

DISCUSSION PAPER SERIES

No. 9297

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INTERNATIONAL MACROECONOMICS



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Discussion Paper No. 9297
January 2013

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January 2013

ABSTRACT

Quantifying the Speculative Component in the Real Price of Oil: The Role of Global Oil Inventories*

One of the central questions of policy interest in recent years has been how many dollars of the inflation-adjusted price of oil must be attributed to speculative demand for oil stocks at each point in time. We develop statistical tools that allow us to address this question, and we use these tools to explore how the use of two alternative proxies for global crude oil inventories affects the empirical evidence for speculation. Notwithstanding some differences, overall these inventory proxies yield similar results. While there is evidence of speculative demand raising the price in mid-2008 by between 5 and 14 dollars, depending on the inventory specification, there is no evidence of speculative demand pressures between early 2003 and early 2008. As a result, current policy efforts aimed at tightening the regulation of oil derivatives markets cannot be expected to lower the real price of oil in the physical market. We also provide evidence that the Libyan crisis in 2011 shifted expectations in oil markets, resulting in a price increase of between 3 and 13 dollars, depending on the inventory specification. With regard to tensions with Iran in 2012, the implied price premium ranges from 0 to 9 dollars.

JEL Classification: F02, G15, G28 and Q43

Keywords: expectations, global commodity markets, inventories, oil price and speculation

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*The views in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the U.S. Energy Information Administration. We thank Christiane Baumeister and Daniel P. Murphy for comments on an earlier draft of this paper.

Submitted 13 January 2013

1. Introduction

The real price of crude oil depends on shocks to the flow supply of oil (defined as the amount of oil being pumped out of the ground), on shocks to the flow demand for crude oil that reflect the state of the global business cycle, on shocks to the speculative demand for oil stocks above the ground, and on other more idiosyncratic oil demand shocks. Especially, the quantification of speculative oil demand shocks has long eluded researchers because it raises difficult problems of identification. A speculator is someone who buys crude oil with the intent of storing it for future use in anticipation of rising oil prices. Such forward-looking behavior invalidates standard econometric oil market models if speculators respond to information not available to the econometrician attempting to disentangle demand and supply shocks based on historical data.

Recent theoretical and empirical work by Alquist and Kilian (2010), Kilian and Murphy (2013), and Baumeister and Kilian (2012a) made considerable strides in addressing these problems within a framework that is theoretically sound and empirically tractable.¹ These studies generalized the structural oil markets models pioneered by Kilian (2009), Baumeister and Peersman (2013), and Kilian and Murphy (2012) to examine the role of speculation and forward-looking behavior with careful attention to the role of spot and futures prices.

The key insight on which the Kilian and Murphy (2013) model builds is that otherwise unobservable shifts in expectations about future oil demand and supply conditions must be reflected in shifts in the demand for above-ground crude oil inventories. Shocks to this expectations-driven or speculative component of inventory demand may be identified and estimated jointly with all other shocks within the context of a fully specified structural vector autoregressive model. This fact allows one to assess how quantitatively important the speculative

¹ There has been renewed interest in theoretical models of the relationship between oil inventories and oil prices in recent years. Other examples include Hamilton (2009), Dvir and Rogoff (2010), Arseneau and Leduc (2012), and Unalmis, Unalmis and Unsal (2012).

component in the real price of oil has been at each point in time from the late 1970s until today. The latter question has been of central policy interest since 2003 when oil prices began to surge to unprecedented levels, raising the question of how policy makers should respond to rising oil prices (see, e.g., Fattouh et al. 2012).

Models aimed at quantifying the speculative component in the real price of oil depend crucially on the quality of the oil inventory data. There are no readily available data for global crude oil inventories. Kilian and Murphy (2013) instead relied on a proxy constructed from publicly available U.S. Energy Information Administration (EIA) data. The objective of this paper is to explore how sensitive the conclusions reached by Kilian and Murphy are to the use of an alternative proxy compiled by the *Energy Intelligence Group* (EIG), a private sector company which provides detailed accounts of crude oil inventory stocks by region as well as oil at sea and oil in transit. We examine how the use of this alternative proxy affects our assessment of the causes of the oil price surge from 2003 to mid-2008 and of the subsequent collapse and partial recovery of the real price of oil. We also examine for the first time the role of speculative demand during the Libyan Revolution, the Arab Spring, and recent tensions with Iran ranging from the Iranian nuclear threat to the EU's decision in early 2012 to impose an oil import embargo on Iran. These recent episodes are of particular interest both because they provide additional evidence about the role of expectations shifts and because many pundits have conjectured that rising oil prices in recent years may be attributed to these events. Our focus throughout the paper is on providing results in a format that is immediately useful for policy makers. For this purpose, we design two new presentation tools that summarize – at each point in time – how many dollars of the inflation-adjusted price of oil must be attributed to which demand or supply shock in the global market for crude oil.

The remainder of the paper is organized as follows. Section 2 reviews the structure and identifying assumptions of the structural vector autoregressive model to be used throughout this paper. Section 3 compares the two alternative proxies of changes in global above-ground crude oil inventories. In section 4, we re-estimate the Kilian-Murphy model using these alternative proxies on data extending to 2012.5. We quantify the effects of speculative demand using measures of their cumulative effects as well as counterfactuals for the real price of oil. The conclusion in section 5 links our discussion of speculation in the physical market for crude oil to recent debates about the role of speculation in the paper market for crude oil.

2. A Review of the Structural Oil Market Model

The analysis in this paper builds on the structural oil market model proposed by Kilian and Murphy (2013). The data are monthly. The sample period extends from February 1973 until May 2012. The model includes four variables: (1) the percent change in global crude oil production, as reported by the U.S. Energy Information Administration, (2) a suitably updated measure of cyclical fluctuations in global real economic activity proposed by Kilian (2009), (3) the real price of crude oil (obtained by deflating the U.S. refiners' acquisition cost for crude oil imports by the U.S. CPI), and (4) the change in above-ground global crude oil inventories. The construction of the latter series is discussed in more detail in section 3. The model is estimated using seasonal dummies and 24 autoregressive lags. This ensures that the model is able to capture slow-moving cycles in global real activity and in the real price of oil.

The structural shocks are identified based on a combination of sign restrictions and bounds on the short-run price elasticities of oil demand and oil supply. The key identifying assumptions are restrictions on the signs of the impact responses of the four observables to each structural shock. There are four structural shocks. First, conditional on past data, an

unanticipated disruption in the flow supply of oil causes oil production to fall, the real price of oil to increase, and global real activity to fall on impact. Second, an unanticipated increase in the flow demand for oil (defined as an increase in oil demand for current consumption) causes global oil production, global real activity and the real price of oil to increase on impact. Third, a positive speculative demand shock, defined as an increase in inventory demand driven by expectations shifts not already captured by flow demand or flow supply shocks, in equilibrium causes an accumulation of oil inventories and raises the real price of oil (see, e.g., Alquist and Kilian 2010). The accumulation of inventories requires oil production to increase and oil consumption to fall (associated with a fall in global real activity). Finally, the model also includes a residual demand shock designed to capture idiosyncratic oil demand shocks driven by a myriad of reasons that cannot be classified as one of the first three structural shocks.

In addition to these static sign restrictions, the estimates shown in this paper also impose the dynamic sign restriction that structural shocks that raise the price of oil on impact do not lower the real price of oil for the first 12 months following the shock. The rationale for this restriction is that an unexpected flow supply disruption would not be expected to lower the real price of oil within the same year nor would a positive flow demand or speculative demand shock. Finally, the model imposes the restrictions that the impact price elasticity of oil supply is close to zero and that the impact price elasticity of oil demand cannot exceed the long-run price elasticity of oil demand, consistent with conventional views in the literature. These elasticities can be expressed as functions of the impact responses in the structural vector autoregressive (VAR) model.

The model's focus on above-ground crude oil inventories is consistent with conventional accounts of speculation involving the accumulation of oil inventories in oil-importing

economies. An alternative view is that speculation may also be conducted by oil producers who have the option of leaving oil below the ground in anticipation of rising prices (see Hamilton 2009). An accumulation of below-ground inventories by oil producers in anticipation of rising prices would be equivalent to a reduction in flow supply. In short, flow supply shocks and speculative supply shocks are observationally equivalent.

It is worth stressing that the model allows for heterogeneous expectations among participants in the physical oil market to drive up the real price of oil. The resulting price increase will curb oil consumption, resulting in an accumulation of oil inventories, rendering this type of shock a speculative demand shock (also see Hamilton 2009). The model also allows for exogenous shocks in the oil futures market to be transmitted to the physical market for crude oil. An exogenous increase in oil futures prices driven by the financialization of oil futures markets, for example, by standard arbitrage arguments would raise inventory demand, as participants in the physical market expect the price of oil to increase. This mechanism is central to the Masters Hypothesis of how the financialization of oil futures markets may affect the real price of oil in physical oil markets (see Fattouh et al. 2012). By the same logic, the absence of speculation in the physical market under the maintained assumption of arbitrage would imply the absence of speculation in the oil futures market.

It is possible to drop the assumption of arbitrage between the physical market and the paper market for oil, of course, but not without removing the very channel through which the financialization of oil markets has been thought to affect the real price in the physical market.² The Kilian-Murphy model of the physical oil market in any case was designed to remain valid

² An alternative channel of transmission would involve time variation in the risk premium. There is strong empirical evidence against time variation in the risk premium in oil markets, however, at least until 2005 (see, e.g., Alquist and Kilian 2010; Hamilton and Wu 2012a). Moreover, the effect of a time-varying risk premium on the spot price of oil is likely to be small, as shown in Fattouh and Mahadeva (2012) using a calibrated model.

even if there are limits to arbitrage between oil futures and spot markets. In fact, one of its advantages is that the identification strategy does not require the existence of an oil futures market, but remains valid even in the absence of an oil futures market. This allows the use of data back to 1973 in estimating the model. For further details and discussion the reader is referred to Kilian and Murphy (2013).

