

# Oil Consumption, Economic Growth, and Oil Futures\*

Robert C. Ready<sup>†</sup>

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## Abstract

I present evidence that increases in the cost of hedging oil price exposure in futures markets from 2005 to 2012 coincided with increases in uncertainty about long-run oil supplies. Motivated by these results, I provide new evidence on the relations between oil consumption, oil prices, and economic growth, and build on this evidence to develop a quantitative real business cycle model to study oil price risk. Calibrated model results can match relations between oil prices and economic quantities, and can rationalize behavior in equity and futures markets as a consequence of changing risk premia driven by increases in long-run oil supply uncertainty.

Keywords: oil prices, production-based asset pricing, long-run risk

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<sup>†</sup>Department of Finance, Simon School of Business, The University of Rochester. E-mail: robert.ready@simon.rochester.edu.

# 1 Introduction

How much does it cost to hedge exposure to oil prices in financial markets? In this paper I provide evidence from both oil futures and equity markets that this cost rose substantially in 2005 and remained high until 2012. I also show that this hedging cost coincided with a period of increased concern about long-run global oil supplies. To study the implications of this increased supply uncertainty for asset prices, I develop a quantitative real business cycle model for oil prices in the production-based Long-Run Risks (LRR) framework of Bansal and Yaron (2004), Kaltenbrunner and Lochstoer (2010) and Croce (2014).

Motivated by new empirical evidence presented here, the model incorporates a relation between oil prices and future productivity growth, recursive Epstein and Zin (1989) preferences, and an exogenous supply of an oil good endogenously allocated as both household consumption and an input to production. Calibrated model results are simultaneously able to match the behavior of oil prices, asset returns, and economic aggregates. Using the model, I show that an increase in long-run oil supply uncertainty is able to quantitatively account for most of the observed increases in hedging premiums.

The model presented here represents a novel approach to understanding oil's role in the economy and the implications for asset prices, and contributes to a growing recent literature on the sources of risk and return in commodity markets. One strand of the literature focuses on the macroeconomic drivers of commodity, and more specifically oil, risk. Casassus, Collin-Dufresne, and Routledge (2005) study oil price risk in a general equilibrium economy with time additive preferences and oil as an input to production, while Acharya, Lochstoer, and Ramadorai (2013) study expected returns to oil futures in a model with time-varying hedging incentives of oil producing firms.

In related work, Baker and Routledge (2012) examine the impacts of changing wealth shares for oil producing countries on oil price risk in a two-country endowment model with risk sharing and recursive preferences. Additionally, in a concurrent paper, Hitzemann (2014) studies

the relation between oil exploration, inventories, oil prices, and aggregate equity returns in a production based model with recursive preferences. However, none of these papers consider changes in long-run oil supply uncertainty, the allocation of oil to consumption and as an input to production, or the relation between oil prices and productivity growth.<sup>1</sup>

Another literature focuses on the impacts of financial frictions or increases in financial investment, often referred to as “financialization”, on commodity markets. Recent papers by Basak and Pavlova (2013), Baker (2012), Hamilton and Wu (2013), and Sockin and Xiong (2015) provide theoretical models describing the impacts of financialization on commodity markets, while Buyuksahin and Robe (2011), Hamilton and Wu (2012), Cheng, Kirilenko, and Xiong (2014), Singleton (2013), Tang and Xiong (2012), Henderson, Pearson, and Wang (2014), Cheng and Xiong (2013), and many others examine these issues empirically. In this paper, I abstract away from financial frictions to study the extent to which a neoclassical production economy with a rich oil sector can explain the observed behavior in oil futures.

The 2005 to 2012 period at issue in this paper is often characterized as a period associated with financialization. Increases in financial investment have been suggested as a potential source of many changes in these markets including higher prices, changing correlations among the prices of commodities and other assets, as well as changes in expected returns. Here I provide evidence suggesting that changing fundamentals may have also played a role, at least in explaining the hedging premia in oil futures markets.

Using forecast data, I first provide evidence that the increased slope in the term structure of oil futures documented by Hamilton and Wu (2013) is the result of increased hedging premiums rather than changes in expectations about future price growth. I also show that the volatility of long maturity futures prices greatly increased over this period, suggesting increased uncertainty about long run oil prices.

To relate this to fundamental uncertainty, I provide data on news articles to show that

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<sup>1</sup>Ready (2012) considers oil futures and supply uncertainty in a pure endowment economy with recursive preferences.

attention on long-run oil supply conditions abruptly increased in 2005 and remained high until 2012, and I document that this period also featured an abrupt drop in the share of worldwide oil production coming from OECD countries. I also show that the increase in the slope of the futures curve is a pattern unique to oil and energy futures, although financial investment increased across the entire commodity asset class. To provide evidence that these changes were not confined to oil futures markets, I also document large impacts on the cross-section of industry equity returns which are consistent with changes in the cost of hedging oil price risk. Finally, I show that the cost of hedging appears to have fallen from 2012 to 2014, coinciding with reduced uncertainty about long-run prices following dramatic increases in U.S. oil production.

The model then provides a unified framework for these findings in a benchmark, frictionless, complete markets setting. When the oil supply is constrained and unable to respond to changes in oil prices, oil prices exhibit less mean reversion and shocks to oil prices are expected to persist, creating increased uncertainty about long-run prices. This in turn creates increased volatility in long-run future prices, a striking feature of the data over this time period. These highly persistent shocks have a larger impact on the wealth, and therefore the marginal utility, of the representative agent, which in turn creates an increase in the hedging premium associated with this shock. The calibrated model is able to match the observed dynamics of oil prices and macroeconomic aggregates, including the dynamics of the allocation of oil to production and consumption, and the fact that high oil prices lead to a reduction in the labor supply but only a small reduction in aggregate investment. A comparative static exercise demonstrates that an increase in the long-run uncertainty of oil supply shocks implies an increase in the hedging premium which is quantitatively consistent with the data.

Oil has not been studied extensively in the LRR literature, despite the fact that oil futures are particularly interesting assets to study in this context. The models in this literature rely on recursive preferences and highly persistent shocks to expected growth to match macroeconomic and asset pricing facts, and have been successful in a variety of settings including equities

(Bansal and Yaron (2004)), currencies (Colacito and Croce (2011), Colacito and Croce (2013), and Bansal and Shaliastovich (2012)), labor frictions (Favilukis and Lin (2012)), and credit markets (Bhamra, Kuehn, and Strebulaev (2009)). Apart from some recent exceptions (Kung and Schmid (2015), Ward (2014), Collin-Dufresne, Johannes, and Lochstoer (2014)) these models are typically agnostic as to the source of changes in expected growth. In contrast, oil prices have long been cited as predictor of economic growth (Hamilton (1983), Hamilton (2005), Barsky and Kilian (2004)). Here I present new evidence that oil prices robustly predict future productivity growth, and that this predictability is unique from the innovation and research channels documented by Kung and Schmid (2015) and Ward (2014).

In addition to being liquid claims on a predictor of future growth, oil futures also allow for the persistence of shocks to precisely calibrated in the model. As emphasized by Bansal and Yaron (2004), while the level of expected growth can be inferred from pricing ratios, its persistence is difficult to estimate accurately. This is potentially important, since the price of risk associated with shocks to expected growth is extremely sensitive to this parameter. Indeed, highly persistent shocks are the key ingredient which allows these models to generate high risk premia necessary to match data on asset prices. Over the 2005 to 2012 period, the observed increase in the volatility of long-maturity oil futures implies an increase in the expected persistence of oil supply shocks, coinciding with an increase in the cost of hedging these shocks. This finding provides novel evidence on the importance of persistence in determining the risk premia associated with expected growth shocks.

Finally, the allocation of oil to both consumption and production is an important feature of the model, and is motivated by new evidence presented here on the relation of household consumption and oil prices. Household gasoline consumption accounts for roughly 65% of petroleum consumption in the U.S. economy, yet oil is often modeled as purely an intermediate input to production.<sup>2</sup> In these models, the price of oil is a function of aggregate output and aggregate oil

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<sup>2</sup>See Rotemberg and Woodford (1996) and Casassus, Collin-Dufresne, and Routledge (2005) as examples of models where oil is solely an input to production. In more recent work, Sánchez (2011) and Bodenstein,

consumption, a relation that holds only loosely in the data. In contrast, I model oil as an explicit component of the household's consumption basket, resulting in a direct connection between oil prices and the level of household oil consumption relative to consumption of other goods. I show that this relation is strong in the data, and that real oil prices over the last 35 years can be closely approximated by a function of the levels of household consumption of gasoline and household consumption of other, non-oil, goods. This new result is an important contribution of the paper, and allows for the study of oil prices in a quantitative macroeconomic model.

The rest of the paper is organized as follows. Section 2 presents empirical evidence of changes in the behavior oil future prices, as well as evidence on the relation of oil prices and the macroeconomy. Section 3 introduces the model. Section 4 presents the model results along with a comparative static exercise for regimes with both high and low long-run oil price uncertainty, calibrated to match observed economic and futures data. Section 5 discusses the implications of a shift in long-run uncertainty for equity and futures returns and presents supporting empirical evidence. Section 6 concludes.

## **2 Empirical Results**

Before presenting the model, this section presents the motivating empirical analysis. The model will be primarily used to explore the potential causes of the changes in oil futures behavior from 2005 to 2012, so I present those changes in detail. I also present new data on the relations between oil consumption, oil prices, and economic growth to motivate the structure of the model.

### **2.1 Data Sources and Sample Period**

Data on total U.S. oil consumption comes from the Energy Information Association (EIA). Data on household consumption and GDP come from the BEA's NIPA surveys. Data on TFP, hours

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Guerrieri, and Kilian (2012) examine the allocation of oil to production and household consumption, however to my knowledge no prior work examines household oil consumption in an asset pricing context.

worked, and capital supply are from the San Francisco Federal Reserve.<sup>3</sup> Data on oil futures are for the NYMEX West Texas Intermediate (WTI) contract, and come from the Commodity Research Bureau.<sup>4</sup> All data are for the U.S. economy. Data on miles per gallon of the U.S. passenger car fleet are from the National Transportation Safety Board.

The macroeconomic data and oil spot price are typically available for longer time series. To be consistent with other macroeconomic studies of oil prices, I report data for 1970-2012. The structural change in open interest generally attributed to financialization is usually identified as occurring near the end of 2004 (Hamilton and Wu (2013)). For futures data I focus on two subperiods, the pre-financialization period from 1997 to 2004, and a post-financialization period of 2005 to 2012.

## 2.2 Changes in the Term Structure of Commodity Futures

In this section I document changes in the term structures commodity future prices, returns, and volatilities over two subperiods: 1997 to 2004 and 2005 to 2012. The choice of the pre-financialization period is different from previous works, which often use a longer pre-financialization sample. Here I focus on equal length time periods to highlight structural changes in this specific time period, rather than longer term trends in futures markets.

I follow convention and define the log of the excess return to investing to a one-month investment in a fully collateralized future contract maturing at month  $t + j$  as

$$r_{t+1}^j = f_{t+1}^{j-1} - f_t^j \quad (1)$$

Where  $f_t^j$  is the future price at time  $t$  for a contract maturing at time  $t + j$ .

The slope of the futures curve at time  $t$  for a given maturity  $t + j$  is the difference between two adjacent futures

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<sup>3</sup>[http://www.frbsf.org/economics/economists/jferald/quarterly\\_tfp.xls](http://www.frbsf.org/economics/economists/jferald/quarterly_tfp.xls) .

