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CONSISTENCY IN FORECASTING OIL PRICES AND GROSS DOMESTIC PRODUCT

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Abstract

This paper explores the difficulties in creating accurate long- or medium-term crude oil price forecasts, specifically the challenge of creating consistent forecasts for both gross domestic product and crude oil prices. There is circularity between crude prices and GDP; crude prices affect GDP, while GDP of both importer and exporter nations affect the demand for and price of crude oil. This paper seeks to understand how the two variables interact, and whether or not forecasters have created consistent predictions based on the interaction. Before implementing empirical work, this paper discusses the other variables that influence oil prices and explores existing forecasting methodologies. The paper concludes that forecasters have not created consistent forecasts nor accounted for the complex relationship between GDP and crude prices.

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1. Introduction

This paper addresses the problem of creating accurate crude oil price forecasts. Many institutions including investment banks, governmental agencies, and international research institutions publish oil price forecasts. However, most fail to account for the complex relationship between crude oil prices and GDP. Crude prices and GDP affect one another. Rising oil prices decrease the GDP of importer nations and increase the GDP of exporters. Furthermore, the GDP of supplier nations affects the price of oil, as does the GDP of importers. The ultimate goal of this paper is to understand this relationship and determine whether or not forecasters have created consistent predictions for future GDP and crude prices.

Oil prices are a function of supply and demand, both of which are a function of GDP. When importer GDP rises, for example, demand rises. GDP is also a function of crude oil prices, as crude oil prices will affect a nation's income. The expected future price will depend on expected GDP of importer nations, supply, and exogenous factors.

$$E_t[P_{t+i}]=f\ E_t[\sum(Y_{t+i}+S_{t+i}+x_{t+i})|\Omega_t]$$

This basic price function is what forecasters use in their predictions. $E_t[P_{t+i}]$ is the expectations formulated at time t of what prices will be at time $t+i$. Y represents GDP, S represents supply, x represents exogenous factors, and Ω represents available information. Because the prices at $t+i$ will depend on these factors from time t to time $t+i$, the factors are summed over the period t to $t+i$. For simplicity's sake, the previous equation's complexity will be suppressed and notated as:

$$E_t[P_{t+i}]=f\ E_t[Y_{t+i}, S_{t+i}, x_{t+i}]$$

This equation represents an equilibrium condition. Simply, expected prices are a function of expected supply and demand, here represented by GDP. Many forecasters ignore another equally important effect. When forecasters create predictions for GDP, they must make some implicit assumptions about oil prices. For example, an increase in oil prices will increase exporter GDP and decrease importer GDP. Therefore, GDP is a function of the crude price and other exogenous variables.

$$E_t[Y_{t+i}]= f\ E_t[P_{t+i}, x_{t+i}]$$

Because world GDP depends on oil prices, forecasters make assumptions about future oil prices to predict GDP. When oil price forecasters then use a forecasted GDP in their price predictions, they often fail to account for these previous assumptions about crude prices. If a predicted oil price does not match the initial oil prices assumptions used when forecasting GDP, the forecasts will be inconsistent.

The effects of crude oil prices are varied, international, and extremely important. Crude prices have global implications not only for economics, but also for political stability, peace, and geopolitics. The oil market is facing many changes in the coming years. With the increasing role of renewable sources in the energy market and the new production of shale oil, now is the time to determine an accurate forecasting method and seek to understand this market.

This paper begins with an examination of economic literature on oil prices. It will then show tests of the literature models, before discussing forecasting models and their accuracy. Finally, it will move to a discussion of the accuracy of forecasting models and address the issue of consistency between forecasted GDP and crude oil prices.

2. Literature Review

While many economists have written on the subject of oil prices and forecasting, few have explored the issue of consistency between GDP and crude prices. To understand the accuracy of price forecasts, we must understand how variables have affected oil prices in the past. The current literature has made important progress on explaining past oil prices, yet the literature on forecasting is underdeveloped in comparison.

2.1 Supply and Demand Models

In their 2009 paper "Three Epochs of Oil," Eyal Dvir and Kenneth Rogoff work to explain trends in volatility and persistence in oil prices. They divide historical oil price data from 1860 to 2008 into three distinct time periods. The periods from 1861 to 1878 and 1972 to 2008, according to their model, have high volatility, price persistence, and prices compared to the interim period. They note that these two periods of high volatility and persistence coincide with periods of rapid industrialization by emerging economic powerhouses and periods of uncertainty regarding supply. In the period from 1861 to 1878, the United States was the rapidly industrializing nation. The supply uncertainty was the result of the newly emerging railroads and their control of transportation. American oil supply came almost entirely from a few small fields in Pennsylvania. The railroads to these fields held a monopoly on transportation, and could therefore control the supply of oil flowing to the rest on the nation. The Standard Oil Company had also created a series of short-distance oil pipelines that exacerbated the problem of limited transportation. This transportation monopoly broke in 1879 with the completion of the Tidewater long-distance pipeline. Standard Oil joined in creating more long-distance pipelines, which broke the transportation monopoly entirely.

A similar situation of growing demand and constrained supply began in the 1970s. In this case, most of East Asia was rapidly industrializing. The supply monopoly came from OPEC, formed in 1960. United States oil production peaked in 1970, and the Middle East became the only region with excess oil reserves. This increased OPEC's market power. After the American production peak, Gulf oil producers began partially to nationalize their oil resources. As demand increased, OPEC sought to curtail supply. The combination, Dvir and Rogoff argue, is the root cause of higher prices, volatility, and persistence.

