Working Paper Series
Congressional Budget Office
Washington, D.C.

CBO's Oil Price Forecasting Record

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Working Paper 2020-03

May 2020

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The information in this paper is preliminary and is being circulated to stimulate discussion and critical comment as developmental analysis for the Congress.

For helpful comments and suggestions, I thank Wendy Edelberg, Michael Falkenheim, Sebastien Gay, Joseph Kile, Jeffrey Kling, Mark Lasky, Michael McGrane, and Chad Shirley (all of CBO), as well as Thomas Lee of the Energy Information Administration. Finally, I thank Pranav Bhandarkar for fact check review and Gabe Waggoner for editing.

www.cbo.gov/publication/56356

Abstract

CBO forecasts benchmark prices of oil to support its economic and budgetary projections. This paper describes the method CBO uses to forecast oil prices and assesses the quality of the agency's projections during the 1993–2019 period, including how that quality compares with that of other forecasts.

- **CBO's Method for Forecasting Oil Prices.** CBO projects benchmark prices for three subperiods of the forecast window. During the first subperiod, CBO relies on futures prices for two types of crude oil traded globally and information about the expected relationship between those futures prices and the expected spot price at future dates. Projections during the next subperiod are based on expectations of real (inflation-adjusted) growth of oil prices and inflation. For the last subperiod, projected growth of oil prices is based only on expectations of inflation.

- **Quality of CBO's Forecasts.** CBO's forecasts of the average price of imported oil used by refiners (a measure representative of the price of all oil used domestically) were, on average, close to the actual values for the agency's first-year and fifth-year projections—that is, the year the forecast is released and then 4 calendar years later. Measures of the variability of CBO's forecast errors were nearly three times higher for CBO's fifth-year forecasts than for its first-year forecasts, consistent with the greater uncertainty of future prices. Overall, the quality of CBO's forecasts compared favorably to a forecast using a fixed real price and to other oil price forecasts from the Energy Information Administration and IHS Markit. Those forecasts were compared using first-year and fifth-year projections and each of the three subperiods underlying CBO's price projection of imported oil.

Keywords: oil prices, financial market, energy, forecast, projection, accuracy

JEL Classification: Q02, Q47, C00, G17

Notes

Numbers in the text and tables may not sum to totals because of rounding.

Unless otherwise noted, all years referred to in this paper are calendar years.

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Summary

Twice yearly, the Congressional Budget Office prepares forecasts of economic variables that underlie its projections of the federal budget.[1] Oil prices are one such variable. This paper describes the methods that CBO uses to forecast oil prices and evaluates the quality of the agency's historical forecasts—how small projection errors were, on average, and how their size tended to vary—including how the quality compares with that of other available forecasts. That analysis uses an approach similar to the one CBO regularly uses to evaluate the quality of its economic projections.[2] This analysis focuses on oil prices observed through 2019 and does not include the unexpected drop in oil prices in 2020.

How Does CBO Project Oil Prices?

CBO estimates its measure of oil prices—the refiner acquisition cost (RAC) of imported oil—on the basis of the prices of two crude oil benchmarks, Brent and West Texas Intermediate (WTI), that are widely traded in world oil markets. CBO forecasts prices of all three in each of three distinct periods in the projection window (consisting of the year in which the projection is released plus the next 10 years). For the first 4 years of the projection, CBO uses futures prices along with an expectation of how they are related to expected spot prices in the future to project the prices of Brent and WTI over that period. For the following 5 years, those oil price benchmarks are projected to grow at a constant real (inflation-adjusted) rate and a variable nominal rate. To estimate those rates of growth, CBO relies on outside estimates of real oil price growth and the agency's own forecast of general inflation. For the final 2 years of the forecast, Brent and WTI are projected to grow only at the nominal rate of inflation, remaining constant in real terms. CBO uses those forecasts of the two benchmark crude oil prices to forecast the imported RAC on the basis of the historical relationship between the imported RAC and those benchmark prices.

What Is the Quality of CBO's Oil Price Forecasts, and How Does That Compare With Other Forecasts?

The quality of the historical forecasts was measured by the degree that forecasted values differed from actual values. In this analysis, CBO examined two aspects of quality—centeredness (how close, on average, a projection is to actual values in percentage terms) and accuracy (how widely spread out the differences are). The first was measured by the mean (average) error of the forecast. The second was measured by the mean absolute error (the mean error when the signs of

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[1] Most recently, Congressional Budget Office, *The Budget and Economic Outlook: 2020 to 2030* (January 2020), www.cbo.gov/publication/56020; and *An Update to the Economic Outlook: 2019 to 2029* (August 2019), www.cbo.gov/publication/55551.

[2] See Congressional Budget Office, *CBO's Economic Forecasting Record: 2019 Update* (October 2019), www.cbo.gov/publication/55505.

the errors are ignored) and the root mean square error (the average error when larger individual errors are weighted more heavily).

As measured with those criteria, the quality of CBO's historical forecasts was consistent with that of other analogous forecasts over comparable periods. Over the full 1993–2019 period in which CBO's forecasts are available, the centeredness of CBO's forecasts was –1 percent for CBO's first-year forecasts and nearly zero percent for its fifth-year forecasts. For the first-year forecasts, CBO's mean absolute error was 14 percent and root mean square error was 20 percent. For the fifth-year forecasts, mean absolute error was 44 percent and root mean square error was 55 percent. CBO conducted similar measurements over comparable time frames of three alternative oil price forecasts: one that keeps prices fixed in real terms, one from the Department of Energy's Energy Information Administration (EIA), and one from IHS Markit. The measure of centeredness of CBO's first-year and fifth-year forecasts were comparable to those of other forecasts and were usually closer to zero. The measures of accuracy also were usually lower for CBO than for others, so CBO's forecasts have been more accurate over the period evaluated.

Because CBO constructs its forecast of oil prices by using different methods over three distinct periods within the projection window, the agency also compared the quality of its forecast for each subperiod with analogous measures for the three alternative price forecasts. As with the findings of the first-year and fifth-year projections, the quality of CBO's forecast over those subperiods was usually higher than for the other forecasts.

CBO's Method for Forecasting Oil Prices

CBO's primary measure of crude oil prices is the RAC of imported crude oil (imported RAC), which measures the average cost of crude oil that refiners pay for foreign supplies. CBO prepares its forecast of the quarterly imported RAC in two steps. The first step involves creating a forecast of the quarterly prices of two benchmark crude oils that underlie CBO's projection of the imported RAC. The imported RAC is an average of many prices of crude oil, and not all those crude supplies have active futures markets with which to estimate their prices in future years. CBO uses Brent (a benchmark of light-sweet crude oils produced in the North Sea) and West Texas Intermediate (a benchmark of slightly higher quality crude oils produced in Texas and nearby regions) as its benchmarks because each is actively traded in futures markets. CBO includes WTI (a domestic crude oil) because some imported crude oils—certain imports from Canada, for example—are more highly correlated with the price of WTI than with Brent. The second step involves forecasting the imported RAC on the basis of those two benchmark price projections.

CBO focuses on imported oil—as opposed to the composite RAC, which measures the average cost of foreign and domestic supplies—but little difference exists between using those two alternative measures in CBO's oil price projection over longer periods. Since 2000, the average quarterly imported RAC was just 2 percent less than the average composite RAC, and changes in those quarterly averages were almost perfectly correlated even as the share of imported oil used in the United States decreased substantially.[3] Between 1985 and 2006, imported crude as a share of foreign crude imports and domestic crude production grew from 26 percent to a peak of 67 percent.[4] But the development of domestic shale oil production starting around 2009 and the accelerated growth of production since has reduced that share to 36 percent.[5] Imported crude oil now averages a little less than 7 million barrels per day, down from a peak in 2005 of just over 10 million barrels per day.