<sup>4</sup>Since 2011 there has been a divergence between the WTI and other global oil price indices. In unreported analysis, the tests shown in this section were repeated using Brent Crude futures and yielded qualitatively similar results.

$$f_t^j - f_t^{j-1} = E_t[-r_{t+1}^j] + E_t[f_{t+1}^{j-1} - f_t^{j-1}] \quad (2)$$

Equation 2 is simply an identity, and shows that an increase in the slope of the futures curve is either driven by a decrease in expected returns (the first term), or an increase in expected price growth (the second term).

Figure 1 illustrates the two samples at issue to show how this slope changes over time. Panel A shows the time-series of both oil spot prices as well as the slope of the term structure of oil future prices, which is measured as the log of the ratio between the 6-month oil future price and 1-month oil future price. As the figure shows, prior to 2005, the slope of the term structure is strongly negatively correlated with changes in spot prices. However, starting around 2005 the slope of this term structure began to increase despite the fact that oil prices were rising over the same period. This slope remains higher, on average, through the remainder of the sample.

The primary implication of this increase in the slope is that long positions in oil futures became much more expensive, or equivalently, the return to investing in oil futures decreased relative to a given change in the spot prices. To illustrate this, Panel B of Figure 1 plots the cumulative return over each subsample to a strategy which takes a long position in oil prices by rolling over short-term futures each month. In each subsample this return is plotted against the cumulative spot price change over the period. In the first subperiod, the low slope of the futures curve means that this strategy yielded a return in excess of the total change in the spot price. In contrast, the positive slope of the term structure in the second subsample translates into returns that were far below the observed increase in the spot price. This difference is substantial, with the rolling strategy losing roughly 50% over the period, despite the fact that oil prices increased by 50% over the same sample.

[Figure 1 about here.]

These differences in returns are a mechanical outcome of the increased slope in the futures



curve. While Hamilton and Wu (2013) use a term structure model to suggest this is due to a decrease in the expected return associated with investing in oil futures, the patterns in *ex-post* realized returns would be the same if the market expected an increase in the spot price of oil over this period. The typical approach to ascertaining the source of this change would be to simply examine average returns, but due to the very short sample and high volatility of oil prices there is little statistical power to detect a change in expected returns using realized returns. To address this, Panel C of Figure 1 plots the log-difference between the 12-month future price and the consensus one year ahead spot price forecast calculated from the individual forecasts in the European Central Bank's Survey of Professional Forecasters. While this data is only available after 2002, it nevertheless shows that the increasingly upward slope coincides with a increase in the difference between futures prices and oil forecasts, consistent with a decrease in the expected return on a long position in oil futures.

The increase in the implied cost of taking long positions in financial futures is often identified as an impact of increased financial trading in commodity prices (Hamilton and Wu (2013) and Baker (2012)). Though it is true that open interest in oil futures greatly increased over this time, this was true across a broad set of commodities, while these changes in the behavior of the term structure were largely unique to oil prices. Figure 2 illustrates this. The Figure plots the average term structures of oil future prices, as well as the term structure of return volatility, for the two subsamples. For comparison, the figure also plots the term structures for two other commodities, Copper and Wheat. Copper and wheat are chosen as an illustration, since they are respectively the largest metal and agricultural contract in terms of index investment positions, which are often used as a measure of financial investment.

[Figure 2 about here.]

Panel A shows the average term structure of future prices, and shows that the term structure of Crude Oil is indeed more upward sloping in the second period. This pattern is not present in

the other two contracts. For copper, the curve is actually more downward sloping in the second sample, and for wheat there is no apparent change in the slope.

Panel B shows the term structure of the volatility of future returns. This change in the futures term structure has been studied less in the literature, but as the picture shows, the volatility of long term futures has risen substantially, resulting in a flattening of the term structure of future return volatilities for oil. While the volatility of copper and wheat have increased over the period, they do not exhibit the same flattening of volatility shown in oil futures.

In order to illustrate that the changes in oil shown in Figure 2 are statistically significant, and to show that the results for oil are in fact unique among a larger set of commodities, I estimate two regression specifications involving future prices and returns. I do this as opposed to estimating a full term-structure model of oil futures (such as Gibson and Schwartz (1990)) for parsimony and to allow for formal tests of structural changes in parameters. The regressions include an indicator variable,  $\mathbb{1}_{>2004}$ , which takes a value of one for observations after January 2005, and zero otherwise. The sample period for the regressions is January 1997 to December 2012, giving two subsamples of equal length. Table 1 shows the results.

The first specification is designed to test for a change in the slope of the term structure of prices, while controlling for variation in the slope generated by changes in prices and expectations of mean reversion. The slope is estimated as

$$Slope_t = \alpha + \alpha_1(\mathbb{1}_{t>2004}) + \beta r_{t-6,t}^2 + \beta_1(\mathbb{1}_{t>2004})r_{t-6,t}^2 \quad (3)$$

Here the slope at the end of each month, defined as  $f_t^6 - f_t^1$ , is regressed on  $r_{t-6,t}^2$ , the cumulative return of the nearest maturity future for the current month and the previous six months. The coefficient of interest is  $\alpha_1$ , which measures the change in the mean of the slope from 2005 to 2012. The lagged slope and current return are included to control for variations in the expected drift of future oil prices driven by mean reversion. The dummy variable is also

interacted with the cumulative return measure. The results from this regression are shown in Panel A of Table 1. The intercept on the level dummy  $\alpha_1$  is positive and significant at the 1% level for oil futures, as well as at the 5% level for Heating Oil, which is highly correlated with oil prices. However, for all other major commodities this is not the case. There is no significant change in the average slope of prices for any other commodities, with the exception of a small reduction in the slope of silver and gold, changes which are mostly driven by lower interest rates after the financial crisis.

To test for for a change in the expected mean reversion of future prices, I estimate the regression

$$r_t^6 = \alpha^j + \alpha_1^j(\mathbb{1}_{t>2004}) + \beta^j r_t^2 + \beta_1^6(\mathbb{1}_{t>2004})r_t^2 \quad (4)$$

[Table 1 about here.]

Where  $r_t^6$  is the log return on the sixth-nearest futures contract. This return is regressed on the contemporaneous return of the nearest term future contract, again with a dummy included for the intercept and slope. This regression technique is similar to that of Bessembinder, Coughenour, Seguin, and Smoller (1995), who regress changes of long term future prices on innovations in the spot price. As they note, a high degree of expected mean reversion implies that longer maturity contracts move less in response to a change in the level of prices.

As the first column of Panel B shows, the coefficient on the interaction of the dummy variable and the near term future contract have strongly significant positive values for Crude Oil, indicating a decrease in the degree of expected mean reversion, which generates the flattening of the volatility term structure. The intercept dummy is positive but not statistically significant. It is interesting to note that over the full period the long-term future does earn a premium over short-term futures, and is not unique to the 2005 - 2012 period often associated with financialization. I return to this finding in Section 5 and show that this increased return in long-

run futures, which is a natural consequence of a change in the futures curve from downward to upward sloping, is concentrated in the transition period between the two samples.

The increase in the expected persistence of prices is not unique to oil, as several of the commodities had significant decreases in expected mean-reversion in the post 2005 period, but again, only in oil and energy commodities do we see the corresponding increase in the slope of the term-structure of futures prices.

These results show that the increase in the slope of the futures price curve, is in fact unique to oil among commodities. If the explanation is an increase in financial investment, then this is a puzzling result, as one would expect a similar effect across all commodities. This suggests the potential for an alternate explanation of these changes driven by fundamentals of the oil supply. While the increased volatility of long-run oil futures is suggestive that long-run oil price uncertainty was higher than this period, it is also helpful to examine other indicators which are unlikely to be contaminated by changes in the behavior of financial traders.

Figure 3 provides evidence that these changes were reflective of a fundamental change. Panel A plots a novel measure of concern over long-run oil prices, constructed as the number of articles per year in Factiva's "Major News Sources" which contain the term "Peak Oil". This term, coined by geophysicist M. King Hubbert in 1956, refers to the idea that oil production for a given area has reached its maximum level and will continue to fall in the future. As the plot shows, this period of changes in futures markets precisely corresponds with a large increase in the prevalence of this term in the popular press, indicating that there was a substantial level of fear about long-run oil supplies.

Panel B shows a potential source of this worry. The graph plots the percentage of world wide oil production coming from OECD countries. Again, we see a striking change at precisely the same period, with large drops in OECD oil output, leaving more production in the hands of OPEC and other oil producers (e.g. Russia). While the model presented will be agnostic as to the source of increased long-run uncertainty, it is certainly plausible that this change would

create concern about the long-run dynamics of oil supplies.

[Figure 3 about here.]

In order to motivate the structure of a model to study the impacts of long-run oil price uncertainty, I now present new evidence on the use of oil in the economy, and the effects of oil prices on economic growth.

## 2.3 Oil Prices, Consumption, and Output

In the model oil will be used both as a consumption good and an input to production, and oil prices will have an exogenous impact on TFP growth. This section provides support for these features of the model by presenting evidence on the relation between household oil consumption and oil prices, as well as on the relations between oil prices and the various components of aggregate growth.

### 2.3.1 Household Consumption of Oil

To illustrate the importance of oil as a final consumption good, I first consider the expenditure by households on oil consumption relative to total U.S. oil consumption, GDP, and two measures of total household consumption expenditure. Household oil consumption is the nominal expenditure on “Gasoline and Other Energy Goods” from the NIPA survey. Total U.S. oil consumption is calculated using data on “Total Product Supplied” provided by the EIA. To obtain this value, barrels of consumption of each final petroleum product is multiplied by its price in each month.<sup>5</sup> EIA data are not seasonally adjusted, so the data is considered an annual frequency to avoid seasonal effects.

Panel A of Figure 4 shows the proportion of oil consumed by households along with the real price of oil. Household consumption of oil accounts for roughly 65% of oil use in the

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<sup>5</sup>Not all products have a published price, but those that do not are a small fraction of the output of an oil barrel. Furthermore they tend to be cruder refined products (ie. petroleum coke) and therefore account for an even smaller portion in dollar value.

U.S. economy, and this percentage has been fairly stable over the last 25 years. To the extent there is variation, the proportion of household consumption exhibits a clear negative correlation with spot prices, suggesting that household consumption of oil is more elastic than industrial consumption. Panel B of Figure 4 shows a similar graph, this time with the ratio of total economic consumption of oil to GDP. This ratio exhibits a larger amount of variation, with percentages ranging between 2% and 5% over the sample, and is strongly positively correlated with changes in oil prices.

Finally Panel C of Figure 4 shows the percentage of household consumption expenditure allocated to 'Gasoline and Other Energy Goods'. The plot shows this percentage as both the percentage of total consumption expenditure (goods and services), as well as the percent of expenditure on goods. As the plot shows, household expenditure on gasoline has been trending downward over time relative to total expenditure, but this is driven primarily by the increase of expenditure on services. Relative to total expenditure on physical goods, the amount of household expenditure on gasoline has no discernible trend, but again is highly positively correlated with oil prices.

[Figure 4 about here.]

### 2.3.2 Household Consumption and Oil Prices

To help understand how households allocate resources to oil consumption, I first specify a general intratemporal function for household utility over an aggregate consumption good, ( $C_t$ ) and an oil consumption good ( $G_t$ ).

$$V_t(C_t, G_t) = \left[ (1 - a_G)C_t^{1-\frac{1}{\xi_G}} + a_G G_t^{1-\frac{\eta}{\xi_G}} \right]^{\frac{\xi_G}{\xi_G-1}} \quad (5)$$

The function is the Generalized Constant Elasticity of Substitution (GCES) felicity function of Pakos (2004). A Cobb-Douglas utility function is a special case, where  $\xi_G$  and  $\eta$  are equal to

one. The parameter  $\xi_G$  is the elasticity of substitution between oil consumption and aggregate consumption. The parameter  $\eta$  allows non-homotheticity in the utility function. In the data  $\eta < 1$ , implying that oil demand rises more slowly than demand for basic consumption goods as wealth rises (ie., oil is a necessary good as opposed to a luxury good).