Dvir and Rogoff's findings are important to oil price forecasting models. If their historical model is correct, then we should currently be living in a period of high volatility, prices, and persistence. Currently, India and China are still industrializing rapidly. OPEC continues to control a significant portion of the market, but the now increasing production from the United States could help break their monopoly. The increasing production from the shale oil fields reduces the uncertainty inherent in the oil market of the 1970s, but fails to break OPEC's control of the market. This means that the oil market currently fulfills both of Dvir and Rogoff's two criteria—increasing demand from an industrializing nation, and uncertainty of supply—for high volatility, persistence, and prices.

Kilian (2008) reconfirms Dvir and Rogoff's findings. The paper states that oil price shocks since 1970 have been caused by a strong global demand and shifts in demand resulting from market uncertainty about supply shortfalls. This claim underlines Dvir and Rogoff's findings in the period since 1972. Both papers note that the period has seen high oil prices, and both papers observe the confluence of increasing demand and uncertain supply with volatility and high prices. Kilian cites the Iranian Revolution, Iranian hostage crisis, Soviet invasion of Afghanistan, and invasion of Kuwait as causing notable supply uncertainty in the time period. Dvir and Rogoff focus mainly on the long-term implications of OPEC supply restriction, whereas Kilian is more concerned with the immediate effects of political events on supply expectations. Regardless, Kilian's findings confirm Dvir and Rogoff's analysis of the period since 1972. Supply uncertainty and growing demand led to habitually higher prices and price shocks.

Hamilton (2008) also cites supply vulnerability as a cause of "broad behavior" of oil prices from 1970-1997. Hamilton reconfirms the previously mentioned papers by noting that the supply vulnerability coincided with a growing demand from newly industrialized and industrializing nations. Hamilton further notes that growing demand exacerbates problems of uncertainty over supply, as oil is a finite and unrenewable resource. The combination of Hamilton (2008), Kilian (2008), and Dvir and Rogoff (2009) show a broad consensus regarding the causes of oil price volatility: supply uncertainty and rapidly industrialization.

2.2 Elasticity

Another important component of the existing literature on oil prices is research on both the income and price elasticity of demand and supply. The problem with the current literature on oil price elasticity of demand is that it does not account for the effect of oil prices on GDP. Research on price elasticity of demand presumes that GDP changes independently of oil prices, although the two variables affect each other. This does not mean that research on elasticity of demand is not useful in forecasting. Rather, elasticity data can tell us important things about the interplay between GDP and oil prices. Kilian (2008) adopts a model utilizing the price elasticity of demand. He notes that there are multiple behavioral models describing how consumers react to energy prices. The one he implements shows consumers responding "proportionately to a percent change in energy prices, regardless of the magnitude of the change" (Killian, 2008, pg. 7).

Gately and Huntingdon (2002) report a 0.53 long-term income elasticity of demand for oil in non-OECD nations, and a 0.55 long-term income elasticity of demand in OECD nations. Dargay et al. (2007) calculate a -0.55 long-term price elasticity of demand for oil in OECD countries and a -0.18 price elasticity of demand in countries termed "income growers." Kilian (2008) also reports price elasticity of demand for multiple types of energy, although not crude oil. He reports elasticities for different types of energy, but not all are statistically significant. The IEA (2007) reported that oil demand was becoming less responsive to changes in international crude prices, although the report does not quantify this claim. Krichene (2006) reports a long-term price elasticity of supply of 0.08. The very existence of data on price elasticity of demand for oil suggests that changes in oil prices will affect consumption decisions, and therefore GDP. This data quantifies the consistency problem by showing how much the changes in oil prices can affect spending.

Another important finding in Kilian (2008) is the energy price elasticity of investment expenditures in the United States, or the expected change in investment expenditures given a change in energy prices. He finds that residential investment in structures has a -1.02 energy price elasticity of expenditure. Mining structures and other equipment and mining machinery had a large, positive energy price elasticity of expenditure. With these notable exceptions, Kilian notes that there is “no evidence that energy prices exert a large effect on total nonresidential investment expenditures” (Killian, 2008, pg. 20). Kilian’s findings begin to address the interaction between macroeconomic output and energy prices.

2.3 Oil Price and GDP

Much of Killian (2008) addresses the effect oil price changes have on the United States economy. Combining Kilian’s ideas with data from Dargay et al. (2007) on OECD countries, we can extrapolate the reactions of OECD oil importers to changes in oil prices. Kilian (2008) reports that an increase in oil prices will slow the macroeconomy. He also claims that the opposite effect—a decrease in oil prices will boost the economy—exists, as well. When prices increase, Kilian claims that the spending reductions surpass reductions in energy’s share of spending, because increased energy prices will slow many sectors of the economy. Therefore, net spending will decrease by more than the decrease in spending predicted by the price elasticity of demand. Kilian’s research on the energy price elasticity of investment expenditures empirically supports this claim. The energy price elasticity of investment expenditures on structures shows that spending on durable goods such as residential buildings will decrease with increasing oil prices. Kilian also notes a decrease in commercial automobile purchases. A one percent increase in oil prices leads to a statistically significant 0.76 percent decrease in consumption of motor vehicles and parts.

Kilian (2008) highlights the consistency problem between GDP and oil prices while taking a step towards solving it. A higher GDP in the United States would imply that the United States would demand more oil, raising the price of oil. Yet Kilian shows that a rising oil price has a negative effect on the GDP of the United States. These concurrent and circular shifts in supply and demand make it more difficult to forecast oil prices accurately.