How CBO Projects Prices for Brent and WTI Crude Oil

CBO's projection window covers 11 years in total: the year in which the forecast is released and the next 10 years. CBO projects average spot prices quarterly for Brent and WTI over three distinct subperiods within that window:

- **Initial 4 years**, corresponding to the availability of prices in well-developed futures markets;

- **Middle 5 years**, corresponding to CBO's general expectation that U.S. and world economies will return from any short-term economic slowdowns or booms and grow, on average, steadily thereafter; and

- **Final 2 years**, corresponding to the observation that oil prices have had little long-term directionality.

Initial Years. For the initial 4 years of the forecast—the year of the forecast and the next 3 years—CBO projects prices for Brent and WTI by first converting the monthly futures prices into quarterly averages for each benchmark crude oil. For a January forecast, CBO typically finalizes its oil price projection in the first two weeks of December and relies on futures prices at

[3] CBO recently investigated whether to adjust its macroeconomic model to use the composite RAC to account for greater reliance on domestic supplies of oil. The agency concluded that an adjustment would have little quantitative impact on CBO's macroeconomic forecasts.

[4] Determined using data from Energy Information Administration, *Monthly Energy Review*, Table 3.1, "Petroleum Overview"; Table 3.3b, "Petroleum Trade: Imports by Type"; and Table 3.3e, "Petroleum Trade: Exports by Type" (March 2020), www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf (3.1 MB; accessed April 22, 2020).

[5] Though the volume of imported oil has declined, one reason imports remain elevated is because the United States exports large volumes of crude oil, which was not permitted before 2016. U.S. refiners are generally better configured to process heavier, less costly crude oils. Because U.S. production of shale oil—a light crude oil—has grown dramatically over the past decade, the lifting of the ban on crude oil exports has allowed supplies of U.S. light crude to be sent overseas in exchange for additional imports of heavier foreign crudes.

that time.[6] (The agency uses a similar process for the update to the budget and economic outlook typically produced in summer.)

The agency then adjusts those quarterly futures prices to account for differences in the risk of buying supplies of oil earlier by entering into a futures contract instead of waiting and purchasing oil at spot prices later. Specifically, future spot prices are uncertain and market prices are volatile, so risk-averse buyers and sellers of oil have an incentive to contract at earlier times for deliveries later: A futures contract locks in the price the buyer will pay for later supplies. Changes in oil prices tend to be positively correlated with changes in gross domestic product (GDP)—although supply factors exert a negative influence on that relationship, as discussed below. Therefore, buyers of futures contracts tend to financially benefit in good economic times and experience losses in bad economic times, creating a positive systemic risk for the buyer. In return for taking on that risk, the buyer expects to receive a premium, which takes the form of the contracted futures price of oil being less than the expected spot price, all else equal.[7] In other words, the buyer of the futures contract can expect to earn a profit by buying crude in the futures market at a price below what they expect they can sell that supply at the date of expiry.[8] In equilibrium, that expected return compensates the buyer for the uncertainty that spot prices may depart from expectations. Sellers of crude oil—though they receive a lower price for their supply than what they would expect to receive by not contracting ahead and instead selling only in the spot market—receive a guaranteed price for their supply, which reduces their own risk.

CBO estimates that the risk adjustment, first estimated at 1 percent per year in 2010, has since risen to about 2 percent per year beginning in 2019.[9] In the agency's assessment, market changes over the decade—chiefly, the growth in U.S. shale production, which has propelled the United States to become the world's largest oil producer—have increased the risk premium for oil. The risk premium for oil weighs two factors: price effects resulting from demand-side changes (greater or lesser preference for oil) and effects stemming from supply-side changes (higher or lower supply available in the market). Demand-side changes in oil prices tend to be procyclical

[6] CBO has sometimes updated its projections before the release of its outlook whenever oil prices changed significantly between December and the release of the budget and economic outlook.

[7] Christopher R. Knittel and Robert S. Pindyck, "The Simple Economics of Commodity Price Speculation," *Macroeconomics*, vol. 8, no. 2 (April 2016), pp. 85–110, https://doi.org/10.1257/mac.20140033; and Robert S. Pindyck, "The Dynamics of Commodity Spot and Futures Markets: A Primer," *Energy Journal*, vol. 22, no. 3 (2001), pp. 1–29, www.jstor.org/stable/41322920.

[8] A purchaser of a futures contract, such as a refiner, may choose to use that contracted supply of oil instead of selling it at the prevailing market price. That also represents a return to the refiner because, in expectation, the refiner can purchase crude oil inputs at a lower price than if it had waited and instead purchased crude in the spot market.

[9] CBO phases in the risk adjustment to futures prices for crude oil—by a little less than one-half of 1 percent per quarter for the 2 percent overall risk adjustment (and by about one-quarter of 1 percent for the 1 percent overall adjustment)—and compounds that adjustment quarterly.

with economic activity: The demand for oil rises during expansions and increases oil prices, for instance. That positive relationship between economic activity and demand-driven increases in oil prices is enhanced by the gains to U.S. oil producers, who produce oil today in much greater volumes than during times past.

In contrast, supply-side increases in oil prices—for example, by the Organization of Petroleum Exporting Countries withholding crude supplies from the market or by unplanned reductions in supply elsewhere—generally had a negative effect on economic activity and were countercyclical when the United States was not such a large producer of oil. But the growth in U.S. domestic production is an offset against that negative association: As in earlier times, domestic oil producers receive higher prices for their production, but now those benefits are greater because of the much larger volume of oil produced today. The benefits to domestic suppliers help offset a larger portion of negative effects of supply-driven increases in prices. As a result, the overall relationship between oil prices and the U.S. economy is now weighted more heavily toward the demand-driven relationship between oil prices and economic activity. On net, that greater weighting has resulted in a more positive risk premium.

Middle Years. For the next 5 years of the projection (years 5 through 9 of the 11-year window), CBO extends the quarterly projection of Brent and WTI in the first 4 years by combining a constant quarterly projection of real price growth for those oil benchmarks with a quarterly projection of overall inflation.

For growth of real prices of Brent and WTI during that portion of the forecast window, the agency relies on EIA's projection of long-term real prices available in CBO's most recent long-term outlook. To smooth out year-to-year variation, CBO uses a multiyear average of EIA's annual rates of real price growth of imported oil for years starting midway through CBO's forecast window to estimate a constant rate of growth of real prices of Brent and WTI. On the basis of EIA's most recent forecast, real price growth for those benchmarks is projected to average about 1.8 percent per year over the 2026–2040 period (a little less than 0.5 percent per quarter).[10]

To account for nominal growth in oil prices, CBO uses its own forecast of annual inflation as measured by the GDP deflator. The agency relies on that economywide measure of price growth because oil is used during all stages of production and in all parts of the economy. As projected

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[10] See Energy Information Administration, *Annual Energy Outlook 2020*, *With Projections to 2050* (January 29, 2020), www.eia.gov/outlooks/aeo/.

in CBO's most recent outlook, growth in the GDP deflator is expected to average a little more than 2 percent per year over the forecast period (about 0.5 percent per quarter).[11]

In contrast to the method for the initial years, CBO does not rely on prices of Brent and WTI in futures markets for middle or late years. When the agency was formulating its current method for projecting oil prices, reliable futures prices were available only for a year or two into the future.[12] But even once futures contracts became available for more years in the future, longer-term futures continued to be traded much less often than near-term futures. That trend raised some question about the reliability of the price information in making longer-term price projections.[13]

Because CBO uses different methods of constructing projections of benchmark oil prices for initial and middle years, those two methods are blended to smooth the transitional period. CBO projects benchmark prices by using both methods for the last year of the initial period and the first year of the middle period (eight quarters in total) and then calculates a time-weighted average of both results. That average initially places more weight on the estimates using the method of the initial years and puts more weight later on the estimates using the method of the middle years.