First order conditions imply that  $p_t$ , the log of the price of a unit of oil consumption  $G_t$  in terms of units of the numeraire good  $C_t$ , is given by

$$p_t = \log\left(\frac{a_G}{1 - a_G}\right) + \frac{1}{\xi_G}(c_t - \eta g_t) \quad (6)$$

To estimate the utility parameters, I use the dynamic OLS method described by Stock and Watson (1993), which includes both leads and lags of the growth rates of the independent variables to control for endogeneity.<sup>6</sup> The form for the regression is

$$p_t = \beta_0 + \beta_1 c_t + \beta_2 g_t + \sum_{t=-k}^k \Gamma_{1,k} \Delta c_{t+k} + \sum_{t=-k}^k \Gamma_{2,k} \Delta g_{t+k} \quad (7)$$

The coefficients are related to the parameters of the utility function  $V_t$  by  $\beta_1 = \frac{1}{\xi_G}$  and  $\beta_2 = \frac{\eta}{\xi_G}$ . It is worthwhile to note here the implications of considering oil directly as a consumption good. While clearly consumers do not consume crude oil, and ultimately I will be concerned with pricing futures for delivery of crude oil, there is a very tight relation between crude oil prices and the price of gasoline. Gasoline then enters households' consumption primarily through automobile use. To account for changes in the efficiency of converting oil to consumable goods, I adjust the level of oil consumption by the multiplying it by average miles per gallon taken from the Bureau of Transportation Statistics. The assumption underlying this adjustment is that the household consumption good is not actually gasoline, but rather miles driven. Therefore, I also adjust the price of oil by miles per gallon to obtain a measure of price per mile. Accordingly, in the regression of Equation (7), I substitute  $p_t$  with  $(p_t - \log(mpg_t))$ , and  $g_t$  with  $(g_t + \log(mpg_t))$ .

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<sup>6</sup>The analysis is similar to Bentzen and Engsted (1993) and Ramanathan (1999), who use aggregate income and economy wide oil use to estimate elasticities of demand for oil.

I estimate this regression using two different measures of aggregate consumption. The first is consumption of nondurable goods and services, and the second is a Cobb-Douglas aggregate of nondurable goods and services and the stock of durable goods constructed as in Yogo (2006). I also include two different measures of oil consumption. The first is the measure of household consumption from NIPA data, while the second, following Bentzen and Engsted (1993) and others, is the economy-wide measure of product supplied from the EIA. For comparison I also estimate the regression using personal income and GDP in place of consumption. To be consistent with previous studies I do not adjust these variables for efficiency, however doing so does not significantly alter the results. Table 2 reports these regressions for 1981 to 2012, the period for which I have data on aggregate U.S. oil consumption.

[Table 2 about here.]

As this table shows, the measurement of oil consumption from NIPA data does a much better job of explaining oil prices than the measure of aggregate economy-wide oil consumption obtained from the EIA. To illustrate the improvement in fit from using household data as opposed to Figure 5 graphs the predicted values from a simple regression of the log of the oil prices on the logs of aggregate consumption and energy consumption from 1981 to 2012. The relative measures of consumption captures the short term dynamics as well as the long-term trend, while the relative measures of output and total oil consumption do a poor job of capturing both.

[Figure 5 about here.]

### **2.3.3 Oil Prices and Economic Growth**

A common stylized fact from the macroeconomic literature on oil prices is the predictive relation between increases in oil prices and low future economic growth. For instance, Hamilton (2008) estimates a regression of GDP growth on lags of GDP growth and lags of oil price changes, and finds that changes increases in oil prices predict low GDP growth for up to four quarters in



the future. Here I revisit this analysis to attempt to shed light on the source of this change in output.

Using data from San Francisco Federal Reserve which decomposes changes in output into its component parts, I estimate a Vector Autoregression (VAR) for the log changes of hours worked, total capital stock, total factor productivity, and the real price of oil. The VAR is estimated with four lags over the period from 1970 to 2012. Figure 6 plots the impulse response functions for this VAR to a one standard deviation change in the price of oil. The figure shows that the future reduction in growth is not driven by a reduction in capital, as the capital stock shows little discernible response to an increase in oil prices. Instead, the future drop in output is driven by a change in future Total Factor Productivity, along with a reduction in total hours worked.

[Figure 6 about here.]

While the standard VAR framework provides evidence that oil prices impact TFP growth, there are a some issues with this regression, particularly when considered in the context of the model. One confounding feature of the total TFP measure in the VAR is the fact that oil itself is an input into total output. Another is that a portion of U.S. GDP comes from U.S. oil production. To address these issues I again utilize data reported by the San Francisco Federal Reserve which reports utilization adjusted TFP, and decomposes total TFP into “Investment” TFP, including investment goods and consumer durables, and “Consumption” TFP, consisting of TFP for all other output including oil.

In a model with recursive preferences, long-run growth impacts will have important implications for asset prices. In order to study growth impacts at longer horizons than the one year used in the standard VAR framework, I use the ratio of household expenditure on gasoline to expenditures on other goods (excluding services). I then test to see if this value, which is strongly related to oil prices but exhibits very little time trend, is able to predict TFP growth.

Additionally, in the model, the oil price impact on growth will be distinct from a separate,

long-lived shock to aggregate growth. To provide support for this assumption I test for the predictive power of the oil consumption ratio controlling for two other predictors of TFP growth in the recent literature. Kung and Schmid (2015) show that aggregate R&D intensity has predictive power for TFP growth, and Ward (2014) shows a similar result for the price-dividend ratio of the IT sector. For R&D Intensity the data is annual from 1953, while the IT sector price-dividend is available quarterly from 1973.

I estimate forecasting regressions of the form

$$\Delta TFP_{t,t+k}^i = \alpha + \beta^{G/C}(ConsRatio_t) + \beta^X X_t \quad (8)$$

Here  $TFP_{t,t+k}^i$  is the log of utilization adjusted TFP growth from time  $t$  to  $t+k$  for two different sets of goods.  $TFP_{t,t+k}^I$  is productivity growth of investment goods and consumer durables, while  $TFP_{t,t+k}^C$  is all other goods and services, including oil.  $ConsRatio_t$  is the log-ratio of total expenditure on gasoline and other energy goods to household consumption expenditure on all other goods (excluding services).  $X = RDI$  is R & D intensity calculated as in Kung and Schmid (2015), and  $X = IT$  is the P/D ratio of the IT industry as in Ward (2014).

Table 3 shows the results. The ratio of household oil consumption to total consumption strongly negatively predicts  $TFP^I$  in both the quarterly and annual data at both short and long horizons, and this relation is robust to the inclusion of the other predictor variables. Moreover, the power of the other predictors are concentrated in  $TFP_{t,t+k}^C$ , suggesting that the predictive power of oil prices for TFP growth is distinct from previously documented effects.

[Table 3 about here.]

I now turn to the model, which incorporates the empirical evidence on consumption and oil prices, as well as the relation between oil prices and TFP growth. The model shows how an unresponsive oil supply can generate changes in the dynamics of oil futures which are consistent with those observed from 2005 to 2012.

### 3 The Benchmark Model

The model presented here adds an exogenous oil supply to the model of Kaltenbrunner and Lochstoer (2010) and Croce (2014). As in Kaltenbrunner and Lochstoer (2010) the model features households with recursive preferences in the manner Epstein and Zin (1989), and following Croce (2014), the model includes exogenous persistent shocks to the growth-rate of TFP, similar to the long-run shocks to consumption growth in Bansal and Yaron (2004). Oil is used in the economy for household consumption, and as an input to production of a basic good which is consumed by households and used for investment in capital. Oil storage and stochastic oil production volatility are not qualitatively important for the primary results, so they are excluded here for simplicity.<sup>7</sup>

The model is a partial equilibrium framework in the sense that the oil supply is modeled as an exogenous process. Rather than focusing on the oil production decision, the model focuses on the implications of supply conditions for the aggregate economy and observed risk-premia in asset markets. This choice is in contrast to traditional models of commodity futures, many of which consider the problems associated with storage ((Kaldor (1939), (Williams and Wright (1991), Deaton and Laroque (1992), Deaton and Laroque (1996), Routledge, Seppi, and Spatt (2000)) or oil production (Casassus, Collin-Dufresne, and Routledge (2005), Carlson, Khokher, and Titman (2007), Kogan, Livdan, and Yaron (2009)), and usually rely on risk-neutral settings or an exogenously specified risk premium.

#### 3.1 Households

The representative household derives utility from direct consumption of oil,  $G_t$ , consumption of a basic good  $C_t$ , and leisure  $n_t$ .

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<sup>7</sup>Section B of the Online Appendix presents empirical data on storage and futures prices, as well results from a version of the model augmented to include oil storage and stochastic oil volatility. In the extended model, the equilibrium relation between inventories and futures curves holds consistent with the theory of storage (Deaton and Laroque (1992)), but storage has little ability to alleviate long-run shocks, so the asset pricing implications are unchanged.

I define the household's consumption basket

$$\tilde{C}_t = \left[ (1 - a_G) C_t^{1 - \frac{1}{\xi_G}} + a_G G_t^{1 - \frac{1}{\xi_G}} \right]^{\frac{\xi_G}{\xi_G - 1}} \quad (9)$$

as a CES aggregate of oil consumption and basic consumption.<sup>8</sup>

Intertemporal utility is then given by embedding the intratemporal utility across basic consumption, oil consumption, and leisure in the recursive setting of Epstein and Zin (1989)

$$U_t = \left[ (1 - \beta) \left( \tilde{C}_t^{1 - \phi} N_t^\phi \right)^{1 - \frac{1}{\psi}} + \beta \left( E_t[U_{t+1}^{1 - \gamma}] \right)^{\frac{1 - 1/\psi}{1 - \gamma}} \right]^{\frac{1}{1 - \frac{1}{\psi}}} \quad (10)$$

Where  $\gamma$  is the coefficient of risk aversion and  $\psi$  is the intertemporal elasticity of substitution (IES). As in Croce (2014),  $N_t = A_{t-1} n_t$  is the leisure share multiplied by the lag of the aggregate technology shock to ensure model stationarity.  $N_t$  can therefore be interpreted as leisure adjusted for the standard of living.

### 3.2 Production

The household supplies labor to a representative firm which produces the basic good using a capital stock ( $K_t$ ), oil ( $O_t$ ), and labor  $L_t$ . The productivity of the firm is impacted by exogenous productivity shocks ( $A_t$ ) so that output  $Y_t$  is given by

$$Y_t = \left[ (1 - a_O) \left( K_t^\alpha (A_t L_t)^{1 - \alpha} \right)^{1 - \frac{1}{\xi_O}} + a_O O_t^{1 - \frac{1}{\xi_O}} \right]^{\frac{\xi_O}{\xi_O - 1}} \quad (11)$$

The constraints on capital and labor are standard, and the overall supply of hours for labor and leisure are normalized to one.

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<sup>8</sup>Here I do not allow for non-homotheticity in the utility function, though it is a feature of the data on oil consumption. Non-homotheticity can be accounted for by specifying an endowment for oil which ensures that the percentage expenditure on oil is stationary on the balanced growth path. This yields very little change in asset-pricing the implications for the model and is thus omitted for simplicity.

$$Y_t = C_t + I_t \tag{12}$$

$$1 = L_t + n_t$$

The capital stock evolves according to

$$K_{t+1} = (1 - \delta_k)K_t + \Phi\left(\frac{I_t}{K_t}\right)K_t \tag{13}$$

Where  $\Phi$  is an adjustment cost function parameterized as in Jermann (1998).