Findings from Hamilton (2008) present further problems in using GDP forecasts to forecast oil prices. Hamilton argues that oil prices are "an economic variable which...we should be completely unable to predict" (pg. 9). Hamilton bases this claim on a statistical model using lagged variables of real oil prices, GDP growth, and interest rates to predict the oil price. Hamilton shows that these variables are not statistically significant at the five percent level. Hamilton claims that oil prices seem to be a "random walk," which leads to the conclusion that predicting that the future price of oil will equal current price is a perfectly rational forecast. Using this approach, extending the forecast into the future is challenging. In his model, Hamilton predicts the oil price four years into the future to be $115, using a Gaussian distribution. However, given an observed 15.28% standard deviation to the quarterly change in oil prices, prices using this method could be anywhere between $34 and $391 (pg. 6). Such a wide possible range of prices makes a forecast using this method almost meaningless.

The current literature on oil prices and forecasting has many holes that need to be filled. Most of the literature does not touch on the problem of consistency between forecasted GDP and forecasted oil prices. Many papers agree that periods of high demand growth coupled with supply shocks or uncertainty will lead to periods of high volatility and high prices; this will be useful in assessing the accuracy of price forecasts. Because of the findings in Hamilton (2008), we know that a “random walk” style of forecasting will lead to massive variations in forecasted prices, and that using lagged GDP as a regressor of oil prices is not statistically significant.

3. Testing the Existing Models

In attempting to find a realistic method for forecasting oil prices, we must first analyze the models proposed in economic literature. Analyzing the models from economic literature may reveal that the models of academic economists match forecasters' models. For this section, I will use multiple price forecasts from the United States Energy Information Administration (EIA), along with historical price data, and data from economic literature on oil prices.

3.1 Forecasted versus Current Prices

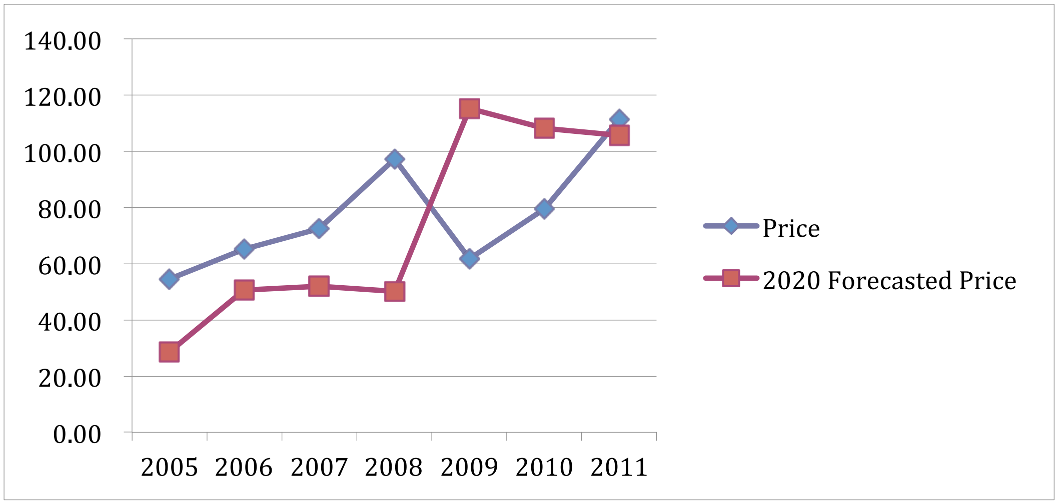
Hamilton (2008) proposes the simplest model for forecasting oil prices. The contention that oil prices follow a "random walk" leads to the conclusion that forecasters should just forecast a future price equal to today's price, and their forecast will lay only a few standard deviations away from the actual price. Table 1 and Figure 1 shows the actual price for the years 2005-2011 along side the price the EIA forecasted for 2020 in that year.

Table 1. Forecasted vs. Current prices

Current Year	Current Year Price	Price forecast for 2020 made in the current year
2005	$54.52	$28.50
2006	$65.14	$50.70
2007	$72.39	$52.04
2008	$97.26	$50.15
2009	$61.67	$115.33
2010	$79.50	$108.28
2011	$111.26	$105.57

Source: EIA

Figure 1. Forecasted vs. Current prices



Source: EIA

The correlation between the actual price and the forecasted price is 0.33. While this correlation is not outstandingly high, it shows that the actual and forecasted price move in the same direction. More interestingly, the average difference between the forecasted price and current price was only $4.45 per barrel. For a long-term forecast, assuming such a small average difference in prices may be naive. In light of this very slight difference, Hamilton's contention that forecasters should pick the current price in forecasting long-term current prices seems accurate. If Hamilton's model is indeed correct, it is rational for forecasters to select an oil price very near to the current price, which forecasters at the EIA have historically done.

3.2 A Random Walk Model

In further testing the Hamilton (2008) model, I constructed a similar model of a random walk with a drift. Hamilton uses a model based on quarterly price changes, but the EIA publishes its price forecasts in its Annual Energy Outlook done on a yearly—not quarterly—basis. Because of this difference between available data and Hamilton's models, some changes will arise in calculating the confidence interval.

The following formula calculates a 95% confidence interval for the annual change in oil prices. s is the number of years between the current year and forecasted year, $\Delta\, \bar{p}$ is the average yearly change in oil prices, $\bar{z}$ is the critical z-value for the 95% interval, and $\sigma_{\Delta p}$ is the standard deviation of the change in oil prices. Hamilton uses 100 times the natural log of the price of oil for p, which is also used in this model.

$$\Delta\bar{p} \pm \bar{z}(\ \sigma_{\Delta p}\sqrt{s})$$

To project a price, Hamilton's random walk framework was used. The upper and lower bounds of the price change in table 2 represent the upper and lower bounds of the 95% confidence interval. For example, using historical price data, the model predicts with 95% confidence that oil prices could decrease by at most \$5.98 or increase by at most \$8.12 in 2013. A random variable between the upper and lower bound was added to the previous year's price to obtain the forecasted price for the following year. Because table 2 represents an eight-year time horizon, s is equal to 8 for all calculations. The mean and standard deviations of changes in price are based on historical price data from 1987-2012.