Late Years. For the last 2 years of the forecast (years 10 and 11 of the forecast window), CBO projects that quarterly benchmark oil prices will increase only at the rate of inflation so that no real growth in prices occurs during those years. The expectation that those prices do not grow in real terms is consistent with those benchmarks' having little overall directionality in the long term. As with the middle years, inflation is measured using CBO's quarterly projection of the GDP deflator.

CBO chooses year 10 as the period when real price growth ceases. That choice serves to balance near-term market conditions, which are described by futures markets, with an outlook that the economy will recover from any short-term disequilibrium and return to a steady rate of growth consistent with the economy's producing at its maximum sustainable level. (The maximum

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[11] Congressional Budget Office, *The Budget and Economic Outlook: 2020 to 2030* (January 2020), www.cbo.gov/publication/56020.

[12] Although oil price futures became available at the New York Mercantile Exchange (NYMEX) starting in 1983 and at the Intercontinental Exchange starting in 1988, those futures were initially available for a term of only about 1 year. Availability expanded over the later years, but not until 2005 did monthly futures become available out through about 5 years.

[13] For the January 31, 2020, trading day at the NYMEX, for example, about 1.5 million transactions were made for 2020 deliveries of crude oil. More than half of those (about 800,000) were for March deliveries alone. The number of transactions for deliveries for the same months (March through December) totaled about 50,000 for 2022 and declined to about 600 in 2024. See https://tinyurl.com/CME20200131 (accessed February 3, 2020; volumes of contracted crude oil futures are publicly available at CME Group for a limited time).

sustainable level is a level of economic activity in which no upward or downward pressure on inflation or interest rates is present.) Among alternative forecasts, a wide range exists over which the transition to no real price growth is modeled to occur. EIA, for instance, projects real growth in the cost of imported oil for its projection out to 2050, whereas other outlooks have real growth of prices ceasing after the first few years. The timing of CBO's transition to no real price growth reflects a middle ground.

How CBO Projects Refiner Acquisition Cost on the Basis of Projected Crude Oil Prices
CBO projects the real quarterly imported RAC as an average of two estimates: one based on projections of real prices of Brent and WTI and the other based on a projection of only the real price of Brent. The specifications use the natural logarithms of the prices involved, with the particular year and quarter of each observation denoted with the subscript *t*.

$$\ln(RAC(1)_t) = \beta_1 + \beta_2 \times \ln(Brent_t) + \beta_3 \times \ln(WTI_t)$$

$$\ln(RAC(2)_t) = \beta_4 + \beta_5 \times \ln(Brent_t)$$

Coefficients for the first equation are estimated starting with data for 2001, whereas those for the second equation are estimated beginning with 2006 data.[14] The second equation is used because the prices of Brent and WTI started to diverge (consistently starting in 2011 but occasionally on a quarterly basis in 2007 and 2009), and the price of Brent exerted more influence on the cost to refiners of acquiring crude oil.[15] That closer dependence on Brent largely occurred for two reasons. First, refiners buy a large share of crude oil either from overseas sources, which generally track the price of Brent, or from domestic sources that have prices more closely linked to Brent than to WTI (Louisiana Light or Alaskan North Slope oil, for example). Second, petroleum products made from crude oil—gasoline, diesel fuel, and others—are traded in international markets, and their prices more closely follow the price of Brent than of WTI.

[14] CBO's estimate of the relationship between RAC and Brent alone is estimated with data starting later than when RAC is measured against WTI and Brent jointly. That was done to capture any newly developing relationship between RAC and Brent that started after 2006.

[15] For many years, the prices of Brent and WTI moved in lockstep, with the price of Brent being a few dollars below that of WTI. Although that relationship would occasionally reverse, the large growth of U.S. shale oil production staring around 2010 often caused the price of WTI to fall below that of Brent. Before 2016, U.S. crude supplies could not, by law, be exported to overseas markets, so that domestic oil prices declined to ensure that domestic refiners purchased the growing supplies. From 2011 to 2014, the monthly price for Brent averaged about $13 per barrel more than for WTI. After the lifting of the restriction on crude oil exports at the end of 2015, that difference declined so that Brent has since averaged about $4 more than WTI, an amount that broadly reflects differences in the costs of exporting those oil supplies to foreign markets.

Starting with those dates, CBO estimates the historical relationships through the most recent quarter of data available each time the agency forecasts prices. Based on data through the third quarter of 2019, the results of the estimation used for the January 2020 projection were:

$$\ln(RAC(1)_t) = -0.26 + 0.65 \times \ln(Brent_t) + 0.39 \times \ln(WTI_t)$$

$$\ln(RAC(2)_t) = -0.33 + 1.05 \times \ln(Brent_t)$$

CBO's overall estimate of the imported RAC is the average of those two estimates. In particular:

$$RAC_t = 0.5 \times RAC(1)_t + 0.5 \times RAC(2)_t$$

Together, those regression equations place about four times more weight on the price of Brent than on the price of WTI. That is, at January 2020 prices of about \$55 per barrel for WTI and \$60 for Brent, a \$1 increase in the price of WTI (with the price of Brent remaining fixed) would increase the estimated imported RAC by \$0.19. By contrast, a similar \$1 increase in Brent would increase the estimated imported RAC by \$0.75 (all else equal).

Assessing CBO's Oil Price Forecast

Oil prices are uncertain and can fluctuate dramatically, causing projections to contain errors. CBO assessed the quality of its forecasts of the imported RAC by using several measures to evaluate how close, on average, the forecasted prices were to the actual imported RAC and how spread out the deviations tended to be. CBO also compared its forecasts with others over similar time horizons. On average, CBO's forecasts were about as close to actual as other forecasts, and the errors tended to be less spread out than those of other forecasts.

CBO's Historical Forecasts and Oil Price Uncertainty

Dating back to 1993 (the earliest that CBO's oil price forecasts are available), CBO's average annual oil price projection of imported RAC was within 20 percent of the actual average about one-third of the time (see **Figure 1**). For the other two-thirds of the time, CBO was about twice as likely to underproject the imported RAC as to overproject it. As expected, forecasts of near-term prices have been more accurate than for longer-term prices. Projections for the average first-year imported RAC (that is, the year of the forecast) were within 20 percent of the actual for 19 of CBO's 27 price forecasts. By contrast, projected fifth-year imported RAC (those 4 years later) were within 20 percent of the actual level for 5 of 23 forecasts. (Fifth-year accuracy cannot be evaluated for the last four of CBO's forecasts because a fifth year for those forecasts has not yet occurred.)

Many of those errors occurred because of sudden, large, and long-lasting changes in market prices. The average yearly imported RAC rose nearly 30 percent in 2004 and through 2019 remained above its 2003 average. Beginning in 2004, forecasts that CBO had made in earlier years underprojected the imported RAC (see **Figure 1**). And because oil prices continued to increase significantly in following years, even newly constructed forecasts underprojected prices. CBO's forecast is designed to balance both upside and downside risks by tracking a middle range of possible outcomes. The probability of an abrupt change in prices in a particular year is typically low so that such changes are usually not in CBO's baseline projection. Thus, the agency did not project the large and persistent upward price movement that began in 2004. Neither did CBO project the approximately 50 percent decline in the average annual imported RAC between 2014 and 2015 that led to many overprojections in later years.

Oil prices are inherently uncertain and hard to predict. For instance, from June 2014 through January 2015, the price of WTI declined from about $110 to below $45 per barrel. Although prices rebounded in the months after, the price of WTI later declined further and finished 2015 at about $35 per barrel, a level unanticipated by the market. Market prices for oil futures and options contracts can be combined to estimate market expectations of future spot prices and the range of uncertainty around them. In summer 2014, before prices fell, EIA estimated a 95 percent chance that prices would be between $80 and $120 per barrel by the end of 2014 and between roughly $65 and $130 by the end of 2015 (see **Figure 2**).[16] On the basis of that estimation, the chance that WTI would fall to the levels it did by the end of 2014 or the end of 2015 was considerably less than 1 percent.[17]

Measures for Assessing CBO's Forecasts

To fully characterize the quality of CBO's forecasts, the agency applies three measures of forecast error to assess its oil price projections: mean error, mean absolute error, and root mean square error.