3. Alternative Proxies for Global Crude Oil Inventories

The ability of structural models to identify speculative demand shocks hinges on the quality of the inventory data. There are no readily available data for global crude oil inventories provided by the EIA or other government agencies. The proxy for above-ground inventories proposed by Kilian and Murphy (2013) – and used by several other recent studies – was constructed by scaling U.S. crude oil inventory data by the ratio of OECD petroleum inventories over U.S. petroleum inventories. Kilian and Murphy observe that this proxy based on readily available EIA data is likely to be accurate for their sample period for three reasons.

First, one can externally validate the fit of the model. There are several episodes for which we have extraneous evidence from industry specialists such as Terzian (1985) or Yergin (1992) that speculation took place in physical oil markets.³ A natural joint test of the structural model and of the inventory data is to compare its historical decomposition against this external evidence. The model passes this test. For example, it detects surges in speculative demand in 1979 following the Iranian Revolution, in 1990 around the time of the invasion of Kuwait, and in late 2002 in anticipation of the Iraq War, as well as large declines in speculative demand in 1986

³ For example, Terzian (1985, p. 260) writes that in 1979 “spot deals became more and more infrequent. The independent refineries, with no access to direct supply from producers, began to look desperately for oil on the so-called ‘free market’. But from the beginning of November, most of the big oil companies invoked *force majeure* and reduced their oil deliveries to third parties by 10% to 30%, when they did not cut them off altogether. Everybody was anxious to hang on to as much of their own oil as possible, until the situation had become clearer. The shortage was purely psychological, or ‘precautionary’ as one dealer put it.” Also see Yergin (1992, p. 687).

after the collapse of OPEC and in late 1990 when the U.S. had moved enough troops to Saudi Arabia to forestall an invasion by Iraq (see Kilian 2008). A second argument in favor of this inventory proxy is that Alquist, Kilian and Vigfusson (2012) and Baumeister and Kilian (2012b) demonstrate that the inclusion of changes in oil inventories in the VAR model improves the out-of-sample predictive power of the VAR model. Third, simple arbitrage arguments suggest that expectations shifts in the oil market should be reflected not only in physical inventories, but also in the oil futures spread (see Alquist and Kilian 2010). This fact allows one to formally test the informational adequacy of the oil inventory proxy since the late 1980s. If there were additional information in the oil futures spread that is not already contained in our inventory proxy, rendering the VAR model informationally misspecified, then the oil futures spread should Granger cause the remaining model variables (see Giannone and Reichlin 2006). A Granger causality test of this proposition does not reject the null at conventional significance levels for maturities of 1, 3, 6, 9, and 12 months, consistent with the view that the inventory data are informationally adequate.

Nevertheless, there is reason to suspect that the inventory proxy used by Kilian and Murphy may have become less accurate in recent years. One reason is the creation of additional crude oil inventories outside of the OECD. For example, in recent years, China embarked on the creation of its own strategic petroleum reserves. While the creation of these reserves was delayed until the construction of suitable storage facilities, and the process of filling these tanks only began in earnest after the end of the sample evaluated by Kilian and Murphy, such events cannot be ignored going forward. Another reason for concern is the much publicized decision by some hedge funds to lease tankers to store crude oil. It is not clear to what extent such storage is covered by conventional measures of inventories. The answer is likely to depend on the location

of the tanker. Nor is it clear how quantitatively important this additional tanker storage is. Even more recently, Iran has increasingly used tankers as oil storage facilities, as it came under pressure from the EU oil embargo and related sanctions by other countries, further adding to the importance of oil stocks held on tankers.

In this paper we address these concerns using an alternative time series for global above-ground crude oil inventory compiled by *Energy Intelligence Group*, a private sector company providing proprietary data crude oil inventory data by region as well as data for oil stored at sea and oil in transit. To the extent that these data overlap with the inventory data provided by the EIA, the data are fully consistent. The advantage of the EIG data is that it is broader in coverage. This greater coverage is not without drawbacks, however. In many cases, direct measurements of oil stocks in other countries simply do not exist and data have to be constructed using rules of thumb such as assuming that stocks equal a fixed number of days of consumption. Thus, one should think of this alternative data set as another proxy for global above-ground crude oil inventories rather than being the definitive source of global inventory data. Notwithstanding this caveat, these alternative inventory data provide a useful check on the proxy proposed by Kilian and Murphy (2013).

3.1. Decomposing Global Stocks of Crude Oil

Crude oil inventories include not just the crude oil held in storage tanks, but also crude oil contained in pipelines and in oil tankers. Some of these stocks are commercial, but others are government owned. The best known example is the U.S. Strategic Petroleum Reserve (SPR), which is part of a broader system of strategic stocks in OECD countries coordinated by the *International Energy Agency* (IEA). In recent years, non-OECD countries like China and India have begun to develop their own strategic oil and product inventories. As reported by the IEA,

China, with 54% of its crude oil consumption in 2011 being met with oil imports, completed 103 million barrels of strategic storage capacity in 2009 with plans to increase its stocks to 207 million barrels by 2013. The filling of some of that capacity in the first half of 2012 likely contributed to an increase in Chinese crude oil stocks, according to IEA estimates. Actual figures on China's strategic stock levels are not regularly disclosed and it is not clear to what extent available storage capacity translates to actual storage. Moreover, it is not always clear how much of the storage refers to crude oil and how much to refined products or whether the official Chinese figures are reliable at all.

Figure 1 helps us assess which of these components have been driving the evolution of global crude oil stocks since 1985. First, oil in transit plays no important role in determining global oil stocks. Second, there is no evidence that the stock of oil stored at sea has changed dramatically in recent years, undermining the view that hedge funds have stored oil in large quantities in 2007 and 2008. Nor is there evidence of a noticeable increase of oil at sea following the oil embargo decision against Iran. Third, strategic crude oil inventories have evolved quite smoothly with no discernible departure from trend in recent years. The jump in 1988 does not appear related to changes in the U.S. SPR. Most importantly, there is no evidence of a rapid build-up of strategic inventories in China or India in particular after 2009. It can be shown, however, that the rate of increase of strategic stocks in the world exceeded that in the U.S. SPR over the same period, consistent with a gradual increase in government owned stocks outside the U.S. Fourth, there is evidence of steady growth in commercial non-OECD inventories after 1993, when China became a net oil importer.

3.2 Comparing the Two Proxies for Changes in Global Crude Oil Inventories

One way of assessing the quantitative importance of the oil inventories is to compare the stock of

inventories to daily oil production. For example, in July of 2012, EIG reports total stocks of 7,148 million barrels in the world. Given a daily flow of oil production of about 75 million barrels, these stocks amount to about three months of oil production. Somewhat smaller numbers would be obtained using the original inventory proxy. What matters for the econometric model, however, is not the level of global crude oil inventories, but how much oil enters and leaves stocks during each month. Figure 2 plots the change in global crude oil inventories, as compiled by EIG, as well as the corresponding series constructed as in Kilian and Murphy (2013) and suitably updated. To make the graph more readable (and without loss of generality), we focus on the subset of the data covering 2003.12-2012.5.

Visual inspection reveals that the changes in the EIG stocks are of far greater amplitude and that the correlation between the two series is low. For example, for the period shown in Figure 2, the correlation of the two proxies is only 31%. Further analysis reveals that this correlation actually has been increasing since the 1980s, rather than declining as one might have expected, given the greater importance of non-OECD inventories toward the end of the sample. In fact, the fit of the two series improves after 2010. This fact implies that whatever is driving the differences in these data series is not related to the creation of strategic stocks in emerging Asia.

Whether the added volatility in EIG inventories reflects noise arising from the construction of the missing data or simply the inclusion of those missing data is difficult to judge. What is clear is the importance of examining how sensitive the conclusions in Kilian and Murphy (2013) are to the choice of the inventory proxy. Given that the EIG data are only available back to January of 1985, for the purpose of the regression analysis in the remainder of the paper we extend the EIG data back to 1973.2 at the same rate of growth as the original proxy used in Kilian and Murphy (2013).

4. Estimation Results

This section examines how the use of alternative inventory proxies affects our assessment of the causes of fluctuations in the real price of oil. In estimating the vector autoregressive models of interest, we specify the real price of oil in percent deviations from its mean rather than in log deviations. This eliminates the log approximation error in fitting the real price of oil. All regression results shown in this paper are based on the seasonally adjusted real price of oil, but given the negligible size of the seasonal adjustment, this fact can be ignored in practice. The reduced-form model is estimated by least-squares. Conditional on this reduced-form estimate we examine 5 million random draws for the rotation matrix, form 5 million candidate structural models, and retain those candidate models that satisfy the identifying restrictions. For further discussion of this estimation approach the reader is referred to Kilian and Murphy (2012).

A practical difficulty in presenting the results of sign-identified models is that there tend to be many estimates of the structural model that are equally consistent with the observed data and the identifying restrictions. Here we deal with this problem by focusing on the structural model with the price elasticity of oil demand in use closest to -0.26 , a benchmark suggested by the posterior median estimate reported in Kilian and Murphy (2013).⁴ This facilitates the exposition. At the end of section 4.1, we provide additional sensitivity analysis with respect to this elasticity and show that our results are quite robust.