Table 2. Random Walk Model Results

Year	Forecasted Price	Price Change, lower bound	Price Change, upper bound
2013	$108.63	-$5.98	$8.12
2014	$112.63	-$5.97	$8.08
2015	$113.63	-$5.97	$8.07
2016	$116.63	-$5.99	$8.05
2017	$117.63	-$5.98	$8.01
2018	$121.63	-$5.98	$8.01
2019	$116.63	-$5.97	$7.98
2020	$112.63	-$5.97	$7.98

On first glance, using a Gaussian random walk model to forecast oil prices may seem realistic. The model's forecasted price for 2020 is $112.63, not far from the then-current 2012 price of $111.63. This forecast, like those made by the EIA, does not stray too far from the current price. The problem with the model, however, is its randomness across the confidence interval. Had the random variable been the upper bound of the confidence interval in every year, the price could have been forecasted to be as high as $178.93. Conversely, if it had been the lower bound every year, the price could have been as low as $63.82, which is lower than the 2006 price per barrel. Generating a random variable on the upper or lower bound of the confidence interval eight successive times is unlikely, but is possible within this model. While a Gaussian random walk is not a horrible starting point for predicting an oil price, it fails to account for too many political, geological, technological, and economic variables that influence the oil price. To create a more accurate forecast, forecasters must include more variables into the model for oil prices.

3.3 Volatility and Price Trends

Another model worth exploring is that proposed by Dvir and Rogoff (2009). Using historical oil price data from 1860 to 2008, Dvir and Rogoff conclude that periods of rapid industrialization within growing nations and periods of supply uncertainty coincide with periods of higher volatility, price persistence, and prices. If we can effectively conclude that we live in a period of rapid industrialization and supply uncertainty, using this model we can also conclude that we are living in a period of higher volatility, which will cause further difficulties in forecasting an accurate oil price.

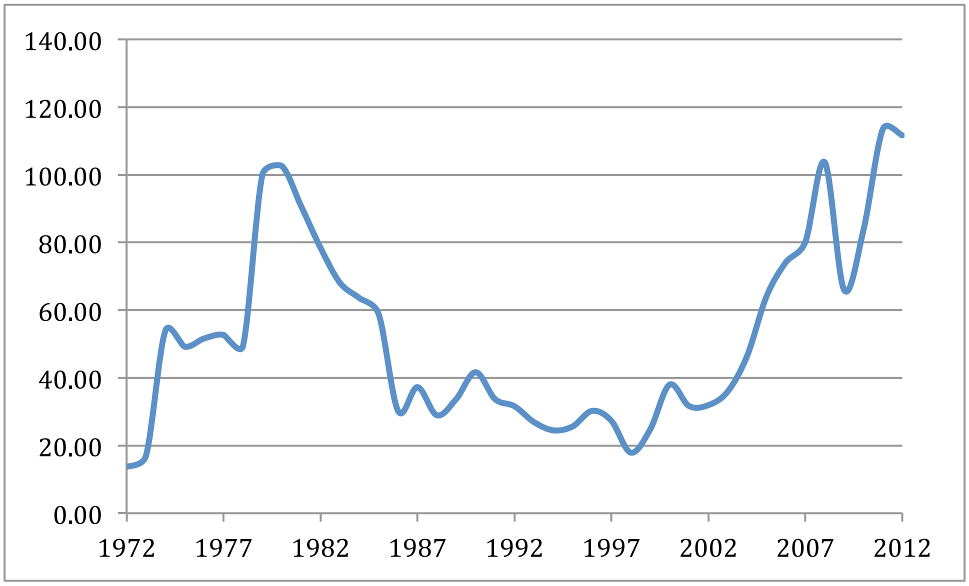
Currently, China is a rapidly industrializing rising economic power. The OECD predicts that between 2013 and 2015, China's GDP will grow 8.5%. Between 2013 and 2060, the OECD predicts that China's GDP will grow 367%. If the OECD's predictions are even remotely accurate, the world will continue to see rapidly increasing industrialization from China for many years to come. This means that China fulfills Dvir and Rogoff's first criterion for volatile oil prices.

Dvir and Rogoff's second criterion for volatility is uncertainty of supply. They attribute the uncertainty of supply from 1972 to 2008 to OPEC's preeminence as an oil producer. Whether OPEC will continue to exert large influence over the oil market is not guaranteed. The United States is yet again producing oil due to the use of hydraulic fracturing, or fracking. Hydraulic fracturing is in the nascent stages of its development, and produces a relatively small amount of oil; OPEC still produces far more crude. According to their own production statistics, the combined crude oil output of all OPEC member nations in 2012 was 32,424,200 barrels per day. The

United States produced only 6,505,000 barrels per day, hardly enough to break OPEC's control of the market. The total daily oil production capacity of the world in 2012 was 72,858,500 (OPEC, 2013, p. 30). These statistics clearly show that OPEC still produces an enormous share of the world's crude oil, roughly 45%. OPEC's control will likely continue because of its vast reserves. While hydraulic fracturing will allow the United States to tap into its reserves, those are only a fraction of OPEC's combined oil reserves. The United States has proven crude oil reserves of 23.27 million barrels. OPEC's combined proven crude oil reserves are 1,201 trillion barrels (OPEC, 2013, p. 22). Through 2012, OPEC has dominated the oil market by producing at near-monopoly levels. With its much higher levels of proven reserves, it will only continue to do so. Hydraulic fracturing will do little to break OPEC's control of the market, which fulfills the second criterion for volatile, high, and persistent oil prices. Supply will remain uncertain, as it is determined by a small group of countries.