The oil supply in each period is  $W_t$  is allocated for production of the final good or direct household consumption so that

$$W_t = G_t + O_t \tag{14}$$

### 3.3 Technology and the Oil Supply

There are three exogenous state variables in the Benchmark Model. The first is the log level of technology process  $a_t$ , the second, following Croce (2014), is the long run persistent component of technology growth,  $x_t$ , and the final variable is the log of the supply of oil produced in each period,  $w_t$ . To ensure balanced growth, the supply of oil and is cointegrated with the level of aggregate technology. The dynamics of the three variables are given by

$$\Delta a_{t+1} = \mu_z + x_t + \zeta w_t + e^{v_t} \sigma_a \epsilon_{t+1}^a \quad (15)$$

$$x_{t+1} = \rho_x x_t + e^{v_t} \sigma_x \epsilon_{t+1}^x \quad (16)$$

$$\Delta w_{t+1} = \mu + (\rho_w - 1)(w_t - a_t - \bar{w}) + \kappa x_t + \sigma_w \epsilon_{t+1}^w \quad (17)$$

$$(18)$$

Here,  $\rho_x$  and  $\rho_w$  govern speeds of mean reversion, the parameter  $\kappa$  allows for the oil supply to respond to increases in expected growth of technology, while  $\zeta$  allows for the level of the oil supply to have an exogenous impact on future TFP growth. Since  $w_t$  is an exogenous variable in the model the social planner is unable to adjust allocations to mitigate this growth effect. The impact of oil prices on TFP in the model can therefore be considered a growth externality of high oil prices.<sup>9</sup> The shocks in the model are distributed  $N(0, 1)$  and assumed to be orthogonal.

### 3.4 Equilibrium

Markets are complete so the solution to the model can be computed by solving the social planner's problem of maximizing  $U_t$ , by choosing consumption, labor, investment, and the allocation of oil between households and production, subject to the exogenous shocks and the resource constraints.

Setting basic consumption,  $C_t$ , as the numeraire good, and following standard calculations (see for instance Yogo (2006)), the stochastic discount factor in the economy is given by

$$\frac{M_{t+1}}{M_t} = \beta \left( \frac{C_{t+1}}{C_t} \right)^{-\frac{1}{\psi}} \left( \frac{\tilde{C}_{t+1}/C_{t+1}}{\tilde{C}_t/C_t} \right)^{\frac{1}{\xi_G} - \frac{1}{\psi}} \left( \frac{N_{t+1}/\tilde{C}_{t+1}}{N_t/\tilde{C}_t} \right)^{(1-\frac{1}{\psi})(\phi)} \left( \frac{U_{t+1}}{E_t [U_{t+1}^{1-\gamma}]^{\frac{1}{1-\gamma}}} \right)^{\frac{1}{\psi} - \gamma} \quad (19)$$

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<sup>9</sup>This externality is similar to the externalities associated with exports considered in the context of international trade. See Feder (1983) and Melo and Robinson (1992).

The risk-free rate is

$$R_t^f = E[M_{t+1}]^{-1} \quad (20)$$

The first order conditions with respect to  $C_t$  and  $G_t$  imply that the spot price of oil is given by

$$P_t = \frac{a_G}{(1 - a_G)} \left( \frac{C_t}{G_t} \right)^{\frac{1}{\xi_g}} \quad (21)$$

Future contracts are assumed to be marked to market each period, so future prices in the model can be calculated recursively using

$$0 = E_t[M_{t+1}(F_{t+1}^{j-1} - F_t^j)] \quad (22)$$

with  $F_t^0 = P_t$ .

As in Croce (2014), aggregate equity returns are calculated as the levered return on investing in  $K_t$ , the stock of basic capital. The marginal value of a unit of extra capital is given by

$$Q_t = \frac{1}{\Phi' \left( \frac{I_t}{K_t} \right)} \quad (23)$$

The normalized return to investing in a unit of capital is given by

$$R_{t+1} = \frac{\frac{dY_{t+1}}{dK_{t+1}} + Q_{t+1} \left[ \Phi \left( \frac{I_{t+1}}{K_{t+1}} \right) - \Phi' \left( \frac{I_{t+1}}{K_{t+1}} \right) \frac{I_{t+1}}{K_{t+1}} - \delta_k \right]}{Q_t} \quad (24)$$

These returns are then an input to the excess levered return on equity

$$R_{ex,t}^{LEV} = \phi_{lev}(R_t - R_{t-1}^f) + \epsilon_t^d \quad (25)$$

Here  $\phi_{lev}$  represents the effect financial leverage, and  $\epsilon_t^d \text{ i.i.d. } N(0, \sigma_d)$  is an idiosyncratic

dividend shock, which does not effect the representative agent’s consumption. The idiosyncratic dividend shock does not impact expected returns, but allows the model to better match the observed volatility of equity returns.

## 4 Benchmark Model Results

The solution to the benchmark model is obtained using perturbation methods to accommodate the high number of state and control variables.<sup>10</sup> The model is calibrated for two parameterizations, representing a “responsive” and “unresponsive” oil supply. The only difference between the two regimes is in the persistence of oil price shocks  $\rho_w$ , which is closer to one in the unresponsive calibration. The complexity of the model makes an explicit regime shifting process computationally infeasible, so I instead I perform the comparative static of examining two different calibrations of the model parameters and comparing them to the two different time periods in the data.<sup>11</sup>

One way to interpret this exercise is that it considers an unanticipated change in supply conditions. For instance, if a sudden increase of world wide oil demand rapidly outstripped available supply capacity, the oil industry may have been quickly forced into a regime where it was unable to respond to subsequent shocks. If this possibility was not anticipated ex ante, the risks associated with this change in supply conditions would not be reflected in future contracts in the first period. While it would be interesting to examine the effects of explicit regime changes, I focus here on the simple exercise of comparing the two regimes, and leave a more general model to future work.

Table 4 presents the calibrated model parameters for utility and the production processes. Most of the parameters are chosen as in Croce (2014) to facilitate comparison. The exceptions are a lower volatility of aggregate consumption but a higher risk aversion, due to the lower observed

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<sup>10</sup>See Appendix A of the internet appendix for a full set of equilibrium conditions and description of the solution method.

<sup>11</sup>Section 5 discusses the implications of an increase in the hedging premia on equity and long-run future returns.



consumption volatility of the more recent sample period used in this paper. Parameters related to oil production and consumption are calibrated to match observed behavior of prices and oil expenditure by households and producers.<sup>12</sup>

Small changes in the levels of  $\rho_w$  and  $\zeta$  can have large impacts on the risk premium associated with oil futures prices. It is therefore important that they are disciplined by other moments in the data.

The levels of  $\rho_w$  across the two specifications are not chosen arbitrarily, but are rather calibrated to match the observed term structure of future return volatility, which are very precisely estimated even in short samples, and on which they have a first order effect.

Likewise the parameter  $\zeta$  is set at -0.004 so that a unit increase in the log of the oil consumption ratio leads to a decrease of approximately 1% in the log of production growth, consistent with the annual regressions in Table 3, which are the more conservative estimates.

The parameter  $\xi_G$  is set at 0.25 to match the value from the regressions in Table 2, and the panel  $\xi_O$  is set at 0.225 to match the negative comovement of oil prices and the share of oil used for household consumption.

In both calibrations, the parameter of  $\kappa$  is set to 0.8. This is done so that shocks to long-run growth expectations have minimal impact on the long-run expected oil price growth, since the oil supply is assumed to be able to respond equally to long-run growth shocks in both cases. This assumption is made so shocks to  $x_t$  do not impact the term structure of oil futures returns, keeping the focus of the analysis on oil supply shocks. While it is interesting to study the interaction of long-run productivity growth shocks and oil prices, the lack of consensus in the literature about the precise nature of these shocks makes the interpretation of these effects difficult, so I do not attempt to address this here.

Panels A and B of Table 5 present aggregate market moments and oil specific moments respectively. These calibrations are shown for unresponsive and responsive scenarios for the

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<sup>12</sup>Section C of the online Appendix presents alternate calibrations of the model.

Benchmark Model.

[Table 4 about here.]

[Table 5 about here.]

Panel A of Table 5 shows that the model is able to do a reasonable job matching macroeconomic moments. The ability of this type of model to match volatilities of macroeconomic aggregates and asset prices over a longer sample period is shown by Croce (2014). Since the sample period here exhibits lower volatility than that in Croce (2014) the model's fit is not quite as good. However, the model is able to generate low consumption volatilities and a reasonably high levered equity premium of 4.98% in the responsive supply calibration.

As Panel B of Table 5 shows, the model is also able to match many of the features of oil futures data. A decrease in the responsiveness of the oil supply leads to a flattening of the term structure of future volatilities, and a more upward sloping term structure of returns and prices.

Figure 7 plots the changes in the term structures of future prices, returns, and return volatilities across the two benchmark specifications alongside the term structures from the data. As the figure shows, the model is able to account for many of the changes in the futures curve across the two regimes. An unresponsive oil supply creates an upwardly sloping term structure of prices, which is driven by a decrease in expected returns across the entire curve.

[Figure 7 about here.]

Unlike reduced form models of oil prices, the model is disciplined by matching many of the macro moments, and therefore fails to perfectly match the quantitative size of the asset pricing facts, but the observed effects are of the same order of magnitude as those observed in the data.

Another shortcoming of the model is that the slope of the futures curve has a strong upward slope in both calibrations due to the lognormal nature of the model. The log of the oil price has zero average growth in the model, but the high volatility of oil prices leads to expected growth

in the level of prices over time which is reflected in the upward slope of the future price curves. Reduced form models, such as Gibson and Schwartz (1990) account for this by imposing an exogenous drift term in prices to offset this effect and match the observed curves in the data, but here the requirements of a balanced growth path and lognormality for tractability preclude this adjustment.

Finally, the model is also able to match the levels and dynamics of oil expenditure by households and by the economy as a whole. Figure 8 graphs a sample path of the model and shows both the ratio of household oil consumption to total oil consumption, and the ratio of total oil expenditure to aggregate output. Panel A of this figure shows that the model is able to match the positive correlation between oil prices and the ratio of total oil expenditure to output, and Panel B illustrates the same negative correlation between oil prices and the ratio of household oil consumption to total oil consumption seen in the data.

[Figure 8 about here.]

To further explore the implications of the model, I now turn to impulse response functions to help understand the mechanisms which generate the observed results for macroeconomic quantities and future markets.

## 4.1 Model Mechanisms

### 4.1.1 Output, Labor, and Investment

Figure 9 shows the impact of the three model shocks on capital, labor, and TFP. As in the data, the effect is concentrated mainly in a reduction of hours worked as workers substitute away from consumption (which requires oil) and into leisure, and this effect is quite strong in both the unresponsive and responsive calibrations. In contrast, the investment effect is more muted, particularly in the responsive case.

The lack of investment response to an oil shock in the responsive regime is due to the fact

that oil is both a final and intermediate good. When oil is needed for both production and consumption, an increase in oil prices does not create a substitution effect from capital goods to consumption goods. Furthermore, since the shocks are short-lived, the wealth effect is also small, and investment is essentially unchanged. However, when oil shocks are expected to persist, a negative oil shock has a long lasting impact on TFP growth, and investment responds following the same intuition involving long-run productivity shocks in the models of Kaltenbrunner and Lochstoer (2010) and Croce (2014). However, even in the unresponsive case, the investment effect in the benchmark calibration is small when compared to the shocks to technology growth.