Figure 3 plots the historical decomposition of the real price of oil obtained from the model obtained under the original specification of the inventory proxy and the model under the alternative specification using the EIG proxy. We follow the literature in focusing on the cumulative effects at each point in time of the flow supply shock, the flow demand shock, and

⁴ Unlike conventional estimates of the price elasticity of oil demand which ignore changes in oil inventories, the price elasticity of oil demand in use is defined to account for changes in inventories in response to an exogenous shift in the supply curve of oil. For further discussion see Kilian and Murphy (2013).

the speculative demand shock. Each panel of Figure 3 shows how the real price of oil (expressed in percent deviations from its sample average) would have evolved, if all structural shocks but the structural shock in question had been turned off. A line that is increasing over time, for example, indicates that the shock in question exerted upward pressure on the real price of oil. Figure 3 shows that, notwithstanding some differences in magnitudes, the two historical decompositions largely agree on the interpretation of key historical events such as the 1979, 1986, 1990, 1997, and 2002/03 episodes. The main focus in this paper is not this historical evidence, however, but the question of how the use of alternative inventory proxies affects our assessment of the causes of the oil price surge between 2003 and mid-2008 and of the subsequent collapse and partial recovery of the real price of oil. For this purpose some alternative presentations of the estimates in Figure 3 are more convenient.

A central objective in this paper is to present the estimation results for 2003 through 2012 in a way that conveys – at each point in time T – how many dollars of the inflation-adjusted price of oil must be attributed to which demand or supply shock in the global market for crude oil. In sections 4.1 and 4.2 we discuss two ways of representing the model estimates that are specifically designed to answer this question. To facilitate the presentation of the results, we denominate the real price of oil in 2012.5 dollars, where 2012.5 is the most recent monthly observation available as of the time the paper was written. We normalize the data such that nominal oil price for May of 2012 coincides with the real price of oil. This allows us to express all results in dollar terms, while embodying an adjustment for inflation measured relative to 2012.5. This approach can be readily adapted to other base years, as more data become available.

4.1 Each Shock's Contribution to the Cumulative Change in the Real Dollar Price of Oil

One useful summary statistic is the cumulative change in the real price of oil caused by a given

structural shock over some period of interest. Our starting point is the historical decomposition underlying Figure 3,

$$y_t = \sum_{i=0}^{\infty} \Theta_i w_{t-i} \approx \sum_{i=0}^{t-1} \Theta_i w_{t-i}, \quad (1)$$

where y_t refers to the 4×1 vector of current observations, Θ_i denotes the 4×4 matrix of structural impulse responses at lag $i = 0, 1, 2, \dots$, and w_t denotes the 4×1 vector of mutually uncorrelated structural shocks (see Lütkepohl 2005, chapter 3). The deterministic regressors have been omitted for expository purposes. In practice, Θ_i and w_t may be estimated consistently from the data and the fitted value of the structural VAR model may be expressed as:

$$\hat{y}_t \approx \sum_{i=0}^{t-1} \hat{\Theta}_i \hat{w}_{t-i}, \quad (2)$$

Our interest centers on the third element of y_t , denoted by y_{3t} , which denotes the real price of oil. Let y_{3t}^i denote the contribution of structural shock i to the real price of oil at date t after expressing the real price of oil in 2012.5 dollars. Then the estimate of the cumulative change in the real price of oil from date t to date T due to shock i can be expressed as $\hat{y}_{3T}^i - \hat{y}_{3t}^i$ and compared with the cumulative change in the actual real price given by $y_{3T} - y_{3t}$. By construction, $\sum_{i=1}^4 (\hat{y}_{3T}^i - \hat{y}_{3t}^i) = \hat{y}_{3T} - \hat{y}_{3t} \approx y_{3T} - y_{3t}$. This decomposition can be applied to any structural VAR model in which the real price of oil is expressed in percent deviations from its mean.⁵

The first row of Figure 4 shows the results for 2003.1-2012.5. The second and third row of this figure show the corresponding results broken down by subperiod with 2003.-2008.6 representing the Great Surge and 2008.6-2012.5 representing the aftermath of the global

⁵ Our approach could be easily modified to deal with models in which the real price of oil is expressed in percent changes. For additional discussion on the tradeoff between these specifications see Kilian and Murphy (2013).

financial crisis. The first column of Figure 4 shows the cumulative change in 2012.5 dollars, obtained from the structural VAR model using the original proxy for inventories proposed by Kilian and Murphy (2013). The second column shows analogous results for the same structural model estimated using the alternative EIG inventory proxy. The first four bars of each of the twelve bar charts show the cumulative contributions of the flow supply shock, the flow demand shock, the speculative oil demand shock, and the other oil demand shock. The last bar indicates the cumulative change in 2012.5 dollars actually observed in the data.

Starting with the results for 2003.1-2012.5 in the first row of Figure 4, we see that of the cumulative 65 dollar increase in the real price of oil over this period, between 38 and 40 dollars must be attributed to the cumulative effect of flow demand shocks, depending on the choice of the inventory proxy, making this result remarkably robust. The original specification assigns an additional 21 dollars to flow supply shocks, compared with only 5 dollars under the EIG specification; on the other hand, the EIG specification assigns 11 dollars of the 65 dollar increase to speculative demand shocks, compared with -2 dollars under the original specification. We conclude that the substantive results in Kilian and Murphy (2013) regarding the 2003-08 surge are remarkably robust both to the extension of the sample size and the choice of inventory proxy. There is no evidence that speculative demand played a significant role in explaining the evolution of the real price of oil since 2003.1. Even allowing for the somewhat larger estimates under the alternative inventory specification, speculative demand shocks account for at most 17% of the observed cumulative increase in the real price of oil since January 2003. We will examine the nature and timing of speculative demand in more detail in section 4.2.

The second row of Figure 4, which focuses on the Great Surge of 2003-08, confirms this general impression. For example, the original specification explains 61 dollars of the 95 dollar

surge in the real price of oil based on flow demand shocks compared with 60 dollars under the alternative specification. At the same time the contribution of the speculative demand shock rises from 4 dollars in the original specification to 17 dollars under the alternative specification. Put differently, the fraction of the Great Surge explained by speculative demand shocks is between 4% and 18%, depending on the specification, compared with a fraction of almost two thirds for flow demand shocks under either specification. The main difference is how much of the remaining third is attributed to flow supply shocks as opposed to speculative demand shocks.

Finally, the third row shows that of the 29 dollar cumulative decline from 2008.6-2012.5, under the original specification 23 dollars is due to flow demand shocks, whereas under the alternative specification 20 dollars are attributed to the flow demand shock. With regard to the quantitative importance of the speculative demand shock, the differences are quite small. Under the original specification this shock accounts for a decline of 5 dollars; under the alternative specification for a decline of 7 dollars. Compared with the total decline of 29 dollars, speculative demand shocks account for between 17% and 24% of the total decline. There is no indication that the supply side of the oil market has been a key determinant of the real price of oil in recent years. Overall, between 20 and 23 dollars of the 29 dollar decline in the real price of oil since its peak in mid-2008 is accounted for by flow demand shocks compared with between -2 and +3 dollars explained by flow supply shocks.

The conclusion that economic fundamentals in the form of flow demand rather than demand for stocks have been the main determinant of the real price of oil in recent years is not overly sensitive to allowing for the possibility of somewhat lower price elasticities of oil demand in use. Table1 presents the minimum and maximum cumulative contribution of each structural shock (expressed in 2012.5 dollars) based on all admissible models with impact price elasticities

of oil demand in use within some pre-specified range. We deliberately tilt these ranges toward zero to demonstrate that similar results are obtained for somewhat smaller price elasticities than in the baseline model. Regardless of the elasticity range and the sample period, Table 1 indicates that the bulk of the cumulative increase is attributed to the flow demand shock and not very much to the speculative demand shock. For example, consider elasticities bounded between -0.15 and -0.3. In that case flow demand shocks account for anywhere between 33 dollars and 54 dollars of the cumulative price increase during 2003.1-2012.5 under the alternative specification, whereas speculative demand shocks account for between -4 and 13 dollars. Under the original specification, flow demand shocks account for anywhere between 38 and 55 dollars of the cumulative increase, while speculative demand shocks account for between -7 and 17 dollars.

4.2. Counterfactuals

Given the differences between the two inventory specifications when it comes to the overall importance of speculative demand shocks since January 2003, it is useful to examine in more detail the nature and timing of the oil price increases associated with speculative demand. This requires a different set of tools. An alternative way of assessing how many dollars of the inflation-adjusted price of oil must be attributed to which demand or supply shock at a given point in time is to represent the model estimates in the form of counterfactuals. The counterfactual is defined as $y_{3t}^i - \hat{y}_{3t}^i \forall t$, where y_{3t}^i denotes the real price of oil in 2012.5 dollars and \hat{y}_{3t}^i denotes the fitted value associated with shock i , as defined in section 4.1. This representation has the important advantage that it avoids the impossible task of having to attribute the mean value of the real price of oil to individual shocks i , while still allowing us to express the counterfactual in dollar terms. The counterfactual series indicates how the real price of oil expressed in 2012.5 prices would have evolved, had one been able to replace all

realizations of shock i by zeros, while preserving the remaining structural shocks in the model. If the counterfactual price exceeds the actual price, for example, this means that the structural shock in question lowered the price. A counterfactual below the actual price means that the shock in question raised the price in this period. The vertical distance between the actual price and the counterfactual price tells us by how many dollars the shock in question affected the real price of oil at this point in time.⁶

It is useful to contrast this approach with the earlier approach of constructing cumulative increases in the price. That approach focused on changes in the price over time explained by a given structural shock rather than the component of the actual price at a given point in time driven by a given structural shock. To move from a plot of the counterfactual to the cumulative increase measure one would have to compare the difference between the counterfactual and the actual price on the first and on the last date of the counterfactual and construct the rate of change over time in this difference. Thus, these representations are mutually consistent, but focus on different aspects of the same data.