Dvir and Rogoff claim that the period between 1972 and 2008 was one of high price volatility. Indeed, the yearly standard deviation of oil prices in this period was $24.98. From 2009 to 2012, the standard deviation was $22.98, still quite high. This shows that oil prices have been highly volatile recently. For the entire period of 1972-2012, the standard deviation was $28.13 per barrel.

Figure 2. Oil Prices, 1972-2012

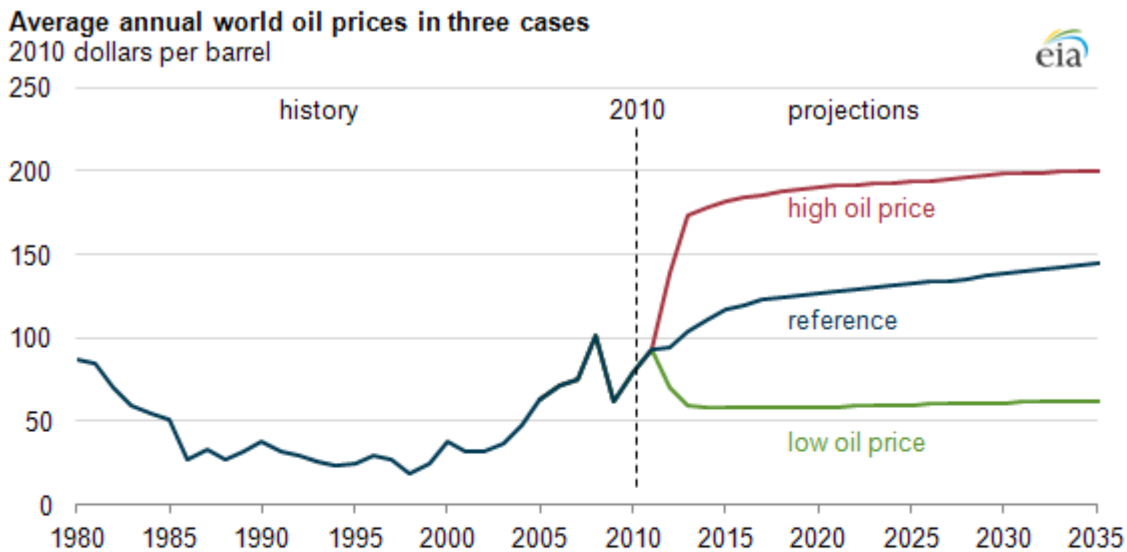


From expectations of China's growth rate and OPEC's continued power over the oil market, we can safely assume—using the Dvir and Rogoff framework—that the oil market from 2012 to 2020 will be volatile with high prices. While this does not tell us what the oil price will be in 2020, it provides a basis for understanding how price trends will look over the time period.

High volatility makes an exact prediction difficult. In the 2012 Annual Energy Outlook, the EIA published three scenario forecasts: one "reference" case, one "low price" case, and one "high price" case (EIA 2012). Although none of the cases fit the Dvir and Rogoff model perfectly, the high price case is the closest. The historical data for periods with high volatility and prices shows that the standard deviation of price will be well above $20, as it was from 1972 to 2012. None of the EIA's cases fit that description. The reference case's standard deviation of price is $10.93; the low case's is only $3.98. The high price case has a standard deviation of prices of $15.76. This is still far below the $28.13 standard deviation of 1972 to 2012, but matches

Dvir and Rogoff's predictions more closely. Furthermore, Dvir and Rogoff's model predicts that oil prices will be generally higher with uncertainty of supply and a rapidly industrializing economic power. This, too, would support the high price scenario. The EIA's predictions in the high price scenario match the Dvir and Rogoff model better than the low price or reference scenario.

Figure 3. EIA Projections



Source: EIA AEO 2012

While analyzing the models in both Hamilton (2008) and Dvir and Rogoff (2009) has not shown an apparent or effective way to forecast a long-term oil price, it has illuminated problems with current models. The model in Hamilton (2008) does not help make a forecast of any accuracy because of the possibility for absurdly high or low prices. Historical data supports the model from Dvir and Rogoff (2009). The model would suggest that the standard deviation of oil prices over the next eight years should be higher than the EIA forecasted, although it does not provide a framework for forecasting an exact price for 2020.

4. Current Forecasting Methodologies

Many agencies create forecasts. The EIA publishes new oil price forecasts annually in its Annual Energy Outlook, and other governments do so as well. Many investment banks also have short-term oil price forecasts that help them trade and price futures and options.

4.1 EIA Price Determinants

The EIA is hardly transparent regarding its forecasting methodologies. In June 2011, the EIA published a series of articles titled “What Drives Crude Oil Prices?” While these publications do not provide a complete picture of the EIA’s methods or models, it does illuminate what the EIA sees as important in the crude oil market. The EIA’s price determinants are supply, demand, financial markets, and balance, or existing crude oil inventories.[1]

The EIA divides supply into OPEC supply and non-OPEC supply; similarly, demand is divided into OECD demand and non-OECD demand. In the two supply sections, the EIA notes that OPEC produces forty percent of the crude oil, and it therefore has a large influence on prices. A decrease in OPEC’s production targets generally leads to an increase in prices. The article also notes that when OPEC had

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[1] It is worth noting that the price of any good depends only on supply and demand; other variables simply influence supply and demand. While the EIA provides strong arguments for why “balance” and “financial markets” influence price, these two variables really influence supply and demand, which is why they can affect prices.

low spare production capacity—defined as the production capacity that could be brought to market in 30 days and sustained for 90—it was less capable of responding to price changes. During periods of low spare capacity, oil prices rose because OPEC could not release more oil into the market to reduce the price (Supply: OPEC). The EIA also claims that any non-OPEC producers were "price takers," and set their production in reaction to the prices already observable in the market (Supply: non-OPEC).