The mean error measures the extent to which the forecasts were systematically too high or too low with respect to actual outcomes. The mean absolute error and the root mean square error (RMSE) focus on the absolute size of the errors without regard to whether they are positive or negative, though RMSE places more weight on larger errors. The mean error measures the centeredness of the forecast—how close, on average, forecasted prices are to actual prices—and the mean absolute error and the RMSE measure the accuracy of the forecast. Together, centeredness and accuracy measure the quality of a forecast.

Mean Error. The arithmetic average of forecast errors—the mean error—measures the centeredness of a forecast. (Centeredness is sometimes referred to as bias: the tendency of a forecast to be systematically too high or too low.) If the mean error—measured as the percentage

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[16] Energy Information Administration, *Short-Term Energy Outlook* (June 2014), www.eia.gov/outlooks/steo/archives/jun14.pdf (0.9 MB).

[17] Measured by the implied volatility of NYMEX crude oil futures, market expectations of oil price volatility were lower than historical levels in 2014. Accordingly, a large change in market prices for oil was then considered particularly less likely than what would have been expected at other times.

by which the forecast differs from actual values on average—is large (whether positive or negative), that would suggest the forecast systemically overstated or understated future oil prices. By contrast, a mean error near zero would indicate that, on average, the forecast accurately projected future oil prices.

However, the mean error does not fully characterize the quality of a forecast. Because positive and negative errors are summed to calculate the average, underprojections and overprojections offset each other. A small mean error might indicate that an oil price projection might have been accurate overall, generally close to the actual outcomes. But a small mean error also can result from large overprojections and large underprojections that offset each other. To distinguish those outcomes, CBO also measures the accuracy of the forecast.

Mean Absolute Error. The mean absolute error measures the average accuracy of forecast errors without regard to whether individual errors are positive or negative. A larger mean absolute error indicates that a typical forecasted oil price differed substantially from the actual value regardless of whether the forecast was above or below the actual value. The mean absolute error is the arithmetic average of the errors when the signs of those errors are ignored, and it ensures that positive and negative errors do not offset each other.

Root Mean Square Error. Forecast accuracy also is measured by the RMSE, an additional measure of the average variation of forecast errors. The RMSE is calculated by squaring the forecast errors, averaging those squares, and taking the square root of that average. That calculation places greater weight on instances in which the forecasted values deviate substantially from actual values. Unlike the mean error, but similar to the mean absolute error, forecast underprojections and overprojections do not offset each other when the RMSE is computed. Because of the additional weight that the RMSE places on large errors, the RMSE is never smaller than the mean absolute error and will be equal to it only when all forecast errors are the same size.

Quality of CBO's Forecasts

To evaluate the three measures of forecast quality, CBO first calculated annual forecast errors for each of the agency's long-term forecasts.[18] To do that, CBO averaged each year's quarterly forecast of imported RAC and compared that with the average actual imported RAC for the year.

The first-year mean forecast error over the 1993–2019 period was about –1 percent, meaning that, on average, CBO underprojected the imported RAC by about 1 percent in the first year (see **Figure 3**). But forecast errors in individual years varied, sometimes considerably: Yearly

[18] Because CBO typically releases budget and economic projections in January, the first year of a forecast is that same year that the projections are released. Similarly, the fifth year of the forecast will be the fourth year after the projections. Accordingly, for CBO's 2015 projection, for example, the first year is 2015 and the fifth year is 2019.

forecast errors ranged from –28 percent (an underprojection) to 54 percent (an overprojection). The average fifth-year error, at zero percent, was about the same as the first-year mean error and suggested that CBO correctly projected the fifth-year imported RAC, on average. However, errors in individual years had more variation: Fifth-year errors ranged from –70 percent to 145 percent.

Consistent with the differences in the range of errors, first-year forecasts were more accurate than fifth-year forecasts, measured by both the mean absolute error and the RMSE (see **Figure 4**). The mean absolute error was 14 percent for first-year forecasts, meaning that a typical first-year forecast was about 14 percent away from the actual value (regardless of whether the forecast under- or overstated actual prices). The mean absolute error was 44 percent for fifth-year forecasts, about three times that for first-year forecasts. Likewise, the RMSE—at 20 percent for first-year forecasts and 55 percent for fifth-year forecasts—was about two and a half times higher for the fifth-year forecasts than for the first-year forecasts. The relative magnitudes of those findings are consistent with longer-term forecasts being more uncertain than shorter-term forecasts.

To investigate the effects of the risk adjustment used when projecting future spot prices, CBO also assessed the quality of its forecasts with and without the risk adjustment. That risk adjustment slightly affects the quality because the risk adjustment itself is small, particularly when compared with often large changes in oil prices (see **Box 1**).

How the Quality of CBO's Forecasts Compared With That of Other Forecasts

CBO also compared the quality between its forecasts and others. Relatively few forecasts of oil prices exist beyond short-term projections of a year or two. Therefore, in this analysis CBO compares its forecast with three alternative forecasts of the imported RAC: a projection that has the imported RAC remaining fixed in real terms, EIA's annual long-term projection of imported RAC, and IHS Markit's monthly projection released monthly to subscribers.[19]

The fixed oil price projection is equivalent to a forecast of real oil prices having a random walk with no drift, meaning that the real price at a moment in time is the best predictor of real prices

[19] EIA's *Annual Energy Outlook* is typically released in the first months of the year, so that, depending on timing, some of EIA's first-year forecast may already be informed by market developments in that year. Because IHS releases new forecasts monthly, CBO relied on IHS's December forecast when measuring its forecast quality starting the next year. See, for example, Energy Information Administration, *Annual Energy Outlook 2019*, *With Projections to 2050* (January 24, 2019), www.eia.gov/outlooks/aeo/; and IHS Markit, "U.S. Economic Outlook: U.S. Short-Term Forecast Tables—Baseline and Alternatives (Excel)" (December 2018; subscription required).

going forward.[20] To compare, the agency constructed a set of fixed-price forecasts by using the most recent imported RAC available when CBO makes its forecast each year in January. Because of a delay of several weeks in when estimates of the imported RAC are available, the most recent estimate is for the third quarter of the prior year. Those quarterly estimates were modeled to grow only by inflation, as measured by CBO's forecast of GDP deflator growth in the January forecast, averaged over the projection window. Because oil prices vary seasonally—the third-quarter imported RAC has averaged about 3.5 percent more than its yearly average since 1988—CBO reduced each fixed oil price projection by that percentage so that the annual projections comport with historical experience.[21]

Historical forecasts from EIA and IHS are not available for the same period as CBO's forecasts. EIA's long-term forecasts are available starting in 1999, and IHS's forecasts are available starting in 2003. To harmonize the periods covered, CBO made three comparisons of the forecasts, one comparison starting in the year when each new forecast is available. Consequently, CBO's forecast is compared with a fixed real forecast starting in 1993; with both a fixed real forecast and EIA's forecast starting in 1999; and with a fixed real forecast, EIA's forecast, and IHS's forecast starting in 2003.