4.2.1. The Great Surge from 2003 until mid-2008

Figures 5 and 6 contain separate counterfactuals for the flow supply shock, the flow demand shock and the speculative demand shock. Figure 5 shows the results for the specification using the original inventory proxy, while Figure 6 shows the corresponding results for the alternative specification based on the EIG inventory proxy. The bottom panels in these figures show that speculative demand shocks did little to increase the real price of oil between early 2003 and early 2008, regardless of the specification. In fact, there is as much evidence that speculative demand

⁶ Alternatively this approach could be applied to a VAR model in which the real price of oil is expressed in percent changes. In that case, the percent changes would have to be cumulated relative to a baseline date. This involves an approximation error in that the cumulative effects of shocks occurring prior to the baseline date are set to zero. Hence, the resulting counterfactual would differ from that obtained by a proper historical decomposition.

lowered the real price of oil slightly as there is evidence that it raised the real price of oil. In any case, the price changes do not exceed 5 dollars either way.

The years of 2007 and 2008 are rightly considered the acid test for the speculation hypothesis in that there is a strong presumption that if speculation mattered in recent years, then it would have done so near the peak of the surge in 2007/08 (see Hamilton 2009). Our evidence shows that regardless of the model specification there is only minimal evidence of speculative demand shifts from January 2007 until April of 2008. In fact, Figures 5 and 6 indicate that during 2007 speculative demand lowered the real price of oil by as much as 13 dollars. Instead, the bulk of the continued increase in the real price of oil in 2007 and early 2008 reflected continued pressure from flow demand. Figures 5 and 6 agree that, starting in 2004, flow demand shocks associated with the global business cycle had been driving up the real price of oil persistently. In the absence of these shocks the real price of oil by mid-2008 would have been lower by 58 dollars in the original specification and by 52 dollars under the alternative specification.

Only starting in April of 2008, when the real price was about to peak, did speculative demand raise the real price by more than 5 dollars – if only under the alternative inventory specification – reaching 14 dollars by mid-year (compared with at most 5 dollars at all times in the original specification). The fact that the increases in speculative price pressures that are detected based on the alternative proxy only occurred in the last months of a price surge that spans five years is important because it contradicts conjectures that the surge itself was sustained only by speculative pressures. Instead, speculative demand, if at all, emerged only when the flow-demand driven price surge was about to peak.

Figures 5 and 6 also agree that in the absence of flow supply shocks the real price of oil would have been higher between 2003 and 2006 by as much as 20 dollars under the original

specification and as much as 12 dollars under the alternative specification. In contrast, after 2007, the real price of oil would have been lower by as much as 8 dollars in the original specification and 9 dollars in the alternative specification. This result is consistent with evidence that oil producers in the Middle East in particular were able to increase production until about 2006 before production growth leveled off.

4.2.2. The Libyan Revolution and the Oil Embargo against Iran

Figures 7 and 8 show the evolution of the counterfactuals after mid-2008. Under the original inventory specification in Figure 7, starting in 2010, flow supply shocks on balance are responsible for raising the real price of oil by as much as 19 dollars. At the same time, flow demand shocks for the most part have also raised the real price of oil – with the exception of a brief period in 2009 – by as much as 52 dollars in late 2011. Finally, speculative demand shocks between late 2008 and early 2011 and again in 2011/2012 generally lowered the real price of oil by as much as 16 dollars. One exception is the peak price period of July 2008, when speculative demand pushed the real price up by 5 dollars. The other exception is February 2011, when speculative demand presumably associated with events in Libya pushed the real price of oil up by a little over 3 dollars. Interestingly, the effect of the simultaneous Libyan flow supply disruption on the real price of oil appears even smaller at the global level. Nor is there evidence in Figure 7 of an increase in the real price of oil in 2012 associated with tensions with Iran. Of course, this does not necessarily mean that this tension does not matter because expectations of lower supply may have been offset by expectations of slowing demand owing to the Euro crisis.

Figure 8 paints a similar picture based on the alternative inventory proxy, except that the cumulative effects of flow demand and flow supply shocks are slightly smaller. The difference is that not only the decline in speculative demand in 2008-09 accounts for up a reduction of up to

24 dollars in the real price of oil, but there is evidence for a shift in speculative demand both during the Libyan Revolution and toward the end of the sample, at a time when tensions with Iran were held responsible for higher oil prices. In the case of Libya, this effect amounts to an increase of up to 13 dollars. This increase is short-lived and not related to the Arab Spring more generally. In fact, there is no evidence that the Arab Spring caused an increase in speculative demand in 2011. During this time, speculative demand, if anything, lowered the real price of oil slightly. Regarding the tension between Iran, there is evidence of an increase of up to 9 dollars in early 2012. The latter effect may cover a variety of concerns ranging from decision to institute the EU oil embargo to the Iranian nuclear threat, but again has to be viewed in conjunction with the looming Euro crisis. It would be a mistake to attribute these effects to Iran alone. While events in the Middle East shape expectations of future supply disruptions, how important they are for the real price of oil also depends on how much flow demand for oil is expected. Expectations of rising prices always reflect an expected shortfall of oil supply relative to oil demand rather than one side of the Marshallian scissors only.

These two examples illustrate that the choice of inventory proxy, while not affecting the interpretation of the surge in the real price of oil from 2003 until early 2008, can make a difference for the interpretation of some episodes in the data. On the basis of the available evidence, it is not clear which of the conflicting interpretations of the data for early 2011 and for early 2012 is preferred. We take comfort in the fact that for most policy-relevant questions – and in particular with regard to the causes of the surge in the real price of oil from early 2003 until early 2008 – the two inventory specifications arrive at the same substantive conclusion that this surge was not caused by speculative demand.

4.2.3. The Role of Flow Supply Shocks and Flow Demand after 2009

Much has been made of the increasing importance of unconventional oil production in recent years. While the model does not allow us to separate the production of conventional and unconventional oil (and indeed such a decomposition would be largely of academic interest when modeling the evolution of the real price), it allows us to assess the overall role played by flow supply shocks in recent years. Figures 7 and 8 show that flow supply shocks slightly lowered the real price of oil in 2010 by about 4 dollars. To the extent that flow supply shocks mattered for the real price of oil after 2010, they tended to increase the real price of oil with estimates ranging from 7 to 19 dollars. These estimates are dwarfed by those for the flow demand shock, however, which continues to be the most important determinant of the real price of oil even after the partial recovery of 2009. This finding is interesting in light of a common view among pundits that economic fundamentals have ceased to be useful in understanding oil prices since 2010 requiring greater emphasis on the psychological element of the market. Our analysis does not support this conjecture.

5. Conclusion

Global commodity markets play an increasingly important role in the world economy, yet economists are only beginning to study these markets. In this paper, we focused on the role of inventories or stocks of crude oil for the determination of the real price of oil. The fact that crude oil is storable allows market participants to speculate in oil by storing purchases of oil for future use in anticipation of rising prices. As a result, shifts in expectations about future oil prices may greatly and immediately influence the real price of oil by shifting the speculative demand for oil. Indeed, such speculative demand shifts have been held responsible for the remarkable surge in oil and other industrial commodity prices that took place between 2003 and

mid-2008.

Compared with markets for other storable commodities, the market for crude oil lends itself to a formal econometric analysis of this question not only because of the importance of crude oil for the global economy, but because of the availability of monthly global data on oil production and above-ground oil inventories dating back many years. Even for crude oil, however, the quality of the inventory data is less than perfect. This paper explored in detail how the use of alternative proxies for global oil inventories affects the empirical results of the structural oil market model of Kilian and Murphy (2013), suitably updated to 2012.5. We concluded that, despite some differences in emphasis, both inventory proxies yield very similar results in general.

We found evidence of speculation driving up the real price of oil in the physical market for crude oil in 1979 after the Iranian Revolution, in 1990 near the time of the invasion of Kuwait, in 2002 in the months leading up to the 2003 Iraq War, in early 2011 during the Libyan crisis and in early 2012 during the Iranian crisis. A common feature of all these episodes of speculative pressures is that they reflect concerns about the stability of oil supplies from the Middle East. We also found evidence that speculation may lower the real price of oil. We identified several episodes in which a reduction in speculative demand contributed to lower oil prices. One example is in 1986 after the collapse of OPEC; another example of speculative downward pressures on the price is late 2008 and early 2009. The latter episode presumably was associated with expectations of a prolonged global downturn rather than improved oil supplies.

Episodes of increased speculative demand in the physical market for crude oil do not line up at all with increases in measures of the participation of financial investors in oil futures markets. Indeed, the view that an exogenous shift in the participation of financial investors in oil

futures markets explains the surge in the real price of oil during 2003-08 can be ruled out on the basis of our results. By standard arbitrage arguments, speculation in financial markets for oil cannot affect the real price of oil in physical markets unless there is a shift in inventory demand. Our analysis found no evidence of such a shift, consistent with a general lack of evidence for the hypothesis that the financialization of oil markets caused oil price increases (see, e.g., Büyüksahin and Harris (2011), Irwin and Sanders (2012), Fattouh and Mahadeva (2012), Hamilton and Wu (2012b)). This does not necessarily mean that the financialization of oil futures markets did not matter, but that it should be modeled as part of the endogenous propagation of shocks to economic fundamentals rather than as an exogenous intervention. This interpretation is consistent with the view that index funds simply followed market trends set in motion by earlier shocks to economic fundamentals rather than creating market trends of their own for reasons not related to economic fundamentals.