On the demand side of the market, the EIA notes that non-OECD demand drives the market to a greater degree. Although OECD countries consume 53% of the crude oil worldwide, their consumption is declining. OECD countries are more demand elastic than non-OECD countries, as developed countries can substitute away from oil more easily to alternative fuel sources. Dargay et al. (2007) confirms this assertion. Dargay calculates a long-term price elasticity of demand in OECD countries of -0.55, and only -0.18 in countries labeled "income growers." This large difference between the price elasticity of developed and developing countries confirms the EIA's demand claims. OECD countries also have fewer fuel subsidies that shield consumers from crude oil prices, so consumption decisions in OECD countries follow changes in oil prices more closely than non-OECD country consumption decisions (Demand: OECD). As OECD consumption has declined, non-OECD countries have increased their crude oil consumption by 40% between 2000 and 2010. The EIA notes that China, India, and Saudi Arabia had the highest crude consumption growth rates over the period. Countries with higher growth rates—such as non-OECD countries and rapidly industrializing nations—will also have rapidly rising oil consumption. Developing countries also have larger manufacturing sectors relative to their GDPs, unlike OECD countries, which have larger service sectors. Because of larger manufacturing sectors, developing nations will demand more oil to run plants (Demand: Non-OECD). These combined effects make demand from non-OECD counties a more stable and foundational demand, despite their lower overall levels of consumption.

The EIA's section on financial markets notes that oil prices are correlated with many financial instruments. Futures and swaps contracts can put pressure on oil prices in either direction. The EIA defines two types of players in the market for financial products based on crude oil, commercial and non-commercial traders. Commercial traders are those who want to buy or sell actual, physical crude oil, such as sellers or buyers trying to lock in a price for the future. Non-commercial traders are investors who attempt to profit from discrepancies between current and future prices, such as banks, hedge funds, and money managers. The EIA argues that increased non-commercial trading can amplify price movements, but they largely dismiss financial markets as less important than the actual physical market for oil. They state "no definitive conclusion either proving or disproving a causal linkage between non-commercial trading and large energy price swings over the past few years has been reached" (Financial Markets). While the section does not explicitly demonstrate how the EIA uses financial markets to forecast prices, it shows that the EIA considers traditional, physical supply and demand drivers to be more influential to oil prices than financial markets. For a long-term forecast, financial markets will matter even less. The EIA notes that swaps and futures contracts put pressure on prices, but most of these contracts will expire before they can influence long-term prices. While financial markets may influence prices, their influence will not matter much to long-term forecasters.

The final price determinant the EIA lists is balance, or the worldwide crude oil inventory. In the section on balance, the EIA notes that inventory stocks can influence prices in either direction, depending on futures. The EIA also shows that “inventory builds tend to go hand-in-hand with increases in future oil prices.” Many countries have reserve stocks, but data on reserves is often incomplete, especially for developing nations (Balance). The lack of information on reserves from developing nations is a problem for forecasters. Since non-OECD demand is a more important driver of crude prices, information from these countries is more pertinent to forecasting. Since this information is scarce, forecasters do not understand the relationship completely.

In the concluding article on crude price drivers, the EIA notes that geopolitical and weather events often have a large impact on oil prices. Essentially, these events just influence supply, as they can destroy oil stocks and create difficulties with transporting oil to the market. These events have a smaller impact if the world has built up crude inventory. However, because of such events, there is often a risk-premium built into forward rates. The EIA lists twelve events since 1971 that influence crude prices (Spot Prices). The major suppliers of oil—OPEC nations—are often subject to large political upheavals, wars, invasions, revolutions, and abrupt regime changes. Even in short-term models, political and weather events are largely unforeseeable. No matter how sophisticated a statistical model, it cannot predict the Iranian revolution or invasion of Kuwait. Such events will matter more for short-term price forecasts. In the long-term, the market will regain equilibrium despite short-term shocks. This does not mean that weather and politics do not affect long-term prices. In the long-term, forecasters could assume that climate change will alter consumption decisions. Governments may shift increasingly toward "green" policies and technologies that exclude oil, for example. Although the weather and political events the EIA describe mostly affect the short-term price, permanent changes in politics and weather could affect the long-term price.

4.2 An EIA Model

Throughout the series of articles on price determinants, the EIA never proposes a definitive model for forecasting or discloses its exact forecasting methodology. While this information is not transparent in its AEO reports, the EIA has a section of its website dedicated to describing its models and methods. The AEO model is not in this section, but an article entitled "Petroleum Products Supply Module Short Term Energy Outlook Model" from May 2013 shows the EIA's regressions for forecasting output of finished oil products. In doing so, the EIA also forecasts inputs for finished oil products, including crude oil. The paper examines the inputs of crude oil to United States refineries, which represents a piece of American demand for crude.

In this paper, the EIA regresses crude oil refinery inputs on lagged variables of refined oil consumption, current costs of finished oil products, cost of acquisition of crude oil, and dummy variables accounting for seasonality of demand (Petroleum

Products, 2013 p. 8). The model has been highly accurate in forecasting short-term inputs of crude oil; in 2010 the forecast was 0.7 percent above the actual input, and in 2011 it was 1.1 percent below the actual input (Petroleum Products, 2013 p. 30).

