House Hypothesis, the U.S. Government's first reaction to the sharp oil price increase was an appeal to OPEC to step up production levels. Under normal market conditions, such an appeal would have been an appropriate response as OPEC production increases generally contribute to moderate gasoline inflation, as shown by our empirical analysis. However, our results also indicate that, in periods of hyper-backwardation, OPEC production does not affect the price of gasoline. An explanation for this finding is that, in 2022, global inventories were limited, global supply buffers (including OPEC's production spare capacity) were severely restrained, and OPEC members could not meet their quotas. These findings suggest that viewing political pressure on OPEC producers as a tool to counter U.S. gasoline inflation is likely ineffective when global oil supply buffers are depleted.

Perhaps, in view of low levels of spare capacity, OPEC members disregarded appeals from the White House and the IEA to leverage their spare capacity and boost supply (Saadi et al., 2022). During the OPEC+ meeting on March 31, 2022, members affirmed their view that the increase in crude oil price was being driven by geopolitics rather than market fundamentals and, accordingly, decided to stick to the 0.43 million barrel/day production increase that was previously agreed upon during the 19th OPEC and non-OPEC Ministerial Meeting (OPEC, 2021a, 2022a).

As a boost of OPEC production was not realized, the White House announced an unprecedented 180 million barrel SPR release (1 million barrels per day for six months) and stated that the U.S. would seek a coordinated SPR release with other IEA member countries (Brower and Politi, 2022; Nardelli et al., 2022). Nevertheless, by June/July 2022, there were still growing concerns about surging gasoline prices worldwide (Ard et al., 2022).

That a massive SPR drawdown can be unsuccessful in moderating concerns about gasoline inflation is consistent with the findings of this study. Our results indicated that SPR releases under the hyper-backwardation regime may fuel, rather than tame, gasoline inflation. Hence, in the context of the 2022 hyper-backwardation, the SPR release might have caused more harm than benefit from the perspective of domestic gasoline consumers.

As discussed in the previous section, SPR releases are generally either neutral or beneficial in contrasting gasoline inflation, consistent with the White House hypothesis. Therefore, it is puzzling that drawdowns can be counter-productive exactly when oil scarcity is most keenly felt, as shown by our analysis and in accordance with the impact of the 2022 release on gasoline prices. We provide two complementary explanations for this result, the first stemming from interpreting SPR releases as an expectation coordination mechanism and the second linking the effect of drawdowns to the size of global supply buffers.

SPR releases attract a high level of attention from investors and the public, as they are interpreted by the market as the U.S. Government's response to exceptional market conditions typically caused by exogenous shocks to oil supply, such as extreme weather events (e.g., Hurricane Katrina in 2005) or geopolitical conditions that adversely affect oil supply (e.g., the IEA-coordinated release in 2011 in response to disruptions in Libya). Besides its practical impact on oil supply, a release informs market participants that the U.S. Government has assessed a specific oil market supply shock (which causes extreme backwardation) as an emergency state. Hence, the releases may act as a coordination mechanism to form expectations of dire oil supply conditions that are more negative than those implied by the market-based expectations of oil price dynamics (which are captured by the WTI spread), resulting in increasing gasoline prices.

SPR releases may also affect gasoline prices if they change market participants' expectations regarding the effectiveness of global supply buffers to manage future oil price spikes and volatility. If markets believe that the global spare supply is depleted, they might infer that future oil shocks will be more extreme. In this scenario, oil prices (and, thus, gasoline prices) would have to rise to compensate investors for higher uncertainty levels. Naturally, for this mechanism to be effective, the release has to be sufficiently large to have a material impact on global supply buffers. It is likely that the 2022 SPR drawdown showed this feature—being the largest in the reserve's history—bringing the SPR to a size last observed in the 1980s.

It should be noted that Russia's 2022 crude oil production disruption could have been offset by a globally coordinated SPR release and OPEC coupled with U.S. spare capacity utilization. However, should all these sources be used to offset Russia's crude production, the global oil market would have been left with minimal supply buffers to calm oil markets and manage oil price spikes and volatility. In this hypothetical scenario, oil shocks would likely be extreme, and prices would have to rise to compensate investors for higher uncertainty levels. While this scenario did not fully materialize, the OPEC spare capacity was very low in 2022, and the SPR release caused the SPR to drop dramatically (Courvalin et al., 2022; Finley and Krane, 2022). The increase in gasoline prices during the 2022 hyper-backwardation market is thus also consistent with market participants imbuing the weakening of the global oil supply buffers into prices.

Another aspect of the March 2022 release that bears considering is the difference between crude oil produced in the U.S. which could be used to replenish the SPR and the quality of crude oil best suited for U.S. refineries (Finely, 2022). The substantial crude supply disruptions and re-configuration of petroleum global trade flows amid the Russia–Ukraine conflict in early 2022 raised concerns about quality differentials, the flexibility of refiners to adjust and, consequently, the margins of refineries (Finley and Krane, 2022). The reason is that refineries are usually optimized to process specific crude oil grades and, thus, costs are likely to increase due to the mismatch in oil quality.[31] The resulting implication is that SPR releases that provide less than a match for the configuration of U.S. refineries might be less effective in moderating gasoline inflation, due to the relatively higher refining costs.

In summary, with regard to the effect of SPR releases on gasoline inflation, the results of this study demonstrate that, although the releases can alleviate gasoline price inflation in severely tight markets (i.e., the super-backwardation regime), they are detrimental when global supply buffers are overstretched (i.e., the hyper-backwardation regime), as seen in 2022. This finding is consistent with Kilian's (2009b) argument that SPR releases in the absence of sufficient buffers to deal with an emergency will lead to a dramatic increase in oil prices.