Despite evidence that speculation may have raised the real price of oil by between 5 and 14 dollars from March of 2008 until July of 2008, the bulk of the cumulative increase of 95 dollars (measured in 2012.5 dollars) from 2003 until mid-2008 (and much of the evolution of the real price of oil since then) must be attributed to shifts in flow demand, associated with shifts in the global demand for oil from emerging Asia and from the OECD. Flow demand shocks account for as much as 61 dollars of that increase with flow supply and idiosyncratic demand shocks adding between 17 and 30 dollars, depending on the specification. In short, the surge in the price of oil and other industrial commodities appears to be driven primarily by economic fundamentals. This fact has important implications for policymakers. For example, current policy efforts aimed at tightening the regulation of oil derivatives markets cannot be expected to lower the real price of oil, given that excessive speculation in these markets was not the cause of earlier

increase in the price of oil in the physical oil market. To the extent that higher demand for oil from emerging Asia caused that surge, as has been suggested by Kilian (2009) and Kilian and Hicks (2013) among others, one would not expect higher oil prices to disappear, unless global growth slows down further.

Finally, we examined for the first time the evolution of the real price of oil since 2010. We confirmed that for this period as well, flow demand shocks have been the primary driver of the real price of oil. We also examined the role of speculative shocks. It has been conjectured that the Libyan Revolution in early 2011 affected the real price of oil by shifting speculative demand (see Baumeister and Kilian 2012a). Ours is the first study to examine this question formally. We provided evidence that the Libyan crisis indeed shifted expectations in oil markets, resulting in a price increase of between 3 and 13 dollars (in 2012.5 consumer prices), depending on the specification of oil inventories. This increase is short-lived and not related to the Arab Spring more generally. In fact, there is no evidence that the Arab Spring caused an increase in speculative demand in 2011. With regard to tensions with Iran in early 2012 (ranging from the decision to impose an EU oil import embargo to the Iranian nuclear threat), the evidence is more mixed. The implied price premium ranges from 0 to 9 dollars, depending on the specification. Finally, we found no indication that higher demand for strategic oil inventories from emerging Asia (or for that matter Iranian storage of oil on tankers in recent years) played an important role determining global oil inventories or the real price of oil after 2009.

Regarding the flow supply of oil, we showed that to the extent that flow supply shocks mattered for the real price of oil after 2010, they tended to increase the real price of oil with estimates ranging from 7 to 19 dollars. There is no indication that the supply side of the oil market has been a key determinant of the real price of oil, however. For example, between 20

and 23 dollars of the 29 dollar decline in the real price of oil since its peak in mid-2008 is accounted for by flow demand shocks compared with between -2 and +3 dollars explained by flow supply shocks.

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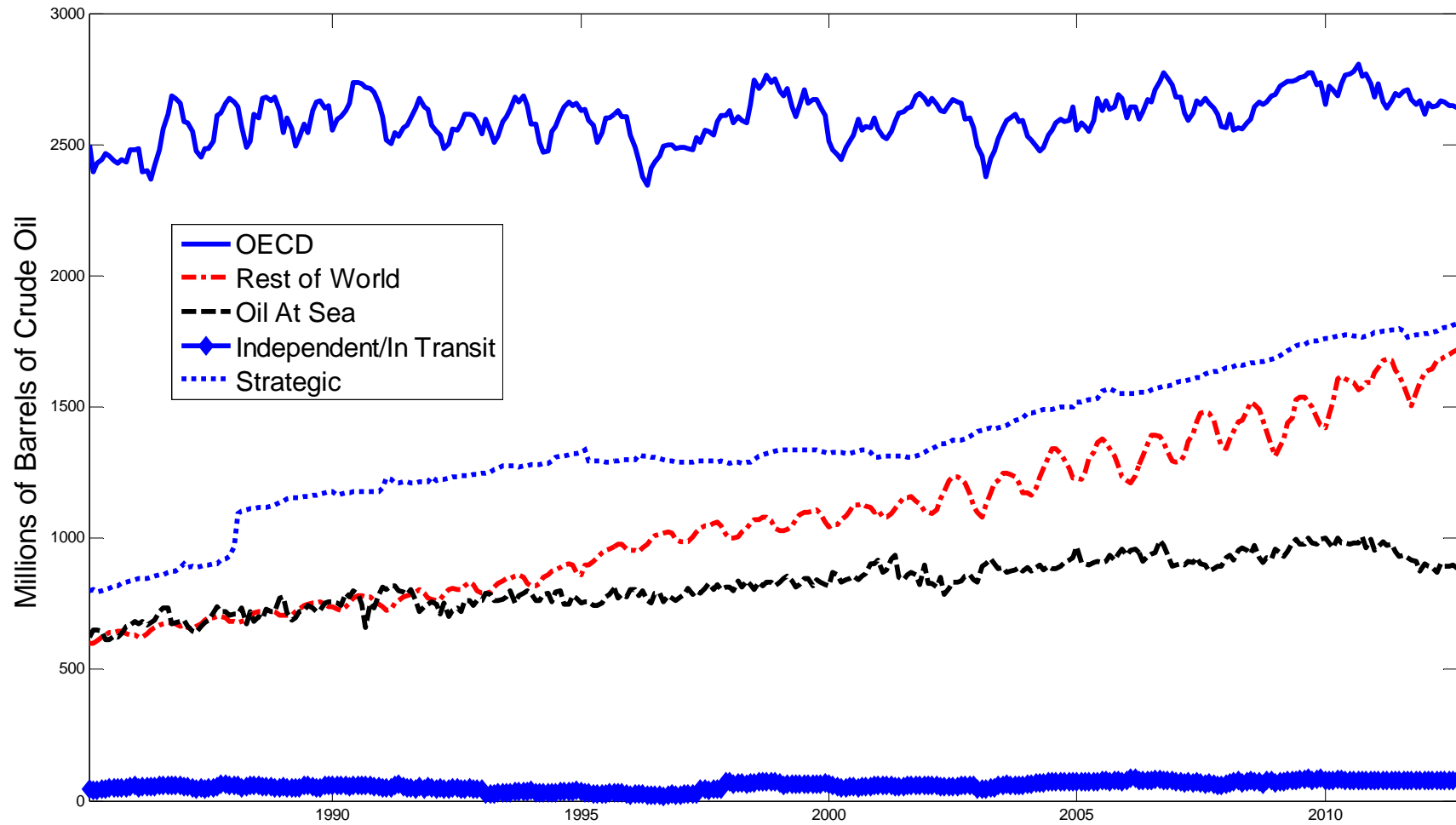
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**Table 1. Sensitivity Analysis with Respect to the Price Elasticity of Oil Demand in Use
Minimum and Maximum Cumulative Contribution to the Real Price of Oil in 2012.5 Dollars**

Evaluation Period	Range of Price Elasticity of Oil Demand	Model based on Original Inventory Proxy				Model based on EIG Inventory Proxy			
		Flow supply	Flow demand	Speculative demand	Other demand	Flow supply	Flow demand	Speculative demand	Other demand
2003.1-2012.5	[-0.3,-0.15]	[10,21]	[38,55]	[-7,17]	[-4,10]	[4,15]	[33,54]	[-4,13]	[3,17]
	[-0.25,-0.2]	[10,21]	[38,54]	[-6,13]	[-4,9]	[6,11]	[37,42]	[-1,13]	[6,17]
2003.1-2008.6	[-0.3,-0.15]	[6,19]	[61,72]	[4,16]	[0,14]	[6,24]	[36,65]	[12,18]	[8,21]
	[-0.25,-0.2]	[6,18]	[62,71]	[4,14]	[0,14]	[10,16]	[48,58]	[13,18]	[12,18]
2008.6-2012.5	[-0.3,-0.15]	[-2,4]	[-29,-7]	[-16,1]	[-6,-3]	[-11,-1]	[-21,1]	[-17,-5]	[-9,3]
	[-0.25,-0.2]	[-1,4]	[-27,-12]	[-14,-1]	[-6,-4]	[-6,-2]	[-16,-9]	[-14,-5]	[-6,2]