While this method may be highly accurate for short-term forecasts, it is problematic for longer time horizons. If the EIA were to use such a model for a long-term forecast, it would need long-term forecasts of other variables. For example, if the EIA wanted to forecast crude oil inputs eight quarters in the future, it would need forecasts seven quarters in the future for refined oil consumption, finished oil products, and all other variables acting as lagged variables in their regressions. This model would have consistency issues; all forecasted variables would have to be consistent, independent, and exogenous before creating the final regression. Thus, this model is not useful for long-term forecasting.

4.3 The Russian Model

In 2013, the Russian Academy of Sciences published a long-term forecast report titled "Russian and Global Energy Outlook to 2040." The methodology section of the forecast describes a complex and detailed forecasting model. The model includes 192 countries, each of which has its own forecasted demand for energy and oil. The model calculates demand based on forecasted GDP, population, energy policies, and energy efficiency in each country. From this model, the paper moves to a "Balance Module" that calculates the balance between coal, gas, and liquid fuels. Finally, the "Resource modules" calculate the minimum cost of meeting energy demand (Arkhipov et al. 2013 p. 96-97).

The report also outlines the most important drivers of supply and demand. The report argues that the most important drivers of supply are new production technologies, resource base development, political constraints on production, environmental policy, and technical and economic profitability of new resources. The most important drivers of demand are environmental policy, promotion of a particular energy, technologies of energy consumption, demographic changes, and GDP changes. Also affecting the price—to a lesser degree, the report claims—are external factors such as natural disasters and geopolitics, and expectations of market participants (Arkhipov et al. 2013 p. 30).[2]

The Russian Academy of the Sciences may go about forecasting demand in a consistent way with GDP. The methodology section of the report is not clear or extensive, although it makes clear that forecasts are based on finding equilibrium of supply and demand. If the forecasters had estimated GDP, then estimated demand using GDP, the consistency problem would exist because it is impossible to estimate GDP without having some assumptions about oil prices. If the forecasters estimated a demand curve for each country using its policies, technologies, and demography, it could be an accurate representation of the country's demand. The forecasters could then create a supply curve in a similar manner, using their drivers of supply. This would create the market equilibrium, from which forecasters could make accurate crude price assumptions before forecasting GDP. The Russian Academy of Sciences does not make it completely clear whether or not this is how they forecasted prices.

[2] Like the EIA model, the Russian report claims that variables besides supply and demand influence prices. Again, prices in any market are the result of equilibrium between supply and demand; other variables simply affect supply and demand.

If so, the report could have highly consistent assumptions about GDP and crude prices.

4.4 Determinants of Crude Prices

Table 3 summarizes the price determinants postulated in the EIA and Russian Academy of the Sciences reports.

Table 3. Price determinants

EIA	Russian Academy
Supply Drivers	
Supply: OPEC	Political constraints
Supply: Non-OPEC	New technologies
	Resource development
	Profitability
Demand Drivers	
Demand: OECD	Environmental Policy
Demand: Non-OECD	Energy policy
	New technologies
	Demographic Changes
	Economic Changes (GDP)
Other Drivers	
Balance	Market Expectations
Financial Markets	External Factors
Natural Disasters	
Geopolitics	

Source: EIA and Russian Academy of the Sciences

The EIA and Russian Academy of Sciences largely agree on price determinants, although they call them by different names. As with any market, supply and demand will drive price; the Russian Academy of the Sciences' price determinants delineate more specific drivers of supply and demand, while the EIA simply divides supply into OPEC and non-OPEC, and demand into OECD and non-

OECD. Both forecasters report price determinants other than supply and demand. While these determinants will influence prices, they do so by influencing supply and demand. The Russian model's "Market Expectations" and the EIA's "Financial Markets" play similar roles. The "External Factors" in the Russian model is similar to "Natural Disasters" and "Geopolitics" in the EIA model, although the EIA seems to believe that these variables play a larger role than does the Russian report.

5. The Consistency Problem

A key factor forecasters ignore is the interdependent role of GDP and oil prices. Forecast models use GDP as an indicator of demand, which drives prices. However, prices also affect GDP. While prices will be a function of GDP of both importers and exporters, GDP of importers and exporters is also a function of price. Recall the following equations described in Section 1.

$$E_t[P_{t+i}]=f\ E_t[Y_{t+i}, S_{t+i}, x_{t+i}]$$

$$E_t[Y_{t+i}]= f\ E_t[P_{t+i}, x_{t+i}]$$

Unless expectations about price and GDP are consistent within a forecasting model, forecasts for both will be inaccurate. Creating forecasts of either variable without assumptions about the other is nearly impossible, so agencies must ensure that their assumptions about one variable are consistent with their forecasts of the other.

5.1 Price Relationships

In assessing the consistency problem within forecasts, a few basic relationships are necessary. The first is the income elasticity of demand. Gately and Huntingdon (2002) report a long-term income elasticity of demand of 0.53 in non-OECD countries and 0.55 in OECD countries. A one percent increase in OECD GDP will lead to a 0.55 percent increase in OECD demand for crude oil. The change in

OECD demand can be represented as the change in GDP times the income elasticity of demand, where η_D is the income elasticity of demand.[3]

$$\Delta D_{OECD}=\Delta Y_{OECD}(\eta_{D,\,OECD})$$

The change in worldwide demand will be the change in demand from OECD nations and the change in demand from non-OECD nations.

$$\Delta D=\Delta D_{OECD}+\Delta D_{Non\text{-}OECD}$$

The change in supply will be equal to the change in price times the price elasticity of supply, where η_s the price elasticity of supply. Krichene (2006) reports a price elasticity of supply of 0.08.

$$\Delta S=\Delta P(\eta_s)$$

In any market, supply and demand must be equal in equilibrium. In the oil market, the following equation represents market equilibrium.

$$\Delta Y_{OECD}(\eta_{D,\,OECD})+ \Delta Y_{Non\text{-}OECD}(\eta_{D,\,Non\text{-}OECD})=\Delta P(\eta_s)$$

Assumptions about GDP and prices must be consistent for the two sides of the previous equation to be equal. If we can conclude that forecasted change in supply does not equal forecasted change in demand, then forecasters' assumptions about GDP and price are inconsistent.