Assessment of First- and Fifth-Year Quality. For both the first-year and fifth-year measures, the quality of CBO's projections compared favorably to the other available long-term forecasts (see **Table 1**).[22] For instance, the centeredness of CBO's forecasts over the full 1993–2019 time frame was about the same as for the fixed real forecast. CBO underprojected first-year imported RAC by 1 percent and correctly projected fifth-year values (on average), whereas a fixed real price forecast would have overprojected first-year RAC by 2 percent and fifth-year imported RAC by 3 percent. But CBO's forecasts were more accurate. The mean absolute error of CBO's forecasts was 14 percent for first-year forecasts and 44 percent for fifth-year, compared with 22 percent and 48 percent, respectively, for the fixed real price forecast. Similarly, the RMSE of CBO's forecasts was 20 percent and 55 percent for its first-year and fifth-year forecasts,

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[20] CBO considered how drift affects a random walk, though little reliable information is available about the drift in oil prices beyond the overall trend during the period investigated—a trend that may have arisen simply from chance given the year-to-year volatility of prices.

[21] CBO estimated the 3.5 percent seasonality effect in the third quarter by using data from Energy Information Administration, *Petroleum and Other Liquids: Spot Prices*, www.eia.gov/dnav/pet/pet_pri_spt_s1_m.htm (accessed February 12, 2020); and *Petroleum and Other Liquids: Refiner Acquisition Cost of Crude Oil*, www.eia.gov/dnav/pet/pet_pri_rac2_dcu_nus_m.htm (accessed February 12, 2020).

[22] CBO also investigated a comparison between the quality of its forecast with that of a mean-reverting forecast—a projection in which, absent other market developments, oil prices would either rise or decline to a long-run value depending on whether they were initially below or above that value. But because oil prices have fluctuated so widely, it was not possible to reliably estimate the long-run price of oil toward which oil prices would trend or the rate at which oil prices would converge to that long-run value.

respectively, compared with 32 percent and 60 percent, respectively, for the fixed real price forecast.

Shortening the period allowed CBO to compare its forecasts with those of EIA and IHS. The fixed real forecast had the smallest mean error (closest to zero) for the first-year measure over both the 1999–2019 and 2003–2019 time frames, with CBO's centeredness being about the same as that for EIA in both cases. Except for the 2003–2015 period, in which the mean error for CBO was slightly above that of IHS, CBO's fifth-year forecasts were at least as centered as the other projections for all periods evaluated.

CBO's measures of forecast accuracy were comparable to (and mostly smaller than) the others for all time frames, so that the instances of lower mean errors in other forecasts probably occurred because similarly large individual positive and negative errors in those forecasts offset each other. The mean absolute error and RMSE for EIA forecasts were lower for first-year forecasts over the 1999–2019 period and the 2003–2019 period but higher for fifth-year forecasts during both periods. Similarly, the mean absolute error and RMSE of CBO's forecasts were lower than those of IHS for the first- and fifth-year forecasts.

Assessment of the Quality of CBO's Three Methods of Forecasting Prices. In CBO's assessment, the factors underlying spot oil prices in the future are different across the initial, middle, and late years of the forecast window. As a result, the agency compared the measures of centeredness and accuracy of each subperiod with the corresponding portions of the other forecasts (averaged over the years within each subperiod). The analysis starts in 2003, the most recent year for which all other forecasts were available.

As with the assessment of CBO's first- and fifth-year forecasts, the quality of CBO's subperiod forecasts compares favorably to those of other available forecasts. CBO's forecasts are nearly always more centered than the other forecasts. CBO's mean forecast errors—which range from zero percent to 15 percent—are smaller than the mean errors for EIA or for the fixed real forecast in each subperiod of CBO's forecast (see **Table 2**). CBO and IHS had comparable mean errors for the initial years and for the late-year forecasts, though CBO's mean error was a little more than half that of IHS for the middle years.

Fewer differences were apparent in forecast accuracy. Although the mean absolute error and the RMSE for CBO's projections were nearly always smaller than the others, the differences were often slight (see **Table 3**). For instance, the mean absolute error for CBO for the initial years—at 30 percent—was little different from that for EIA or IHS in that subperiod. Likewise, the RMSE for CBO was much the same as that for IHS for the initial years and the middle years and smaller than that for the fixed real forecast and for EIA in all years. The RMSE for CBO was higher than that for IHS in the late years.[23]

[23] IHS does not make available oil price projections for more than 10 years out, so that CBO's calculation of IHS oil price quality for late years is based only on IHS's 10th-year projection. Because forecasts of longer duration are generally more uncertain than those of shorter duration, the measures of quality of the IHS forecast in the late years are probably understated.

Box 1. [Return to Text]

Assessing Risk Adjustment in CBO's Forecasting Method

Beginning in 2010, the Congressional Budget Office modified its method for forecasting imported RAC in the initial years of the forecast window. The agency began including a risk adjustment to the futures prices of Brent and WTI used in the forecast. At the time, the agency estimated that the price adjustment was about 1 percent per year—that is, expected future spot prices would be about 1 percent higher per year than the price of available futures contracts. CBO recently estimated that, because of market changes since the time the risk adjustment was estimated, the current risk adjustment is about 2 percent per year.

To evaluate how the quality of CBO's forecasts depends on the risk adjustment used when projecting future oil prices, the agency created two synthetic forecasts of imported RAC by using its current projection methods with alternative values for the risk adjustment. The first uses no risk adjustment. The second uses the same 1 percent risk adjustment for all forecasts before 2019 and a 2 percent risk adjustment for the 2019 projection, the first projection after CBO reassessed the risk adjustment in late 2018. In both cases, those synthetic forecasts begin in 2005, the first year that futures prices for Brent and WTI became available out through about 5 years. Thus, the synthetic forecasts represent projections that would have been made using CBO's current approach (with and without the risk adjustment) had that method been in effect in all prior years when market data were available.[1]

Dropping that risk adjustment on the forecast slightly affected first-year forecasts, but the effect was larger for fifth-year forecasts (see **Table 4**). For the first-year synthetic forecast with a risk adjustment, the mean error was slightly closer to zero than for the forecast without a risk adjustment, though the measures of forecast accuracy were largely unaffected. The effect was small because the cumulative adjustment to prices also was small—less than 1 percent for the first-year forecast before 2019 (and less than 2 percent for the 2019 forecast) because the risk adjustment is phased in quarterly. Differences in the forecast imported RAC are larger for fifth-year forecasts owing to the accumulation of the risk adjustment over the first 4 years.