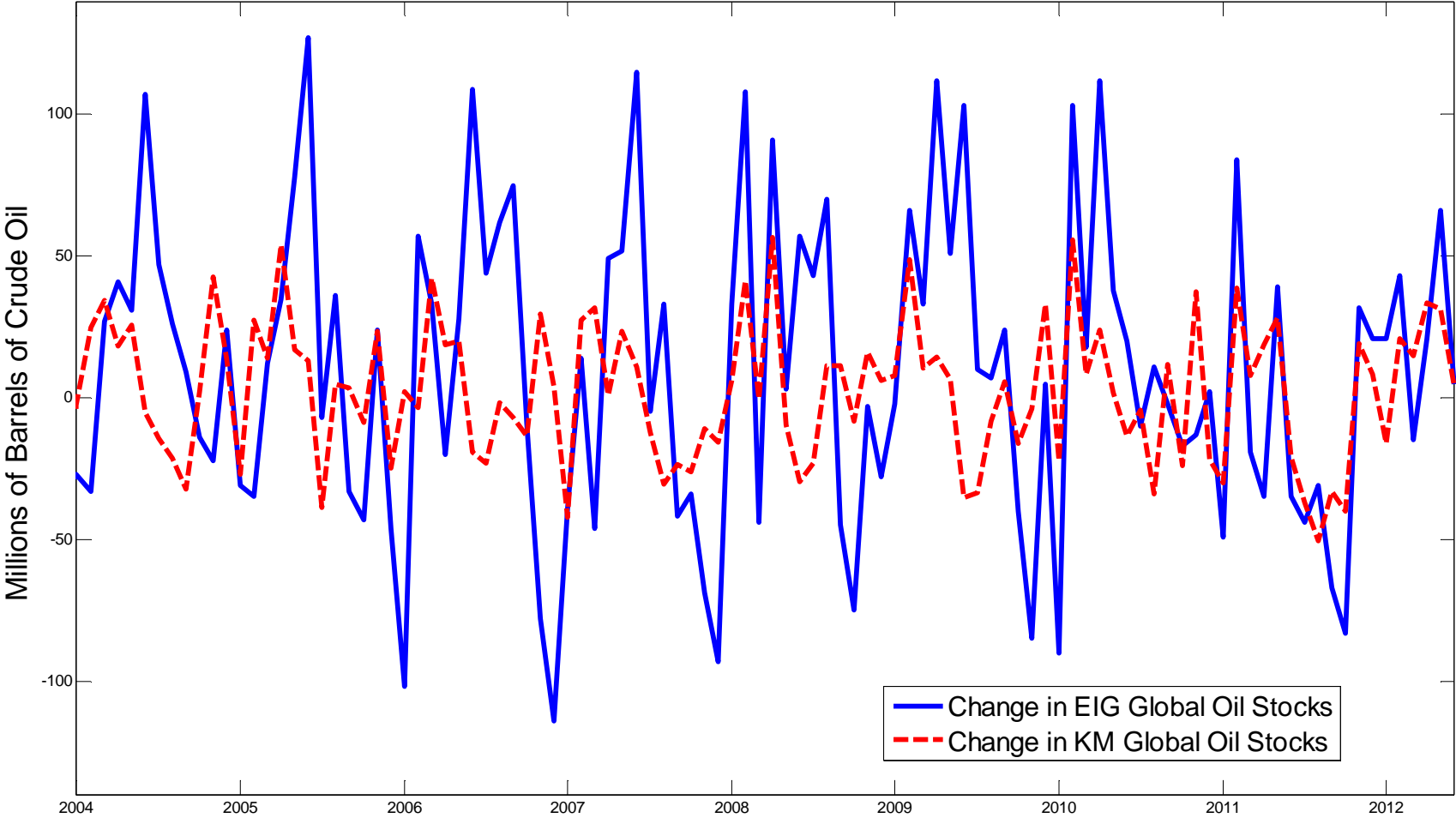
NOTES: The results are based on 5 million draws for the rotation matrix conditional on the reduced-form estimate. The maximum and minimum cumulative contribution is obtained based on all admissible draws inside the pre-specified elasticity range. All dollar entries have been rounded to the nearest integer.

**Figure 1. The Evolution of Global Commercial and Strategic Stocks of Crude Oil
1985.1-2012.8**



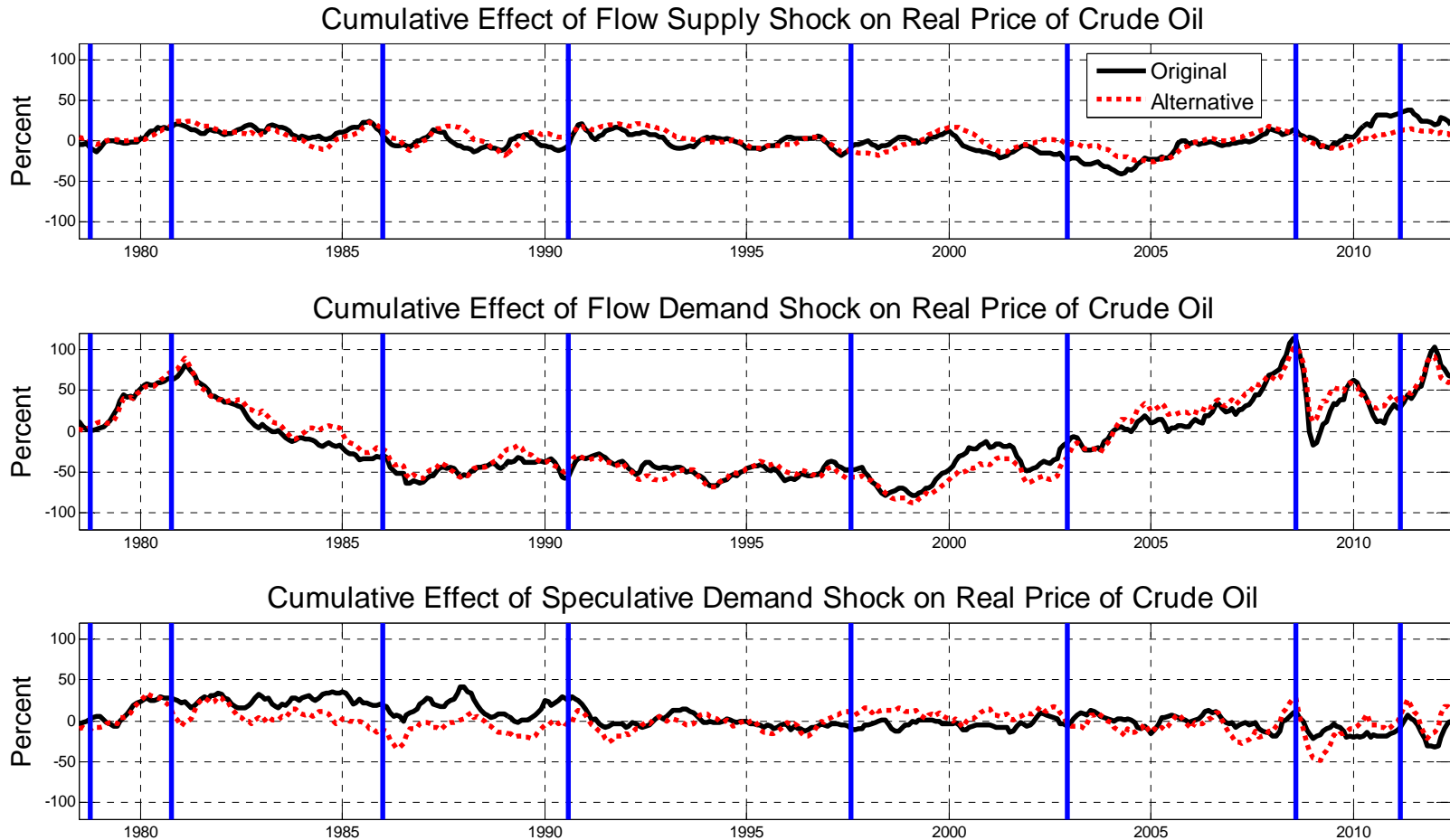
SOURCE: Proprietary data compiled by the *Energy Intelligence Group* (EIG). Reproduced with the permission of EIG.

**Figure 2. Change in Global Crude Oil Stocks
2003.12-2012.5**



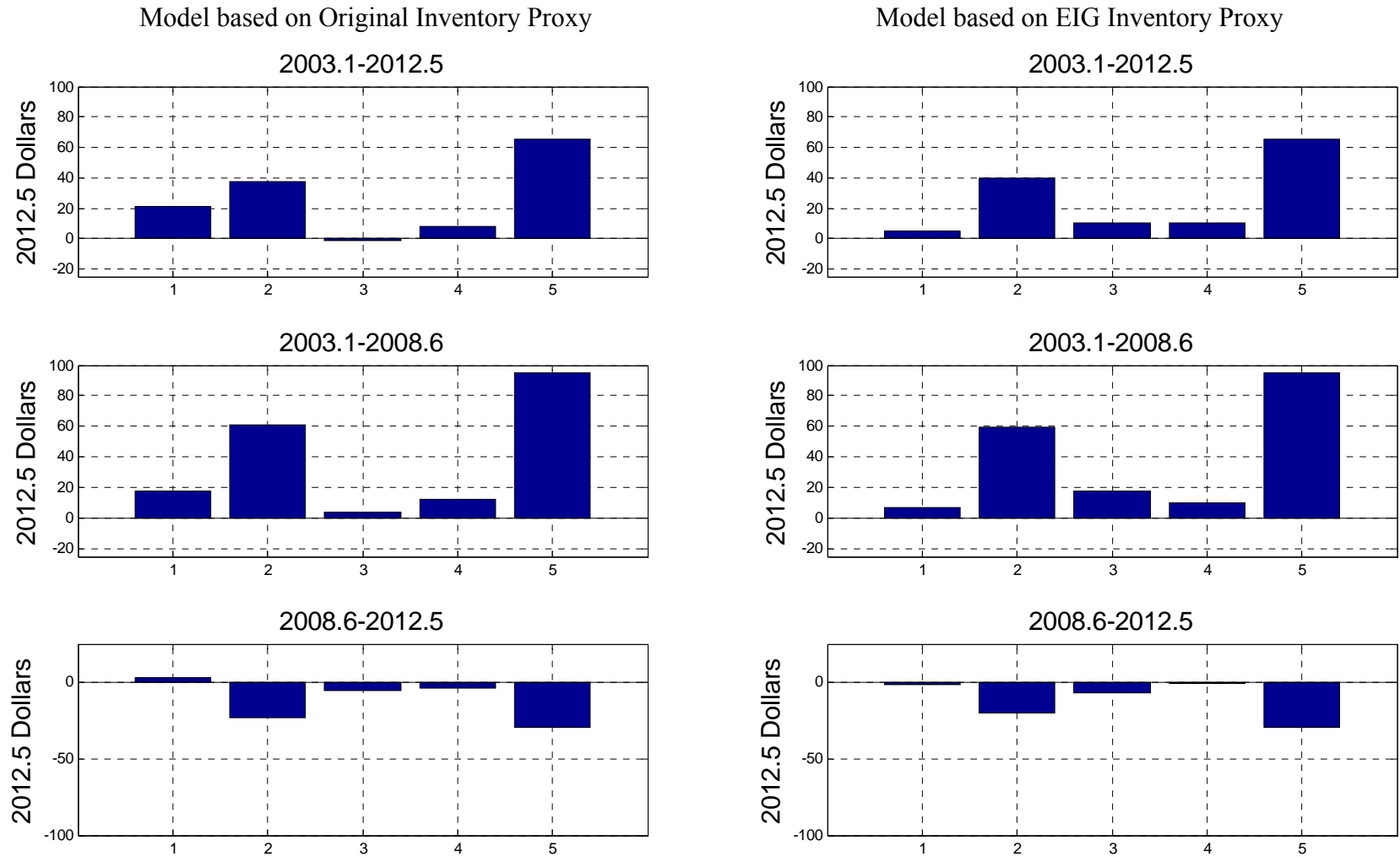
SOURCE: Proprietary data compiled by the *Energy Intelligence Group* (EIG) and computations based on EIA data as in Kilian and Murphy (2013), abbreviated as KM. The EIG data are reproduced with the permission of EIG.