[Figure 9 about here.]

#### 4.1.2 The Term Structure of Oil Futures

In the model, expected returns to oil futures are determined by the exposure of oil future prices to the various shocks as well as the prices of risk associated with those shocks. Changes in these exposures and prices of risk across the two regimes generate the different behavior of the futures curves in the model.

To illustrate this, consider Equation 22. If prices are lognormally distributed, this equation can be restated as

$$f_t^j = E_t[f_{t+1}^{j-1}] + \frac{1}{2}\text{var}_t(f_{t+1}^{j-1}) + \text{cov}_t(f_{t+1}^{j-1}, m_{t+1}) \quad (26)$$

Setting  $j = 1$  and subtracting  $p_t$  from both sides gives an expression for the futures basis, or the slope of the term structure of future prices at the short end of the futures curve

$$f_t^1 - p_t = E_t[p_{t+1} - p_t] + \frac{1}{2}\text{var}_t(p_{t+1}) + \text{cov}_t(p_{t+1}, m_{t+1}) \quad (27)$$

Therefore the slope of the term structure of future prices at a given time includes the expected growth in price, which has both a mean and variance term due to the lognormal nature of the

model, as well as a risk premium generated by the covariance of prices and the stochastic discount factor

To see how the various shocks in the model impact oil prices and the stochastic discount factor across the two regimes, Figure 10 plots these impulse response functions for the benchmark case.

The increase in the slope of the term structure of future prices is driven by the changing risk premium associated with shocks to  $w_t$ . In the responsive case, there is a slight positive return created by a negative correlation with  $m_t$  coming from the short-run productivity shocks, and a small negative return created by the negative correlation with  $m_t$  from shocks to oil production. The two effects yield a slight upward slope in the futures curve.

When oil prices impact future growth, more persistent oil price shocks command a larger level of risk, as evidenced by their increased impact on the SDF in the unresponsive regime. This leads to a stronger positive covariance of  $m_t$  and future returns at all maturities, and equivalently a more upwardly sloping term structure of future prices.

[Figure 10 about here.]

## 5 Futures and Equity Returns during Transition Periods

While the model does not feature explicit regime changes between responsive and unresponsive states, it does provide guidance as to what the behavior of assets would be during such a transition. The primary impact of the increase in long-run uncertainty is a decrease in the discount rate associated with claims which have long exposure with oil prices. This decrease in discount rates will yield increases in value, and these increases will be larger for long duration assets. This can be clearly seen in the futures curve. Holding the price of oil constant, the long horizon futures rise more than the short horizon futures as the slope of the futures curve increases.

Since the explanation of this changing discount rate proposed here is based on impacts to the marginal utility of a representative consumer, this increasing discount rate should impact claims to *all* assets which have exposure to oil prices, particularly those which have long-duration. A natural candidate for such an asset is equity. Rather than examine aggregate returns, I instead follow construct an "Oil Characteristic Portfolio", which is a maximally diversified zero-investment portfolio designed to mimic oil price changes.<sup>13</sup> To construct this portfolio, I begin with the Fama French 30 Industry Portfolios. I then calculate each industry's exposure to oil prices by regressing monthly industry returns on monthly returns to the second nearest oil future over a 10-year presample period of 1987 to 1997. The characteristic portfolio return in each month, which I refer to as  $r_t^{OCP}$ , is then simply the slope of the cross-section industry returns regressed on the estimated pre-sample oil price betas and a constant, as in a Fama and MacBeth (1973) style regression.

I then split the second subsample into a transition period of 24 months from January 2005 to December 2006, and a post-transition period from January 2007 to December 2012. In each of the three subsamples I observe the average returns to 2-month futures, 6-month futures, and the Oil Characteristic Portfolio. The first three columns of Table 6 shows the results, with each panel representing a different subsample.

Panel A shows that all three returns are roughly equal prior to the transition. This however is not the case during the transition period. As a mechanical result of the slope of the futures curve increasing in the transition period, Panel B shows that the long-horizon future outperforms the short-horizon future, earning a return of roughly 1% extra per month. Over this same period, the Oil Characteristic Portfolio earns a very large return (roughly 6% per month), which is consistent with the decrease in discount rates creating a large rise in price. This pattern is again absent in the post-transition period in Panel C.

Though these results are qualitatively consistent, the high volatility and short time period

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<sup>13</sup>See Back, Kapadia, and Ost diek (2013) for a discussion of characteristic portfolios.

means the patterns in means is not statistically significant. To address this, the last two columns of the table plot the results of the following regressions

$$r_t^6 = \alpha^6 + \beta^6 r_t^2 + e_t^6 \quad (28)$$

$$r_t^{OCP} = \alpha^{OCP} + \beta^{OCP} r_t^2 + e_t^{OCP}$$

These regressions test whether or not the long-horizon future and equity portfolio had high returns relative to those explained by movements in the short-run future. Panel B shows returns these two strategies strongly outperformed short-run futures in the transition period, as evidenced by the positive values of the constants in the two regressions. Again there is no evidence of this pattern in the other two periods, as shown in Panel's A and C.

### 5.1 Decreasing Long-Run Supply Uncertainty: 2012 - 2014

This section considers more recent changes in oil markets. While concerns about the long-run supply of oil appear to be able to explain much of the behavior observed from 2005 to 2012, the more recent period has seen large increases in production from technological advancements in extracting oil from shale fields in the United States.<sup>14</sup>The impact of this increased production can be seen clearly in Panel B of Table 3. If these advancements have the potential to reduce long-run uncertainty about oil prices, this should translate into changes in the futures curve and equity returns. I show here that this appears to be the case.

[Table 6 about here.]

Panel A of Figure 11 shows estimates of the persistence of oil price shocks implied by the behavior of long-term futures, as well as the slope of the futures curve adjusted for changes in the level of prices. The figure shows evidence the persistence of oil price shocks has undergone a

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<sup>14</sup>Gilje, Ready, and Roussanov (2015) discusses the impact of this increased oil production on the aggregate U.S. stock market.

drastic drop, suggesting more stable expectations for long run prices. This drop in persistence has also coincided with a shift towards a more downward sloping term structure of future prices.

Panel B plots the cumulative return to the Oil Characteristic Portfolio and the cumulative change in oil prices over the recent period. The increase in production has come primarily from high cost sources of oil, and thus had little impact on overall price levels prior to the end of 2014. Despite this high price, the additional supply capacity appeared to have a large impact on the riskiness of oil futures, by reducing uncertainty about long-run price levels. The observed behavior of oil futures and equity prices is consistent with this translating to a discount rate effect, with a very large negative return to the Oil Characteristic Portfolio over this period despite little change in oil prices.<sup>15</sup>

[Figure 11 about here.]

## 6 Conclusion

The recent focus in commodity markets has been squarely on the behavior of financial speculators. However, using financialization to explain all of the behavior in these markets may be premature when there is still not yet a clear understanding of how these commodities interact more broadly with macroeconomic risk.

This paper contributes several new empirical facts regarding the use of oil in the economy and the relation between oil prices and future growth, and uses these facts to develop a production-based asset pricing model for studying oil price risk. The model is able to match key features of the relation of oil to various macroeconomic aggregates, and illustrates how a change in the dynamics of the the oil supply may provide an explanation for observed changes in the term structure of oil futures and observed patterns of cross-sectional equity returns from 2005 to 2012.

The data and the model suggest that a key driver of the riskiness of oil price shocks is their

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<sup>15</sup>In unreported regressions the  $\alpha^{OCP}$  over this period is significant at the 1% level, while  $\alpha_t^{\delta}$  is negative but insignificant.



persistence. This provides novel evidence for the importance of persistence in determining risk premia, a central mechanism in the LRR literature. This finding also provides hope for the future. New North American sources of production may keep prices more stable in the long term, reducing the persistence and importance of oil price shocks. Indeed, the recent behavior of futures prices and equities shows evidence of these effects.

The results here also highlight the importance of understanding the exact relation between oil prices and economic output. This paper provides evidence that oil price shocks affect future productivity growth and illustrates the potential importance for asset prices. Endogenizing this relation between economic growth and oil prices is an important avenue for future research.

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**Table 1: Tests for Changes in the Term Structure of Oil Futures**

This table reports regressions testing for changes in the term structure of future prices and returns for the period 1997 to 2012.  $\mathbb{1}_{t>2004}$  is a dummy variable that takes the value one for observations after December 2004, and zero otherwise.  $r_t^j$  is the return to investing in the  $j$ -nearest futures contract.  $r_{t-6,t}^j$  is the cumulative return from the month period and the previous six months.  $Slope_t$  is the log difference of the sixth future price and nearest maturity price. Data are monthly. Newey-West standard errors with 6 lags in parentheses.

**Panel A: Tests for Changes in Term Structure of Prices**

	Energy			Agricultural			Softs			Livestock			Metals			
	Crude Oil $Slope_t$	Htg. Oil $Slope_t$	Nat. Gas $Slope_t$	Wheat $Slope_t$	Corn $Slope_t$	Soybeans $Slope_t$	SB Oil $Slope_t$	Sugar $Slope_t$	Cocoa $Slope_t$	Coffee $Slope_t$	Cotton $Slope_t$	Hogs $Slope_t$	Cattle $Slope_t$	Copper $Slope_t$	Gold $Slope_t$	Silver $Slope_t$
$\mathbb{1}_{t>2004}$	1.23** (0.27)	0.83* (0.37)	1.10* (0.50)	0.24 (0.49)	-0.64 (0.62)	0.60 (0.46)	0.29 (0.28)	0.48 (0.77)	-0.48 (0.38)	0.36 (0.86)	-0.60 (0.86)	1.18 (0.87)	0.48 (0.32)	-0.66* (0.36)	-0.11 (0.10)	-0.08 (0.09)
$r_{t-6,t}^2$	-4.21** (1.05)	-5.20** (1.47)	-5.16** (1.04)	-5.43** (1.95)	-4.04** (1.06)	-5.78* (1.68)	-2.84* (1.25)	-4.63** (1.21)	-4.19** (1.46)	-5.34 (3.71)	-1.97 (1.50)	-9.68** (2.24)	-10.06** (2.45)	-3.77** (0.91)	-1.65** (0.34)	-1.17** (0.24)
$\mathbb{1}_{t>2004} * r_{t-6,t}^2$	2.25* (1.12)	4.27*** (1.50)	1.02 (1.58)	-0.06 (2.67)	0.36 (1.54)	3.93* (1.88)	2.61** (1.25)	-0.28 (1.94)	2.88 (1.64)	3.71 (3.83)	-3.44 (4.00)	0.10 (2.90)	6.16* (2.82)	2.19* (1.08)	1.90** (0.65)	1.10** (0.32)
Constant	-0.49* (0.24)	-0.17 (0.33)	0.58* (0.32)	1.97** (0.41)	2.10** (0.34)	-0.54 (0.38)	0.39 (0.27)	-0.47 (0.46)	1.13** (0.34)	1.28 (0.84)	1.71** (0.35)	0.29 (0.68)	0.35 (0.24)	0.06 (0.25)	0.51* (0.05)	0.42** (0.06)
Observations	192	192	192	192	192	192	192	192	190	192	192	192	192	192	192	192
R-squared	0.30	0.26	0.25	0.30	0.31	0.28	0.29	0.29	0.29	0.32	0.30	0.24	0.25	0.31	0.32	0.27