5.2 EIA Assumptions

The basic assumptions underlying the EIA's 2013 Annual Energy Outlook (AEO) show their beliefs about the interaction between forecasted GDP and

[3] The change operator Δ represents the change of a variable from 2010 to 2020, or the 2020 value of the variable minus the 2010 value.

forecasted oil price. The EIA states that the assumed GDP growth rate in OECD countries from 2010 to 2040 will be 2.17%, and will be 4.46% in non-OECD countries (Assumptions, 2013, pg. 24). Using the annually compounded growth equation, this means that the EIA assumes that the total change in OECD GDP from 2010 to 2020 will be 24%, and the total change in non-OECD GDP from 2010 to 2020 will be 55%. In the 2013 AEO, the EIA forecasts the crude price will be $105.57. The 2010 price was $83.07, so the change in price from the period from 2010 to 2020 would be 27%.

5.3 Supply and Demand Equilibrium

Using the supply and demand equations in Section 5.1, the income elasticity of demand from Gately and Huntingdon (2007), the price elasticity of supply from Krichene (2006) yields the following results:

$$\Delta D = \Delta Y_{OECD}(\eta_{D,\ OECD}) + \Delta Y_{Non\text{-}OECD}(\eta_{D,\ Non\text{-}OECD}) = 42.35\%$$

$$\Delta S = \Delta P(\eta_s) = 2.16\%$$

$$\Delta D = \Delta Y_{OECD}(\eta_{D,\ OECD}) + \Delta Y_{Non\text{-}OECD}(\eta_{D,\ Non\text{-}OECD}) \neq \Delta P(\eta_s) = \Delta S$$

Clearly, the changes in supply and demand are drastically different. The market the EIA predicts for 2020 is not in equilibrium. The EIA's forecast does not create consistent predictions about GDP and prices. If the forecast were consistent, then change in supply and demand would be equal.

Although the EIA's forecasts of GDP and crude oil prices do not appear consistent, the equilibrium equation alone does not show all of the EIA's assumptions. Given the EIA assumptions about GDP, demand grows by roughly forty percentage points more than supply over the eight-year period. For supply and demand to become equal, supply must grow or demand must fall from their expected values. Supply growth is the less likely of the two situations. New forms of oil production—such as hydraulic fracturing—are often more costly, and thus harder to bring to market. The price elasticity of supply could increase, as well. On the demand side of the market, demand could shrink every year due to conservation efforts. If demand were to decrease slightly every year from its expected value, then after ten years, supply and demand could be in equilibrium. Furthermore, the EIA may have different expectations about income elasticity of demand than Gately and Huntingdon (2002) report. Gately and Huntingdon (2002) could now be outdated, especially considering the global economic and technological changes since it was published. Without adding a condition about changes in demand or supply, the EIA forecast for crude oil prices is not consistent with their assumptions about GDP.

6. Conclusions

6.1 Empirical Conclusions

Forecasting a long-term oil price is a very complex task. The oil market by nature is highly fickle and affected by a wide array of variables. GDP of importing nations is only one of these variables. In predicting an accurate oil price, forecasters need to create a model that consistently accounts for assumptions of future GDP. Currently, forecasting agencies have not done enough to account for the interdependency of GDP and oil prices.

Forecasting agencies, of course, have much more complex models for predicting a future oil price. The simple equations in this paper ignore many geopolitical, technological, and economic effects. The scope of this paper was limited to exploring the consistency problem between forecasted GDP and prices. It cannot conclude that all oil price forecasts are invalid. Rather, it argues only that forecasters—particularly the EIA—have failed to create a model that forecasts GDP and future crude prices consistently.

6.2 Further Research

The economic literature needs continued research on the consistency of forecasted GDP and crude prices. Updated empirical work calculating long-term income elasticity of demand and price elasticity of supply would make the task easier. To understand this problem fully, economists would also need complete access to and understanding of forecasting methodologies. More complex econometric work would add to the discussion of the endogeneity problem between oil prices and GDP.

Another important question in the oil market is the sustainability of price changes. When the price increases, capital will flow from importer nations to exporter nations; when prices decrease, the opposite is true. With drastic price increases, financial crises could occur if importer nations lose large amounts of capital.

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The Pennsylvania State University

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- Bachelor of the Arts in Economics
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Work Experience

Wheelhouse Analytics

Data Analytics and Financial Services Intern

- Organized and analyzed mutual fund data
- Created graphs, dashboards, and grids of data for broker/ dealers and mutual fund manufacturers
- Created original education material for financial services professionals

The Pennsylvania State University Department of Economics

Research Assistant to Prof. Travis Letellier

- Collected data on the Consumer Confidence Survey
- Regressed macroeconomic data using Stata

Teaching Assistant, Introduction to Macroeconomics

- Proctored exams for a class of over 500 students
- Graded over 100 homework assignments each month

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- Managed the club's growth from under 10 to over 75 paying members
- Applied for and received a $1,600 grant from Penn State
- Wrote and oversaw allocation of a $5,500 semester budget
- Became and officially recognized non-profit franchise of CrossFit Inc.