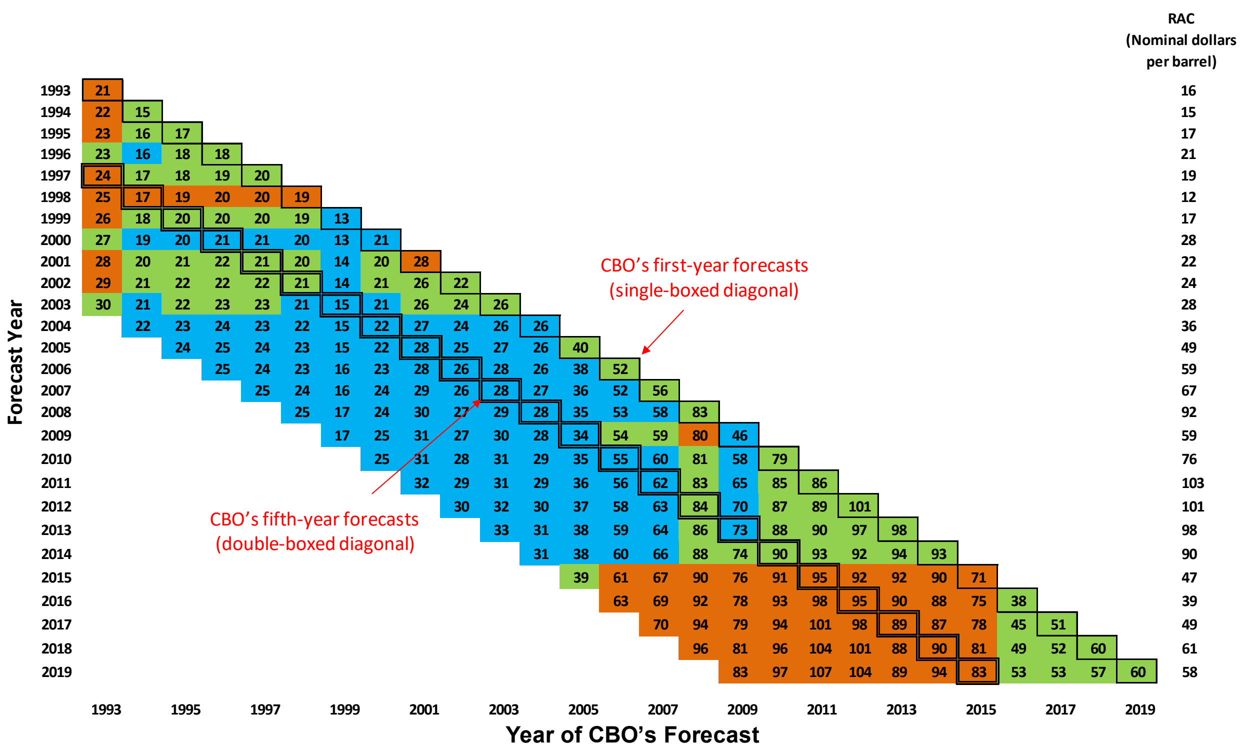
Risk-adjusted prices for fifth-year forecasts had lower quality than those without the adjustment primarily because of large movements in market prices after 2014. For CBO's 2005 through 2010 forecasts, projections of fifth-year imported RAC turned out to be less than actual 4 years later over the 2009–2014 period (see **Figure 5**). During those years, including the risk premium improved the quality of the forecasts. However, the forecasts did not capture the later decline in oil prices starting in 2015, so that the 2011 through 2015 fifth-year imported RAC projections overstated actual values 4 years later (2015 through 2019). In that case, the risk adjustment amplified the overprojection of the forecast. The overprojections in those years were large enough to reduce the overall quality of the forecasts over the full 2005–2015 period for which fifth-year forecast quality can be evaluated. That finding does not suggest that risk adjustments should be excluded as a general matter, only that large changes in market prices can dwarf the small risk adjustment.

[1] Forecasted prices from the synthetic forecast with the risk adjustment are not the same as those of CBO's actual historical forecasts—partly because CBO's current method has not always been in place. It is also because, when re-creating the synthetic forecasts with and without the risk adjustment, the agency standardized the historical futures used as those in early December before each annual forecast. Doing so ensures that the differences in quality between the two synthetic forecasts are only a product of the risk adjustment and not a result of differences between the underlying futures prices used. CBO's actual forecast relied on futures prices at different dates in December and January.

Figures

Figure 1. [Return to Text 1; 2]
A Comparison of CBO's Projections of Imported RAC With Actual Values

Average annual imported RAC of crude oil (Nominal dollars per barrel)



Forecast Year	1993		1995		1997		1999		2001		2003		2005		2007		2009		2011		2013		2015		2017		2019	RAC (Nominal dollars per barrel)
1993	21																											16
1994	22	15																										15
1995	23	16	17																									17
1996	23	16	18	18																								21
1997	24	17	18	19	20																							19
1998	25	17	19	20	20	19																						12
1999	26	18	20	20	20	19	13																					17
2000	27	19	20	21	21	20	13	21																				28
2001	28	20	21	22	21	20	14	20	28																			22
2002	29	21	22	22	22	21	14	21	26	22																		24
2003	30	21	22	23	23	21	15	21	26	24	26																	28
2004		22	23	24	23	22	15	22	27	24	26	26																36
2005			24	25	24	23	15	22	28	25	27	26	40															49
2006				25	24	23	16	23	28	26	28	26	38	52														59
2007					25	24	16	24	29	26	28	27	36	52	56													67
2008						25	17	24	30	27	29	28	35	53	58	83												92
2009							17	25	31	27	30	28	34	54	59	80	46											59
2010								25	31	28	31	29	35	55	60	81	58	79										76
2011									32	29	31	29	36	56	62	83	65	85	86									103
2012										30	32	30	37	58	63	84	70	87	89	101								101
2013											33	31	38	59	64	86	73	88	90	97	98							98
2014												31	38	60	66	88	74	90	93	92	94	93						90
2015													39	61	67	90	76	91	95	92	92	90	71					47
2016														63	69	92	78	93	98	95	90	88	75	38				39
2017															70	94	79	94	101	98	89	87	78	45	51			49
2018																96	81	96	104	101	88	90	81	49	52	60		61
2019																	83	97	107	104	89	94	83	53	53	57	60	58

Source: Congressional Budget Office.

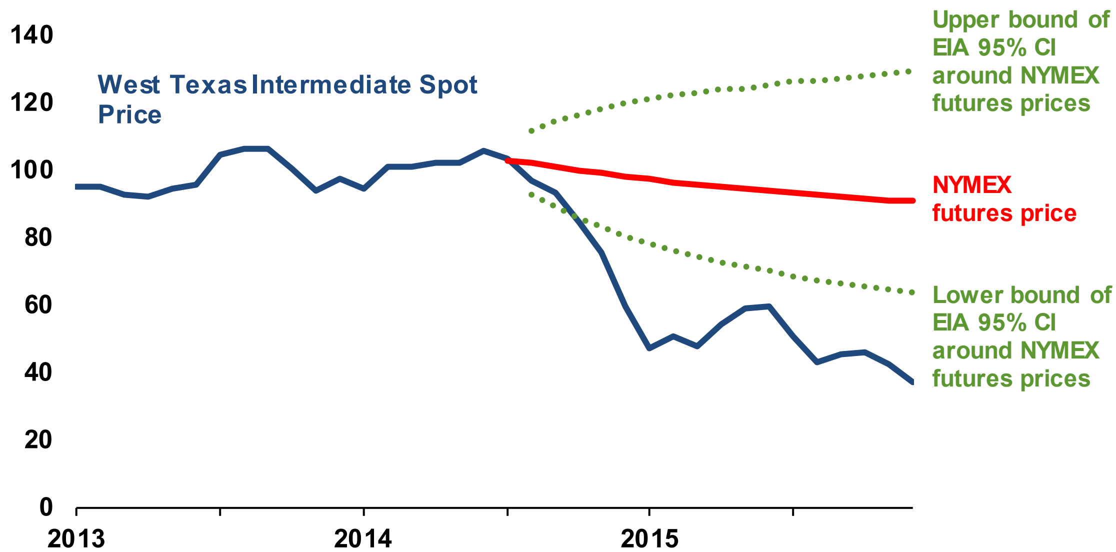
Blue = RAC underprojected by more than 20 percent; green = RAC within 20 percent of actual; orange = RAC overprojected by more than 20 percent. Forty-five percent of projections are coded blue, 31 percent are green, and 24 percent are orange.

RAC = refiner acquisition cost.