**Panel B: Tests for Changes in Term Structure of Returns**

	Energy			Agricultural			Softs			Livestock			Metals			
	Crude Oil $r_t^6$	Htg. Oil $r_t^6$	Nat. Gas $r_t^6$	Wheat $r_t^6$	Corn $r_t^6$	Soybeans $r_t^6$	SB Oil $r_t^6$	Sugar $r_t^6$	Cocoa $r_t^6$	Coffee $r_t^6$	Cotton $r_t^6$	Hogs $r_t^6$	Cattle $r_t^6$	Copper $r_t^6$	Gold $r_t^6$	Silver $r_t^6$
$\mathbb{1}_{t>2004}$	0.19 (0.28)	0.16 (0.39)	-0.91 (0.54)	0.15 (0.36)	0.21 (0.25)	0.54 (0.41)	-0.00 (0.20)	2.37** (0.64)	0.54 (0.31)	0.82* (0.36)	0.28 (0.56)	0.30 (0.78)	0.73 (0.40)	0.31 (0.24)	-0.07 (0.04)	-0.05 (0.08)
$r_t^2$	0.72** (0.02)	0.65** (0.06)	0.51** (0.05)	0.68** (0.03)	0.68** (0.02)	0.73** (0.06)	0.89** (0.03)	0.50** (0.05)	0.87** (0.02)	0.71** (0.04)	0.62** (0.05)	0.15* (0.07)	0.28** (0.07)	0.85** (0.02)	0.98** (0.01)	0.95** (0.01)
$\mathbb{1}_{t>2004} * r_t^2$	0.16** (0.04)	0.25** (0.06)	0.19** (0.06)	0.05 (0.05)	0.07 (0.04)	0.16* (0.07)	0.08** (0.03)	0.02 (0.07)	-0.06 (0.04)	0.18** (0.04)	0.08 (0.07)	-0.04 (0.09)	0.09** (0.10)	0.09** (0.03)	0.02* (0.01)	0.05** (0.01)
Constant	0.60** (0.21)	0.36 (0.33)	1.51** (0.45)	0.56** (0.21)	0.32* (0.13)	0.04 (0.31)	0.43* (0.18)	-0.53 (0.47)	-0.34 (0.23)	-0.30 (0.33)	0.15 (0.42)	1.57* (0.63)	-0.32 (0.30)	0.51** (0.14)	0.06* (0.03)	0.20** (0.06)
Observations	192	192	192	192	192	192	192	192	191	192	192	192	192	192	192	192
R-squared	0.94	0.89	0.85	0.87	0.93	0.85	0.97	0.60	0.94	0.93	0.75	0.05	0.25	0.96	1.00	1.00

Newey-West Standard Errors in Parentheses

\*\* p < 0.01, \* p < 0.05

**Table 2: Oil Prices and Oil Consumption**

Estimation of Stock and Watson (1993) regressions of log real spot price on logs of economic variables.

$$p_t = \beta_0 + \beta_1 x_t^1 + \beta_2 x_t^2 + \sum_{t=-k}^k \Gamma_{1,k} \Delta x_{t+k}^1 + \sum_{t=-k}^k \Gamma_{2,k} \Delta x_{t+k}^2$$

The spot price is the WTI index adjusted by the CPI less energy and divided by average miles per gallon of the U.S. passenger car fleet. Log of Aggregate Cons. is the log of a Cobb-Douglas aggregate of the stock of durable consumption goods and nondurables and services consumption expenditure as in Yogo (2006). Log of nondurables is log of nondurables and services from NIPA tables. Log of household oil consumption is log of consumption of gasoline and other energy goods taken from the NIPA tables and adjusted for U.S. passenger car fleet miles per gallon, log of total oil consumption is the measure of oil "Product Supplied" taken from EIA data. Personal oil consumption, household aggregate consumption and personal income are measured per capita. All data is in real terms. Regressions are performed with contemporaneous differences, as well two leads and lags. Coefficients on difference terms as well as constants are suppressed. Standard errors are Newey-West with two lags.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	$p_t$	$p_t$	$p_t$	$p_t$	$p_t$	$p_t$	$p_t$	$p_t$
Log Aggregate Cons.	2.417** (0.135)				3.321** (0.397)			
Log Nondurables		4.112** (0.228)				0.985 (0.813)		
Log GDP			2.525** (0.145)				2.664** (0.468)	
Log Personal Income				2.950** (0.168)				3.589** (0.528)
Log Household Oil Use	-5.977** (0.241)	-6.763** (0.267)	-6.416** (0.262)	-6.230** (0.257)				
Log Total Oil Use					-8.296** (1.102)	-2.820* (1.316)	-6.641** (1.300)	-7.757** (1.260)
Observations	127	127	127	127	127	127	127	127
R-squared	0.881	0.889	0.888	0.879	0.558	0.256	0.444	0.492

Standard errors in parentheses

\*\* p < 0.01, \* p < 0.05



**Table 3:** Forecasting TFP Growth with Oil and Other Predictors

This table shows results of regressions of the form

$$\Delta TFP_{t,t+k}^i = \alpha + \beta^{G/C} (ConsRatio_t) + \beta^X X_t$$

$TFP_{t,t+k}^i$  is the log of utilization adjusted TFP growth from period  $t$  to  $t+k$ , reported by the San Francisco Federal Reserve.  $i = I$  is productivity of investment goods and consumer durables, and  $i = C$  is TFP for all other products.  $ConsRatio_t$  is equal to the log of the ratio of household consumption of “gasoline and other energy goods” divided by expenditure total expenditure on non-durable and durable goods in the NIPA personal consumption survey.  $X = RDI$  is aggregate R & D intensity constructed as in Kung and Schmid (2015), and  $X = IT$  is the price-dividend ratio of the IT sector constructed as in Ward (2014). Newey-West and Hodrick (1992) standard errors with  $k$  lags in parentheses. Results in Panel A are quarterly from 1973Q1 to 2012Q4, and results in Panel B are annual from 1953 to 2012.

Panel A: Quarterly Data (1973 - 2012)											
Univariate Predictive Regressions of TFP Growth on Oil Expenditure Ratio of Households											
$\Delta TFP_{t,t+k}^I$	$\beta^{G/C}$	NW SE	H SE	$R^2$	$\Delta TFP_{t,t+k}^C$	$\beta^{G/C}$	NW SE	H SE	$R^2$		
1 Qtr	-0.009*	(0.004)	(0.004)	0.047	1 Qtr	-0.003	(0.003)	(0.003)	0.009		
4 Qtr	-0.031*	(0.013)	(0.014)	0.085	4 Qtr	-0.007	(0.008)	(0.011)	0.010		
8 Qtr	-0.075**	(0.021)	(0.025)	0.216	8 Qtr	-0.012	(0.016)	(0.019)	0.013		
12 Qtr	-0.118**	(0.036)	(0.036)	0.332	12 Qtr	-0.013	(0.021)	(0.028)	0.013		
Multivariate Predictive Regressions with IT Sector P-D Ratio											
$\Delta TFP_{t,t+k}^I$	$\beta^{G/C}$	NW SE	$\beta^{IT}$	NW SE	$R^2$	$\Delta TFP_{t,t+k}^C$	$\beta^{G/C}$	NW SE	$\beta^{IT}$	NW SE	$R^2$
1 Qtr	-0.008	(0.004)	0.001	(0.001)	0.049	1 Qtr	-0.002	(0.004)	0.001	(0.001)	0.012
4 Qtr	-0.020	(0.014)	0.008	(0.006)	0.114	4 Qtr	0.000	(0.011)	0.006	(0.005)	0.040
8 Qtr	-0.057*	(0.023)	0.015	(0.009)	0.258	8 Qtr	0.008	(0.020)	0.016*	(0.008)	0.131
12 Qtr	-0.092*	(0.036)	0.022	(0.013)	0.390	12 Qtr	0.020	(0.023)	0.029**	(0.008)	0.297
Panel B: Annual Data (1953 - 2012)											
Univariate Predictive Regressions of TFP Growth on Oil Expenditure Ratio of Households											
$\Delta TFP_{t,t+k}^I$	$\beta^{G/C}$	NW SE	H SE	$R^2$	$\Delta TFP_{t,t+k}^C$	$\beta^{G/C}$	NW SE	H SE	$R^2$		
1 Year	-0.010**	(0.004)	(0.004)	0.094	1 Year	-0.002	(0.003)	(0.003)	0.008		
2 Year	-0.021**	(0.007)	(0.007)	0.196	2 Year	-0.003	(0.005)	(0.005)	0.008		
3 Year	-0.030*	(0.011)	(0.011)	0.245	3 Year	-0.003	(0.006)	(0.007)	0.004		
4 Year	-0.036*	(0.015)	(0.014)	0.229	4 Year	-0.001	(0.007)	(0.009)	0.000		
Multivariate Predictive Regressions with R & D Intensity											
$\Delta TFP_{t,t+k}^I$	$\beta^{G/C}$	NW SE	$\beta^{RDI}$	NW SE	$R^2$	$\Delta TFP_{t,t+k}^C$	$\beta^{G/C}$	NW SE	$\beta^{RDI}$	NW SE	$R^2$
1 Year	-0.010**	(0.004)	-0.002	(0.004)	0.098	1 Year	-0.001	(0.003)	0.009**	(0.003)	0.185
2 Year	-0.022**	(0.007)	-0.007	(0.007)	0.219	2 Year	-0.001	(0.004)	0.018**	(0.005)	0.295
3 Year	-0.031**	(0.011)	-0.011	(0.012)	0.276	3 Year	-0.001	(0.005)	0.029**	(0.007)	0.433
4 Year	-0.036*	(0.015)	-0.011	(0.016)	0.248	4 Year	0.001	(0.005)	0.041**	(0.009)	0.559

Newey-West and Hodrick (1992) standard errors in parentheses  
 \*\* p < 0.01, \* p < 0.05

**Table 4: Model Parameters**

Model parameters for the benchmark calibrations. Model is calibrated at a monthly frequency.

Description	Parameter	Value	
<b>Utility</b>			
Intertemporal Elasticity of Substitution	$\psi$	2	
Risk Aversion	$\gamma$	18	
Discount Factor	$\beta$	.98 <sup>1/12</sup>	
Elasticity of Oil Substitution in Consumption	$\xi_G$	0.25	
Oil Share in Consumption	$a_G$	0.05	
Leisure Share in Consumption	$\phi$	0.2	
<b>Production</b>			
Average Growth of TFP	$\mu$	.18/12	
Volatility of Short Run Shocks	$\sigma_a$	0.0052	
Volatility of Long Run Shocks	$\sigma_x$	0.00052	
Mean Reversion of $x_t$	$\rho_x$	0.982	
Elasticity of Oil Substitution in Production	$\xi_O$	0.225	
Share of Oil in Production	$a_O$	0.55	
Capital Share in Production	$\alpha$	0.32	
Jermann Adj. Cost Parameter	$\chi$	7	
Depreciation Rate	$\delta$	.06/12	
<b>Oil Supply Dynamics</b>			
Volatility of Oil Supply Shocks	$\sigma_w$	0.024	
Exogenous Effect of Oil Supply on TFP	$\zeta$	-0.004	
Oil Supply Reaction to Expected Growth	$\kappa$	0.8	
		Responsive Supply	Unresponsive Supply
Mean Reversion of Oil Supply	$\rho_w$	0.943	0.987

**Table 5: Moments: Data and Benchmark Calibration**

Data and Model moments from the benchmark calibration. Lowercase denotes logs.  $Y_t$  is U.S. GDP in the data and total output of the basic (non-oil) good in the model.  $C_t$  is consumption of nondurables and services and consumption of the basic good in the model.  $I_t$  is aggregate investment in the data, and investment in the basic good in the model.  $G_t$  and  $O_t$  are household consumption of oil and oil used as an input into production.  $r_{ex}^{LEV}$  is the excess market return in the data, and the excess return to capital investment in the model.  $f_t^j$  and  $r_t^j$  are the log price and log return on investing in the  $j$  month future contract.  $\beta_2^{12}$  is the slope of a regression of 12-month future returns on contemporaneous returns to the 2-month future. The unresponsive and responsive regimes differ in their values of  $\rho_w$  as described in Table 4. The model is simulated for 100 simulations of 480 months, and moments are calculated as the average means or standard deviations of the last 360 months of each simulation.