**Figure 3. Historical Decomposition of the Real Price of Oil in Percent Deviations from the Sample Mean
Estimates based on the Original Inventory Proxy and the Alternative EIG Inventory Proxy**



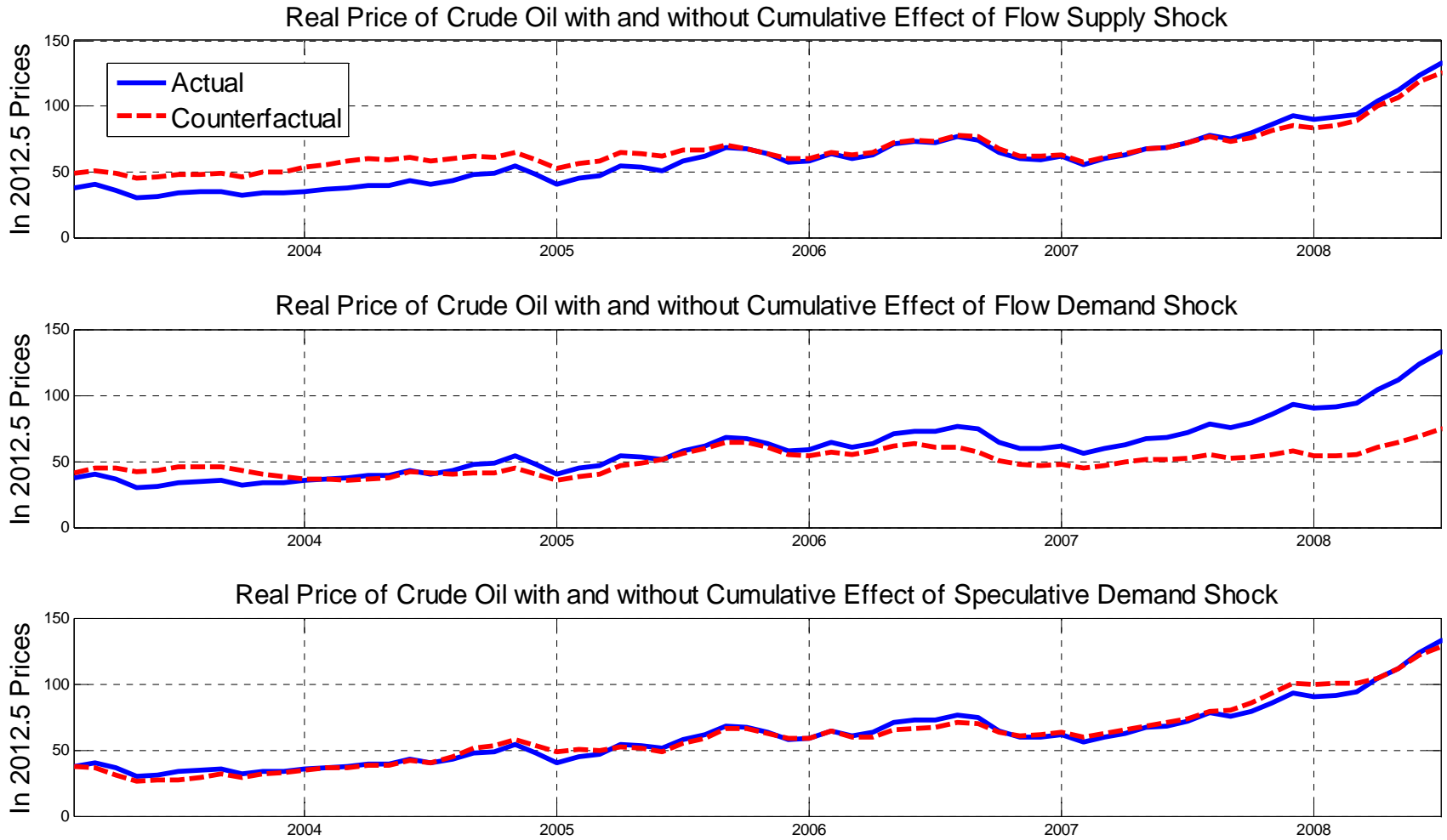
NOTES: The results shown are for the models with a price elasticity of oil demand in use closest to -0.26 , making the results comparable to those reported in Kilian and Murphy (2013). The vertical lines indicate important historical events in oil markets including the Iranian Revolution of late 1978, the outbreak of the Iran-Iraq War in late 1980, the collapse of OPEC in late 1985, the invasion of Kuwait in mid-1990, the Asian Crisis of 1997, the Venezuelan Crisis in late 2002 (followed by the Iraq War in early 2003), the Great Recession of mid-2008, and the Libyan Revolution of early 2011.

Figure 4. Contribution to Cumulative Change in Real Price of Oil by Structural Shock



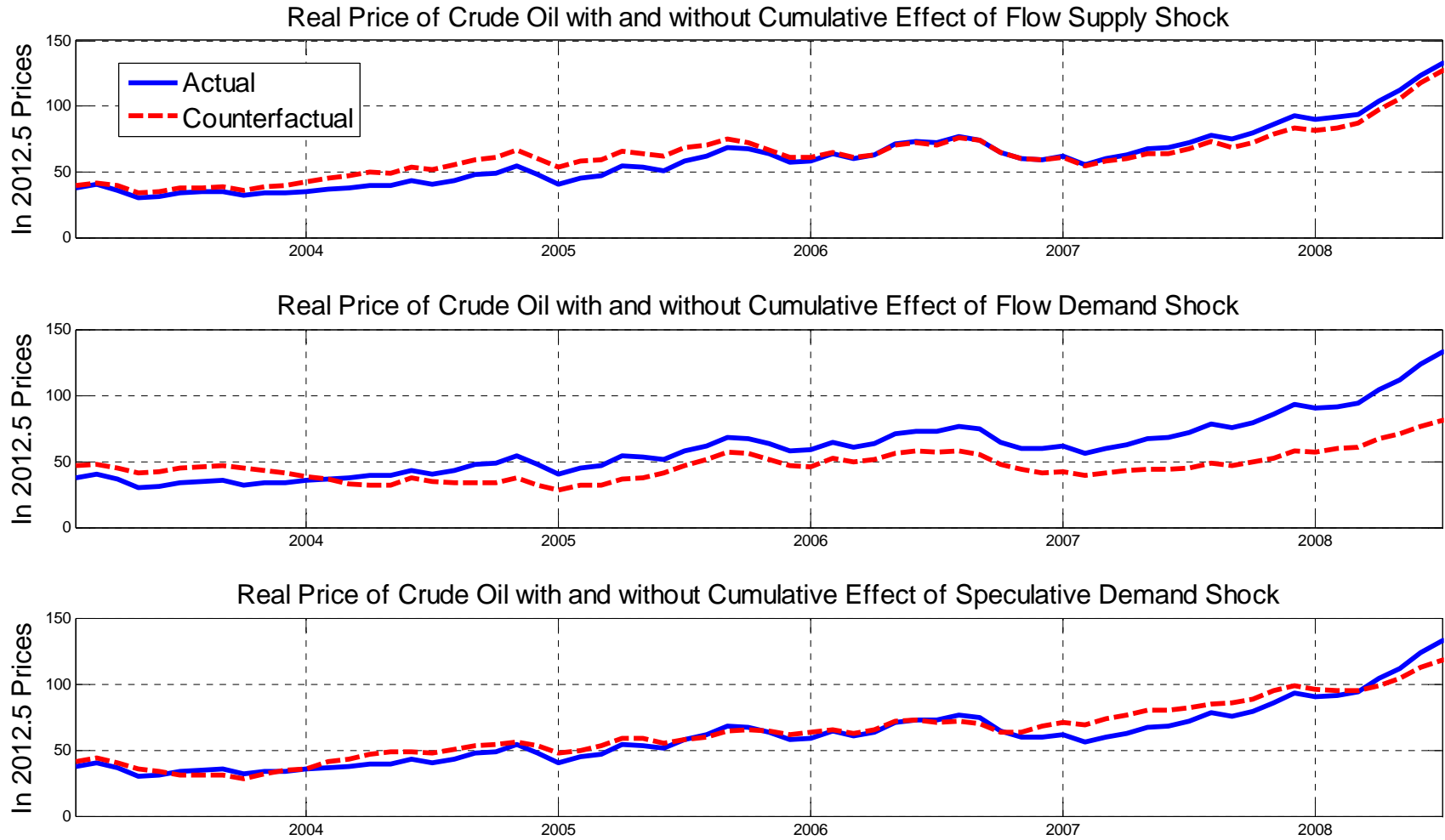
NOTES: 1 = flow supply shock; 2 = flow demand shock; 3 = speculative demand shock; 4 = other demand shock; 5 = observed cumulative change in real price. The contributions of the four shocks add up to the observed change. The figure shows the results for the model whose price elasticity of oil demand in use is closest to -0.26.