Figure 2. [Return to Text]

West Texas Intermediate Crude Oil Price With EIA's 95% Confidence Interval of Future Prices, Using June 2014 NYMEX Futures

Dollars per barrel



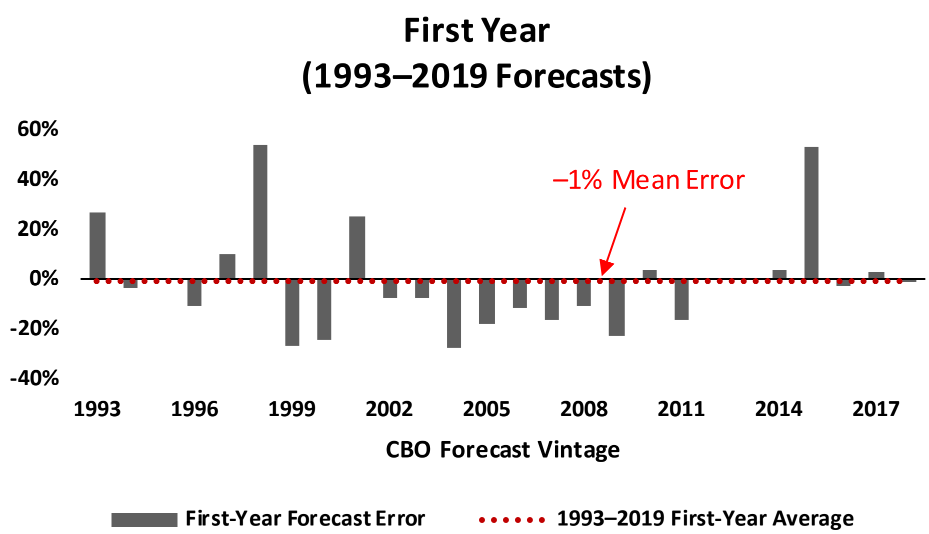
Source: Congressional Budget Office, adapted from Energy Information Administration, *Short-Term Energy Outlook* (June 2014), www.eia.gov/outlooks/steo/archives/jun14.pdf (0.9 MB).

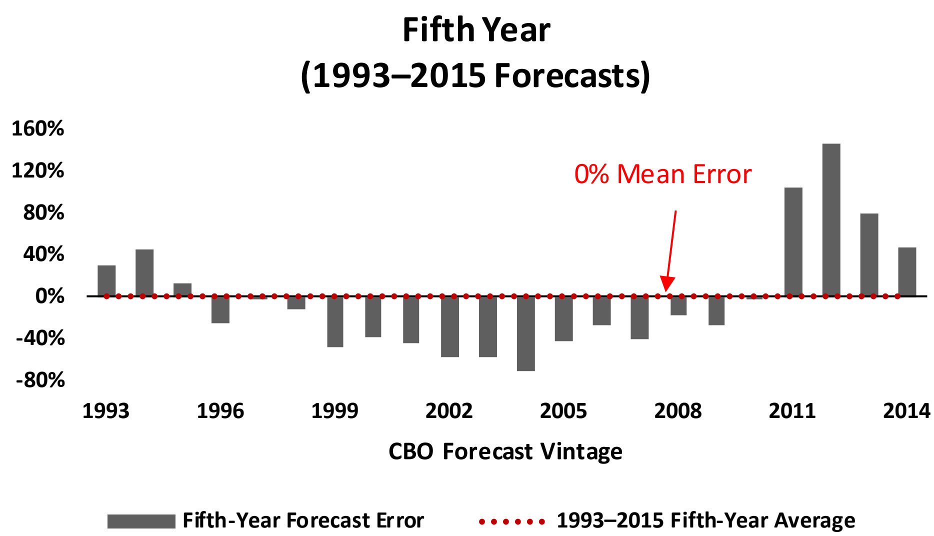
The 95% CIs estimated by EIA were derived from options market information for the five trading days ending June 5, 2014. EIA did not calculate interval estimates for months with few trades in near-the-money options contracts.

CI = confidence interval; EIA = Energy Information Administration; NYMEX = New York Mercantile Exchange.

Figure 3. [Return to Text]
Forecast Centeredness Measured by Mean Error

Percent





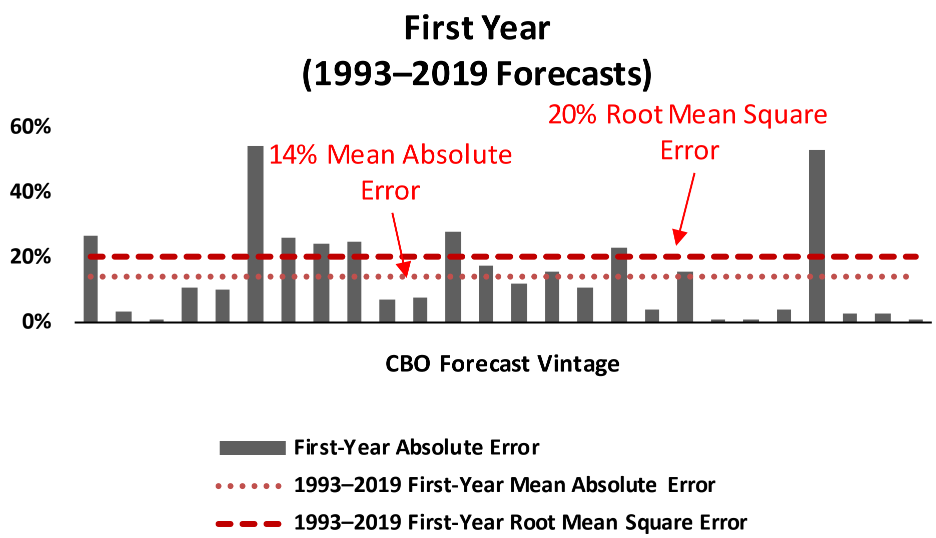
Source: Congressional Budget Office.

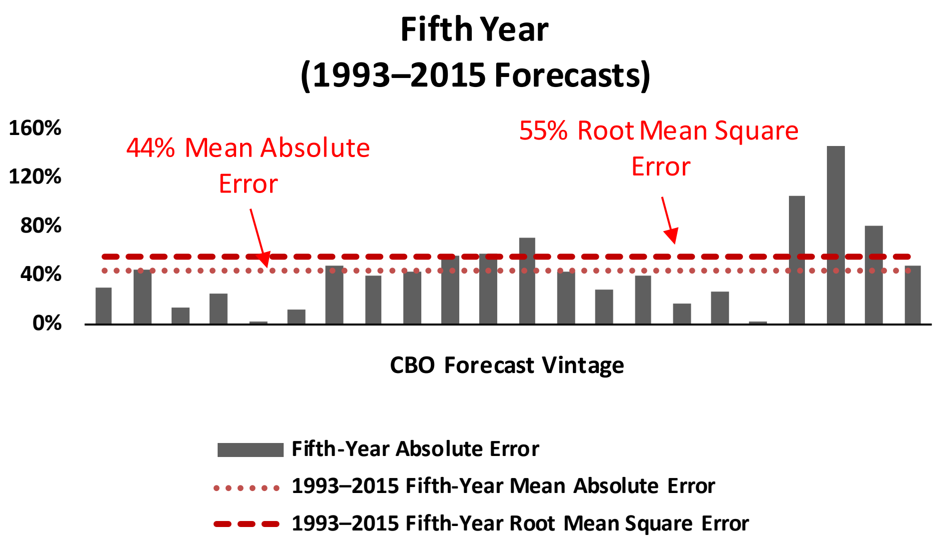
Positive mean errors correspond to overprojections of actual imported RAC; negative errors correspond to underprojections. The centeredness of CBO's first-year forecasts is evaluated through the agency's 2019 forecast. Because CBO's 2015 forecast is the latest for which a fifth-year price projection (4 years later) can be compared with actual prices, CBO's evaluation of centeredness for fifth-year projections of imported refiner acquisition cost extends through 2015.