<b>Panel A: Aggregate Moments</b>						
	<b>Data</b>		<b>Benchmark Model</b>			
	<b>1970 - 2012</b>		Resp.	Unresp.		
	Estimate	Std. Err.	Supply	Supply		
<b>Macroeconomic Quantities</b>						
$E[\Delta y]$	3.08	(0.24)	1.80	1.80		
$\sigma(\Delta y_t)$	1.85	(0.12)	2.21	2.24		
$\sigma(\Delta c_t)$	1.20	(0.15)	1.36	1.29		
$\sigma(\Delta i_t)$	4.67	(0.28)	7.35	7.13		
$E[I/Y]$	16.76	(0.11)	22.43	22.33		
<b>Stock Market and Risk Free Rate</b>						
$E[r_f]$	1.89	(0.20)	2.07	2.41		
$\sigma(r_f)$	1.53	(0.10)	0.64	0.63		
$E[r_{ex}^{LEV}]$	6.20	(1.97)	4.98	4.53		
$\sigma(r_{ex}^{LEV})$	15.87	(0.28)	7.22	7.17		
<b>Panel B: Oil Price Moments</b>						
	<b>Data</b>				<b>Benchmark Model</b>	
	<b>1997 - 2004</b>		<b>2005-2012</b>		Resp.	Unresp.
	Estimate	Std. Err.	Estimate	Std. Err.	Supply	Supply
<b>Oil Expenditure Ratios</b>						
$E[\frac{(G+O)P}{Y}]$	2.89	(0.09)	4.08	(0.22)	3.76	3.75
$E[\frac{G}{G+O}]$	66.34	(0.04)	64.23	(0.05)	62.76	62.77
<b>Oil Futures Prices and Returns</b>						
$E[f_{12} - f_1]$	-5.31	(2.40)	1.78	(1.30)	2.68	7.91
$E[r^2 - \Delta p]$	6.84	(0.66)	-14.04	(0.57)	-0.46	-5.66
$\sigma[r^2]$	31.25	(1.14)	32.91	(1.55)	33.78	33.74
$\sigma[r^{12}]$	17.82	(0.72)	27.37	(1.29)	17.02	28.01
$\beta_2^{12}$	0.45	(0.02)	0.77	(0.03)	0.45	0.75

**Table 6: Equity and Long-Term Futures Returns**

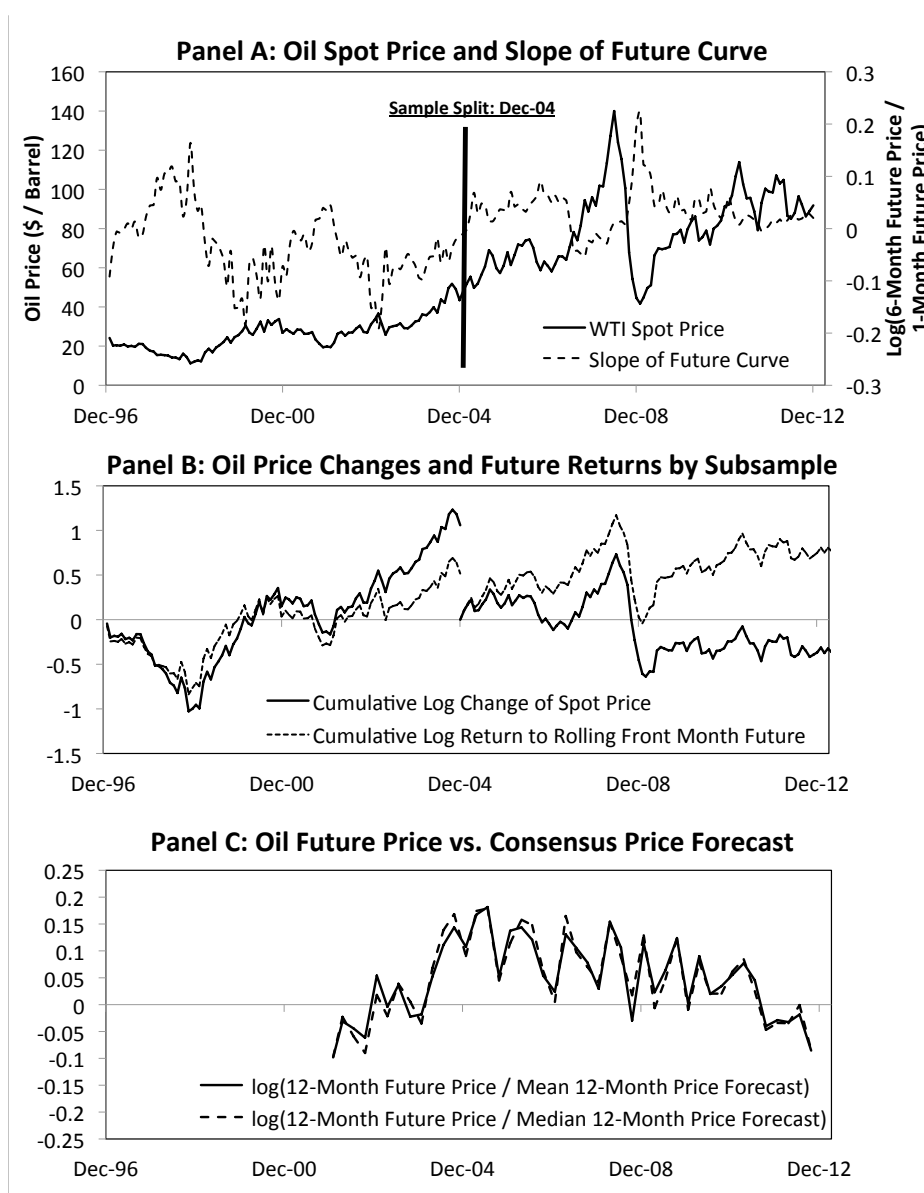
The first three columns shows average monthly returns to the 2-month oil future,  $r_t^2$ , the 6-month oil future,  $r_t^6$ , and the "Oil Characteristic Portfolio"  $r_t^{OCP}$ . The last two columns show regressions of  $r_t^6$  and  $r_t^{OCP}$  on  $r_t^2$ .  $r_t^{OCP}$  is constructed as the slope of a cross-sectional regression of the monthly returns to the 30 Fama-French Industry portfolios on each industry's estimated exposure to oil prices and a constant. The estimated exposure is the beta from a time-series regression of each industry's return on  $r_t^2$  over a 10-year presample period (1986-1996). Newey-West standard errors with 1 lag in parentheses.

<b>Panel A: Pre-Transition Period (1997/01-2004/12)</b>					
	$r_t^2$	$r_t^6$	$r_t^{OCP}$	$r_t^6$	$r_t^{OCP}$
Constant	1.59 (1.02)	1.40* (0.80)	2.04 (2.37)	0.27 (0.21)	0.30 (2.10)
$r_t^2$				0.71*** (0.02)	1.09*** (0.25)
Observations	96	96	96	96	96
R-squared				0.92	0.22
<b>Panel B: Transition Period (2005/01-2006/12)</b>					
	$r_t^2$	$r_t^6$	$r_t^{OCP}$	$r_t^6$	$r_t^{OCP}$
Constant	0.09 (1.64)	1.46 (1.60)	6.79 (5.35)	1.38*** (0.32)	6.57** (2.91)
$r_t^2$				0.91*** (0.04)	2.54*** (0.48)
Observations	24	24	24	24	24
R-squared				0.96	0.51
<b>Panel C: Post-Transition Period (2007/01-2012/12)</b>					
	$r_t^2$	$r_t^6$	$r_t^{OCP}$	$r_t^6$	$r_t^{OCP}$
Constant	0.05 (1.32)	0.13 (1.24)	-0.01 (3.07)	0.08 (0.27)	-0.06 (2.93)
$r_t^2$				0.91*** (0.05)	1.16*** (0.40)
Observations	72	72	72	72	72
R-squared				0.95	0.18

Standard errors in parentheses  
 \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

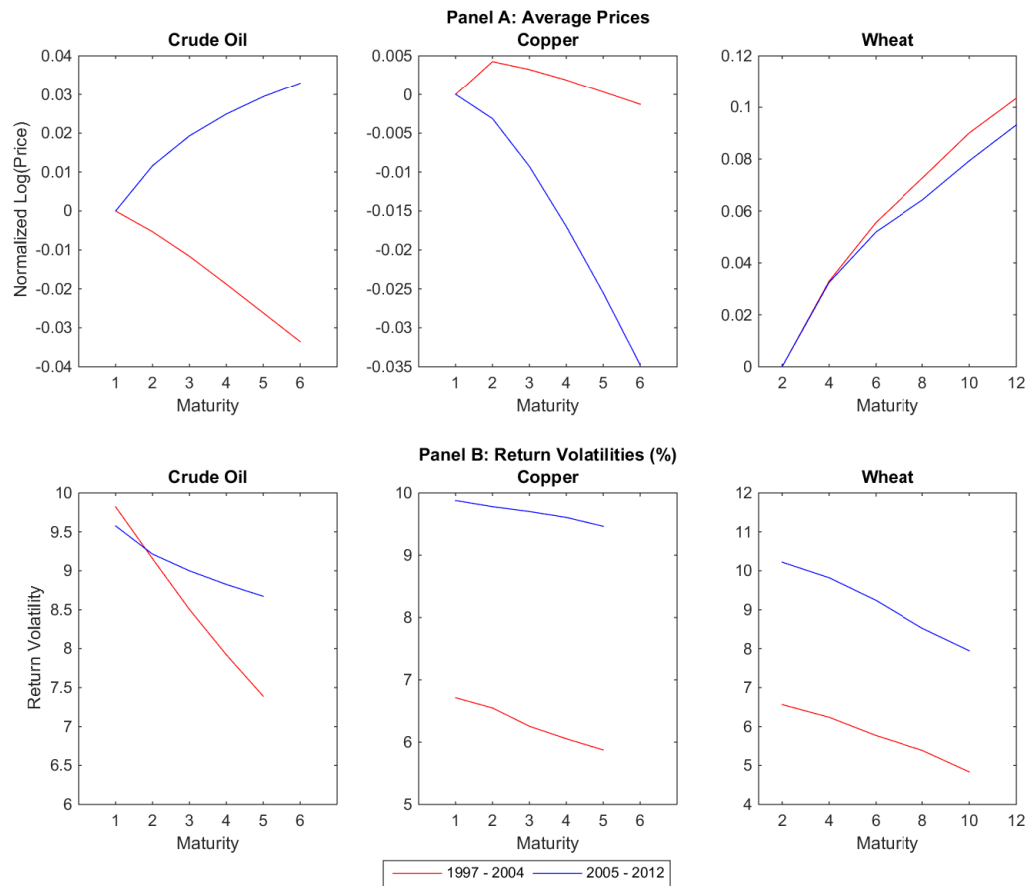
**Figure 1: Changes in Oil Future Prices: 1997 - 2012**

Panel A plots the time series of the spot price of oil as well as the slope of the future price curve, which is measured as the log of the ratio of the 6-month future price to the 1-month future price. The vertical line denotes the January 1, 2005 sample break point. Panel B plots the cumulative change of the spot price in logs in each subsample, as well as the cumulative return to a strategy which buys the second nearest future in each month and then closes out the position by selling the nearest future at the end of the month. Panel C denotes the log-difference between the 12-month future price and the consensus one-year forecast from the European Central Bank's Survey of Professional Forecasters. Futures prices are the NYMEX WTI contract in Panels A and B, for Panel C they are the ICE Brent 12-Month Future.