7. Conclusion

The so-called White House hypotheses can be articulated in two points: that releases of the U.S. SPR effectively balance the global oil market and counter U.S. domestic gasoline inflation, and that OPEC production increases have a deflationary effect on the U.S. gasoline market. In this study, we examined the validity of these claims through the use of a stylized description of the dramatic phases of the oil market, as well as a series of formal econometric models allowing for different oil market regimes.

Our stylized fact analysis indicated that the U.S. cannot be deemed a swing producer or shaper of the global oil market, based on its SPR and spare or shale oil production capacity (for the latter, we note the significant lags associated with bringing more wells online). The IEA joint SPR releases in 2022, representing approximately 9% of the collective emergency reserves of IEA members (IEA, 2022), are likely to have had a trivial effect on global oil prices (see, for example, Fig. 2). The impacts of U.S. SPR releases on global crude oil prices are likely to be short-lived and trivial, if there is any impact at all. Hence, it would be misguided to attribute global oil price decreases solely to SPR releases, as doing so would dismiss the impact of the fundamentals of global markets, expectations, and geopolitical risks. Through the use of Granger causality and threshold cointegration, we presented empirical evidence in support of the view that SPR releases—even exceptionally large ones—are unlikely to affect OPEC production, which vitally influences global oil prices. Thus, the recent SPR releases may not be an effective price control mechanism, beyond the temporary psychological impacts on commodity exchanges.

Similarly, our stylized fact analysis suggested that the November 2021 SPR release announcement by the White House had a negligible effect on domestic gasoline prices (see, for example, Fig. 3). In June/July 2022, there were still growing concerns regarding surging gasoline prices. U.S. gasoline prices are driven by retail gasoline market frictions, rather than determined solely by the U.S. oil industry or the global crude oil market (Golding and Kilian, 2022). Consequently, the argument that U.S. SPR releases can balance the global oil market to ease the burden of domestic heating oil and gasoline prices is questionable.

Results obtained from the formal econometric models enabled us to conclude that the White House hypotheses are generally supported by the data, with two crucial exceptions pertaining to extreme crises. One exception is an extremely oversupplied market, as was the case in 2020 due to the arresting impact of the COVID-19 pandemic. In this scenario, our results indicated that SPR releases have a negligible effect on gasoline price trends.

The second exception supports the argument of Jiang et al. (2022) that geopolitics non-linearly affect petroleum prices. Specifically, in extremely tight oil markets coupled with low global supply buffers, as in 2022, OPEC production increases have only a neutral effect on gasoline prices, while SPR releases might backfire and even worsen gasoline inflation. The implication here is that the SPR does not provide the U.S. with a strategic advantage in energy security precisely during periods of severe supply disruptions. Moreover, in tight oil markets, excess domestic demand relative to domestic supply puts upward pressure on domestic gasoline prices, raising concerns about U.S. energy dependence.

Analysis of the SPR levels also suggested that, from a cost- and impact-optimizing perspective, the U.S. DOE has incentives to release barrels from the SPR during backwardation and initiate a replenishment schedule during contango. This argument could explain the White House's reluctance to refill the reserve in March 2023, although crude oil prices were approximately 70 USD/barrel—a price level described as the "buy zone" (McCormick, 2023). As the market was still in backwardation at the time, the White House's hesitations can be then understood as a rational response to market conditions.

The conclusions of this study regarding the effectiveness of SPR drawdowns on gasoline inflation do not yield insights on other potential benefits or harms associated with SPR releases. An associated line of research is whether the releases can effectively finance the U.S. federal budget deficit by offsetting the negative impact of a shortfall in sour crude oil for the U.S. refining industry, thus sustaining the development of the domestic oil sector and U.S. petroleum exports. Similarly, promising lines of investigation could examine the distribution of SPR releases among domestic and foreign companies by sector and the extent to which the releases are used for hedging, speculation, and political purposes (Horsnell, 2000). Furthermore, it will be important to analyze the composition, implementation, and actual effectiveness of short- and long-term mitigation strategies that the U.S. government chooses to pursue to control retail gasoline prices.

As stated by Finely (2022): "Neither sales from the SPR nor its refilling are without problems, both practical and political in nature. … The SPR moves under consideration are not straightforward in terms of their practical implementation. Nor is their market or political impact."

Author statement

Noha Razek (corresponding author): literature review; background and stylized facts analysis; conceptualization; theoretical background; empirical methodology; diagnostic tests; data characteristics; model specification; implementation of the model using analytical software; empirical economic analysis; variable selection; data collection; figures and tables; and writing - original draft preparation. Noha Razek and Valentina Galvani: abstract; results and discussions; validation; and writing – reviewing. Noha Razek, Valentina Galvani, and Surya Rajan: introduction; conclusion. Noha Razek, Valentina Galvani, Surya Rajan, and Brian McQuinn: writing – editing. Noha Razek and Surya Rajan: proofreading. Valentina Galvani: literature review, variable selection, data collection, conceptualization, and analysis of finance-related factors. Surya Rajan: technical/engineering-related analysis; commenting on the U.S. shale industry. Brian McQuinn: writing, reviewing, and validating political-related commentary; and commenting on President Biden's visit to Saudi Arabia.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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[31] In order to adjust to bans on Russian petroleum imports, U.S. refineries shifted to a less-than-optimal mix of crude imports (Meyer, 2022), potentially due to lower quality oil than the refineries are equipped and optimized for, and due to higher transportation costs because of trade re-shuffling and the replacement of Russian feedstock.

Data availability

The authors do not have permission to share data.

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