Figure 4. [Return to Text]

Forecast Accuracy Measured by Absolute and Root Mean Square Error

Percent





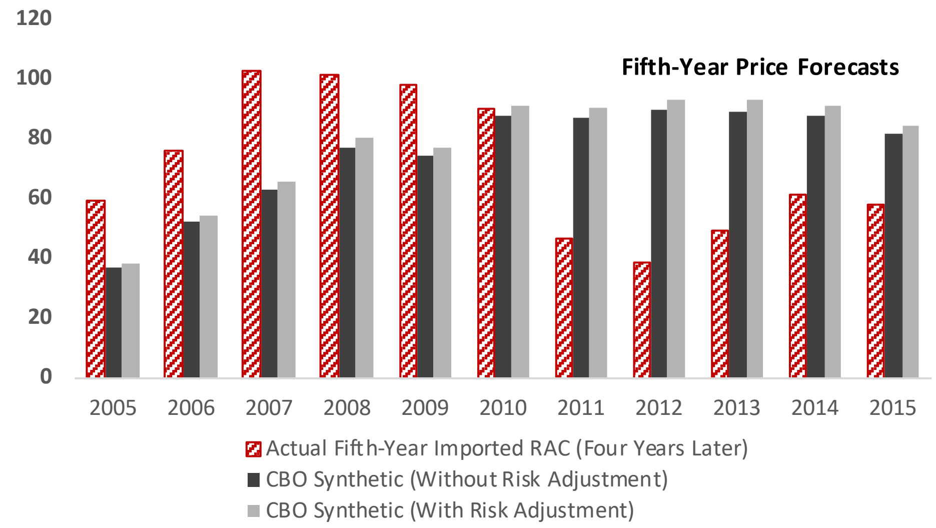
Source: Congressional Budget Office.

The accuracy of CBO's first-year forecasts is evaluated through the agency's 2019 forecast. Because CBO's 2015 forecast is the latest for which a fifth-year price projection (4 years later) can be compared with actual prices, CBO's evaluation of accuracy for fifth-year projections of imported refiner acquisition cost extends through 2015.

Figure 5. [Return to Text]

Fifth-Year Forecasted Imported RAC and Actual Imported RAC 4 Years Later

Dollars per barrel



Source: Congressional Budget Office.

Darkened columns denote CBO's constructed fifth-year forecasts of imported RAC made from 2005 through 2015 (with and without a risk adjustment), the only forecasts for which a fifth year can be evaluated (fifth-year values are those 4 years in the future from when the forecast was released). For instance, the darkened columns for 2005 are the average annual synthetic forecasts of imported RAC for 2009.

Red columns denote the average annual imported RAC 4 years after each CBO forecast. The red column for 2005, for example, is the actual average imported RAC for 2009.

RAC = refiner acquisition cost.

Tables

Table 1. **[Return to Text]**
Comparative Quality of CBO's Forecast of Imported RAC

Percent

	First-Year Oil Price Forecasts				Fifth-Year Oil Price Forecasts			
		Centeredness	Accuracy			Centeredness	Accuracy	
Comparison	Historical Forecasts	Mean Error	Mean Absolute Error	Root Mean Square Error	Historical Forecasts	Mean Error	Mean Absolute Error	Root Mean Square Error
CBO	1993–2019	–1	14	20	1993–2015	0	44	55
Fixed Real	1993–2019	2	22	32	1993–2015	3	48	60
CBO	1999–2019	–5	13	19	1999–2015	–3	52	62
Fixed Real	1999–2019	0	24	34	1999–2015	4	57	69
EIA	1999–2019	–6	12	15	1999–2015	5	58	76
CBO	2003–2019	–4	12	18	2003–2015	11	54	66
Fixed Real	2003–2019	2	24	35	2003–2015	20	60	74
EIA	2003–2019	–5	11	14	2003–2015	20	62	83
IHS	2003–2019	–11	18	20	2003–2015	10	61	72

Source: Congressional Budget Office, using data from Energy Information Administration, *Annual Energy Outlook* (www.eia.gov/outlooks/aeo/), and IHS Markit, "U.S. Economic Outlook: U.S. Short-Term Forecast Tables—Baseline and Alternatives (Excel)"(subscription required).

Positive mean errors correspond to overprojections of actual prices; negative errors correspond to underprojections.

The quality of CBO's first-year forecasts is evaluated through the agency's 2019 forecast. Because CBO's 2015 forecast is the latest for which a fifth-year projection of imported RAC (4 years later) can be compared with actual values, CBO's evaluation of quality for fifth-year imported RAC extends through 2015.

EIA = Energy Information Administration; IHS = IHS Markit; RAC = refiner acquisition cost.

Table 2. [Return to Text]

Centeredness of CBO's Forecast of Imported RAC at Different Forecasting Subperiods

Percent

	Iniitial Years (1–4) (2003–2019 Forecasts)	Middle Years (5–9) (2003–2015 Forecasts)	Late Years (10–11) (2003–2011 Forecasts)
Forecast	**Mean Error**	**Mean Error**	**Mean Error**
CBO	**0**	**15**	**11**
Fixed Real	**14**	**37**	**51**
EIA	**11**	**47**	**48**
IHS	**1**	**24**	**12**

Source: Congressional Budget Office, using data from Energy Information Administration, *Annual Energy Outlook* (www.eia.gov/outlooks/aeo/), and IHS Markit, "U.S. Economic Outlook: U.S. Short-Term Forecast Tables—Baseline and Alternatives (Excel)" (subscription required).

Positive mean errors correspond to overprojections of actual prices; negative errors correspond to underprojections.

Not enough time has passed to compare all CBO's forecasts with actual imported RAC. Therefore, the centeredness of CBO's projections is evaluated through the agency's 2019 forecast (for initial-years projections), 2015 forecast (for middle-years projections), and 2011 forecast (for late-years projections).

IHS does not provide an 11th-year forecast. The accuracy measures for IHS reflect only the accuracy of its 10th-year projection.

EIA = Energy Information Administration; IHS = IHS Markit; RAC = refiner acquisition cost.

Table 3. [Return to Text]
Accuracy of CBO's Forecast of Imported RAC at Different Forecasting Subperiods

Percent

	Initial Years (1–4) (2003–2019 Forecasts)		Middle Years (5–9) (2003–2015 Forecasts)		Late Years (10–11) (2003–2011 Forecasts)	
Forecast	**Mean Absolute Error**	**Root Mean Square Error**	**Mean Absolute Error**	**Root Mean Square Error**	**Mean Absolute Error**	**Root Mean Square Error**
CBO	30	44	63	71	57	60
Fixed Real	40	59	65	79	61	70
EIA	30	49	80	97	64	76
IHS	32	45	64	72	40	44

Source: Congressional Budget Office, using data from Energy Information Administration, *Annual Energy Outlook* (www.eia.gov/outlooks/aeo/), and IHS Markit, "U.S. Economic Outlook: U.S. Short-Term Forecast Tables—Baseline and Alternatives (Excel)" (subscription required).

Positive mean errors correspond to overprojections of actual imported RAC; negative errors correspond to underprojections.

Not enough time has passed to compare all CBO's forecasts with actual imported RAC. Therefore, the centeredness of CBO's projections is evaluated through the agency's 2019 forecast (for initial-years projections), 2015 forecast (for middle-years projections), and 2011 forecast (for late-years projections).

IHS does not provide an 11th-year forecast. The accuracy measures for IHS reflect only the accuracy of its 10th-year projection.

EIA = Energy Information Administration; IHS = IHS Markit; RAC = refiner acquisition cost.

Table 4. [Return to Text]
Quality of CBO's Oil Price Forecast Method With and Without Risk Adjustment

Percent

	First-Year Forecasts (2005–2019 Forecasts)			Fifth-Year Forecasts (2005–2015 Forecasts)		
	Centeredness	Accuracy		Centeredness	Accuracy	
Forecast	Mean Error	Mean Absolute Error	Root Mean Square Error	Mean Error	Mean Absolute Error	Root Mean Square Error
CBO Synthetic (With risk adjustment)	0	11	16	25	51	64
CBO Synthetic (Without risk adjustment)	–1	11	16	20	49	60

Source: Congressional Budget Office.

Positive mean errors correspond to overprojections of actual values; negative errors correspond to underprojections.

The quality of CBO's first-year forecasts is evaluated through the agency's 2019 forecast. CBO's 2015 forecast is the latest forecast for which a fifth-year projection of imported RAC (4 years later) can be compared with actual values. Therefore, CBO's evaluation of accuracy for fifth-year price projections extends through 2015.