Figure 5. Counterfactuals for the Real Price of Oil in 2012.5 Dollars based on the Model Using the Original Inventory Proxy 2003.1-2008.6



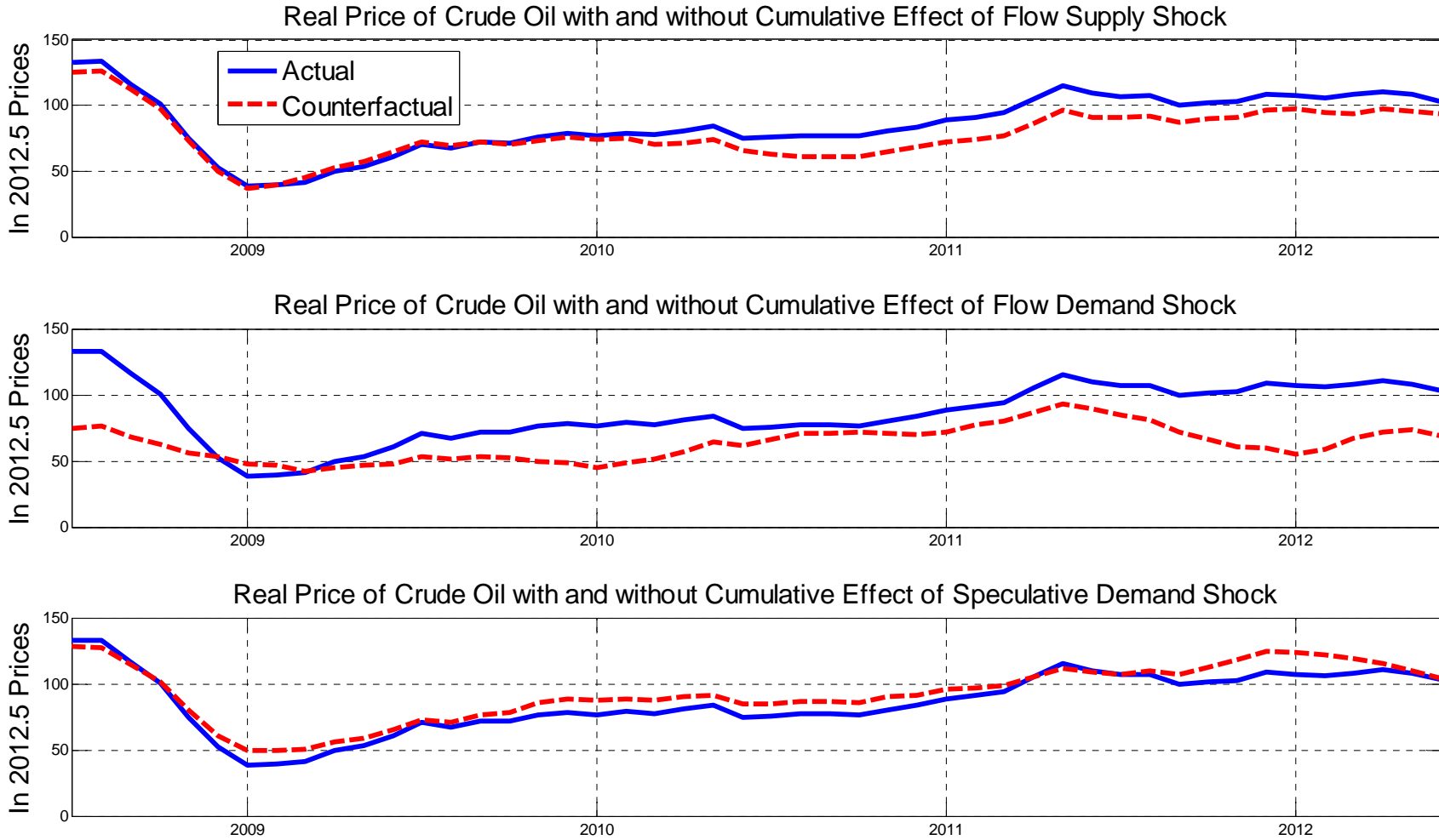
NOTES: The counterfactuals show the evolution of the real price of oil in 2012.5 dollars in the absence of the structural shock in question. If the counterfactual exceeds the actual, for example, the shock in question lowered the real price of oil.

Figure 6. Counterfactuals for the Real Price of Oil in 2012.5 Dollars based on the Model Using the EIG Inventory Proxy 2003.1-2008.6



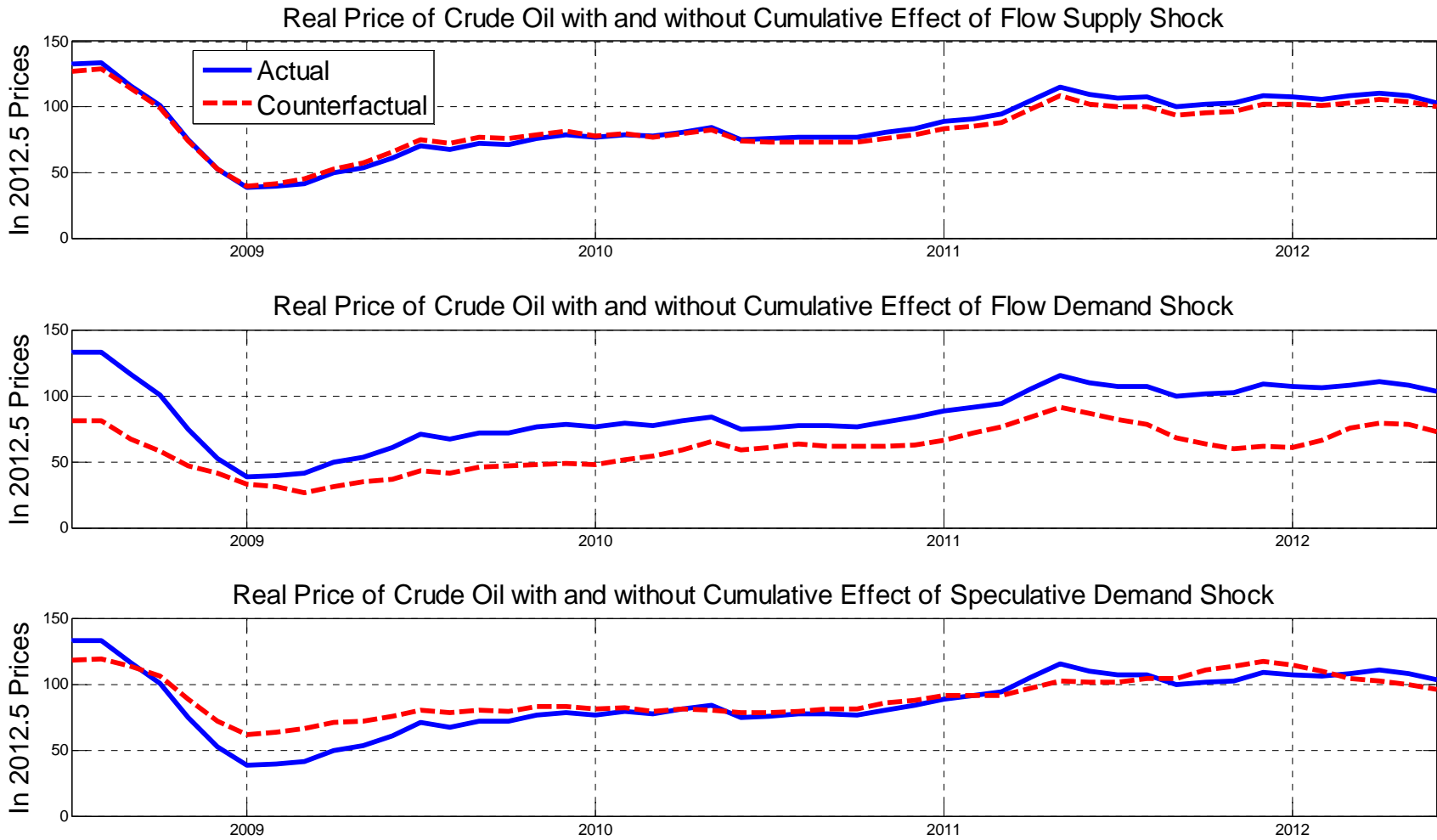
NOTES: See Figure 5.

Figure 7. Counterfactuals for the Real Price of Oil in 2012.5 Dollars based on the Model Using the Original Inventory Proxy 2008.6-2012.5



NOTES: See Figure 5.

Figure 8. Counterfactuals for the Real Price of Oil in 2012.5 Dollars based on the Model Using the EIG Inventory Proxy 2008.6-2012.5



NOTES: See Figure 5.