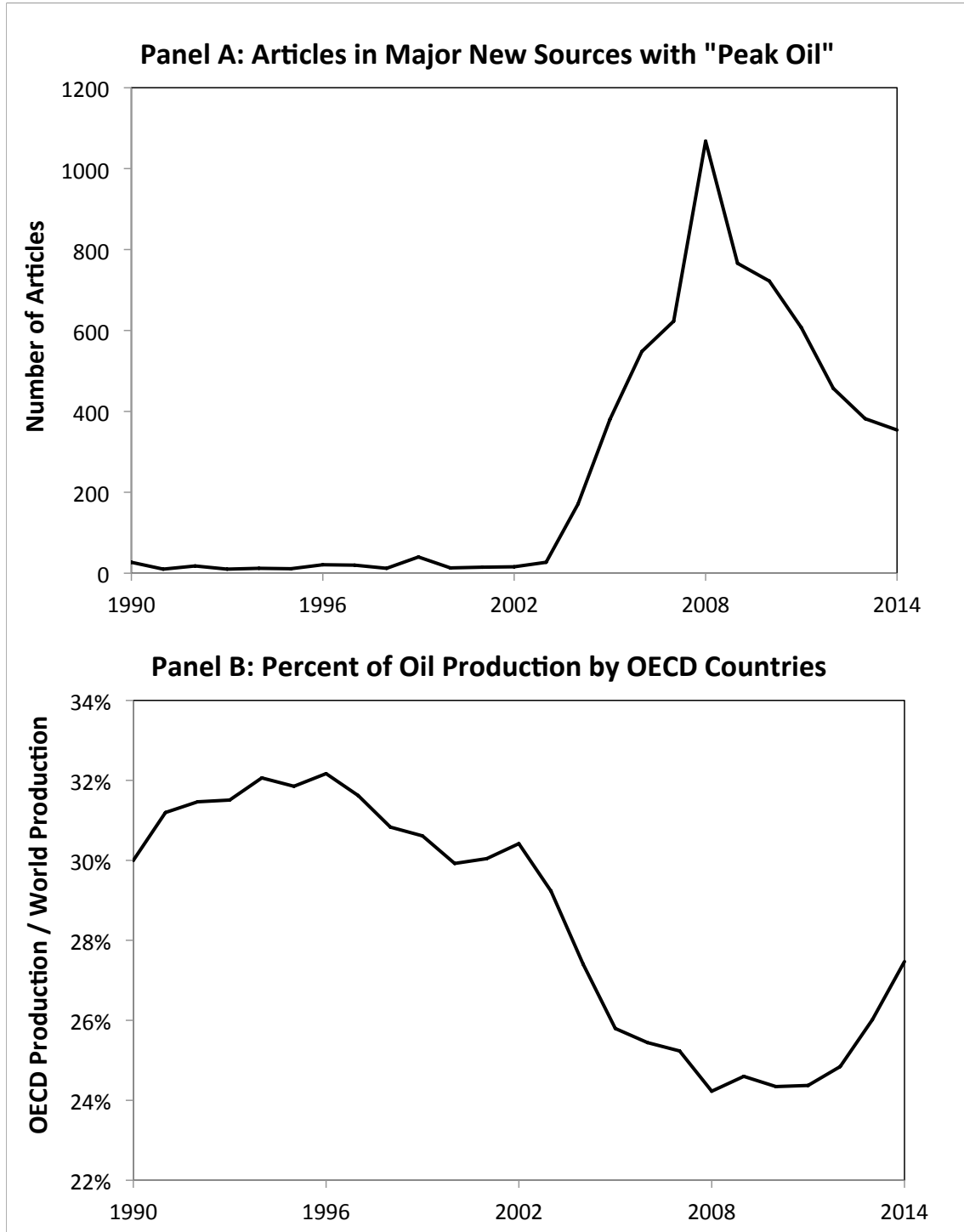
**Figure 2: Changes in the Futures Term Structure: Oil, Copper, and Wheat**

This figure reports features of the futures term structure using the six nearest term futures contracts for Crude Oil, Copper and Wheat over two subperiods, 1997 - 2004 and 2005 - 2012. Panel A reports the average log of future prices for the two subsamples. Price curves are expressed in log differences relative to the nearest term contract. Panel B reports monthly volatility of returns for different maturities.



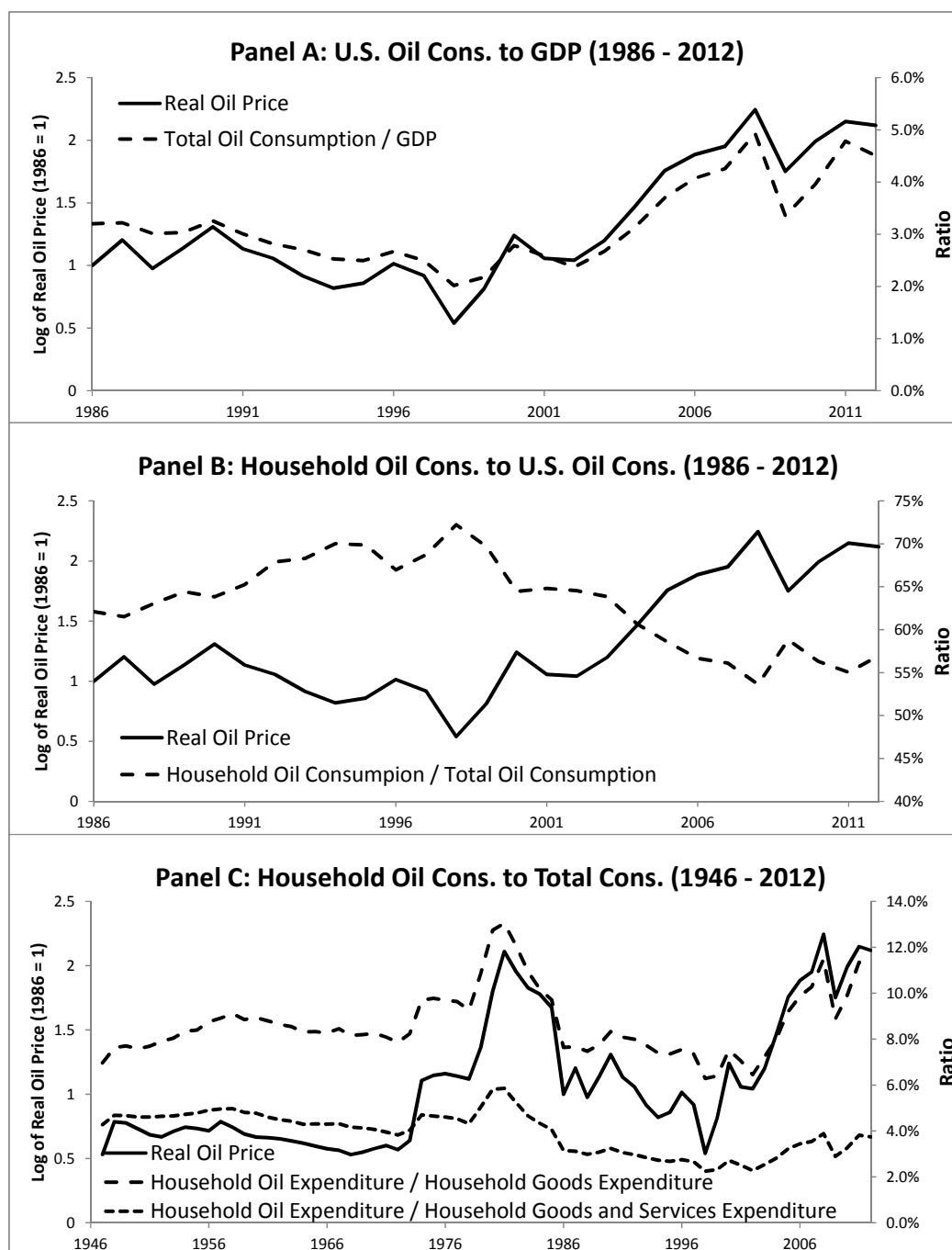
**Figure 3: Changing Supply Fundamentals**

Panel A plots the number of articles by year from Major News Sources in the Factiva database. Panel B plots the portion of global oil production by OECD countries. Data from Factiva and the Energy Information Association.



**Figure 4: Oil Consumption in the U.S. Economy**

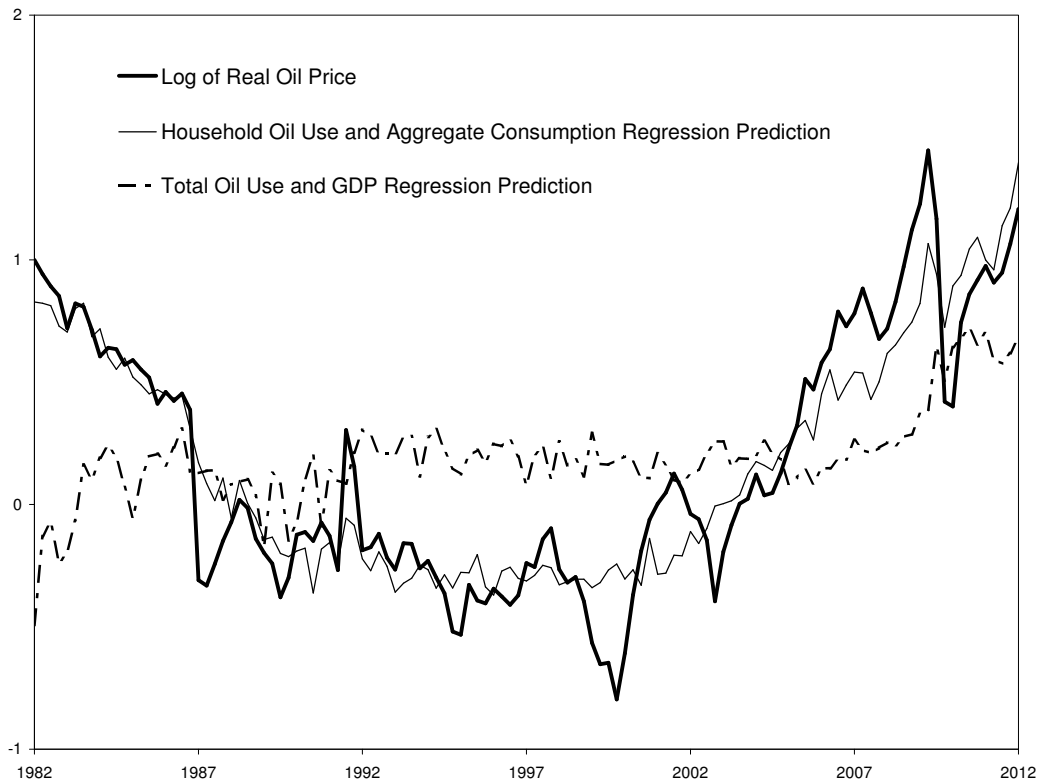
Panel A plots the fraction of total U.S. oil consumption accounted for by households along with the real price of oil. Panel B plots total U.S. oil consumption relative to U.S. GDP. Panel C plots household oil consumption relative to both household goods expenditure, and total household consumption expenditure (goods and services). Household oil consumption is “Gasoline and Other Energy Goods” from the NIPA survey. Total oil consumption is calculated using consumption data and prices from the EIA. Real price of oil is the WTI index deflated by the CPI (excluding energy) goods. Data are annual.





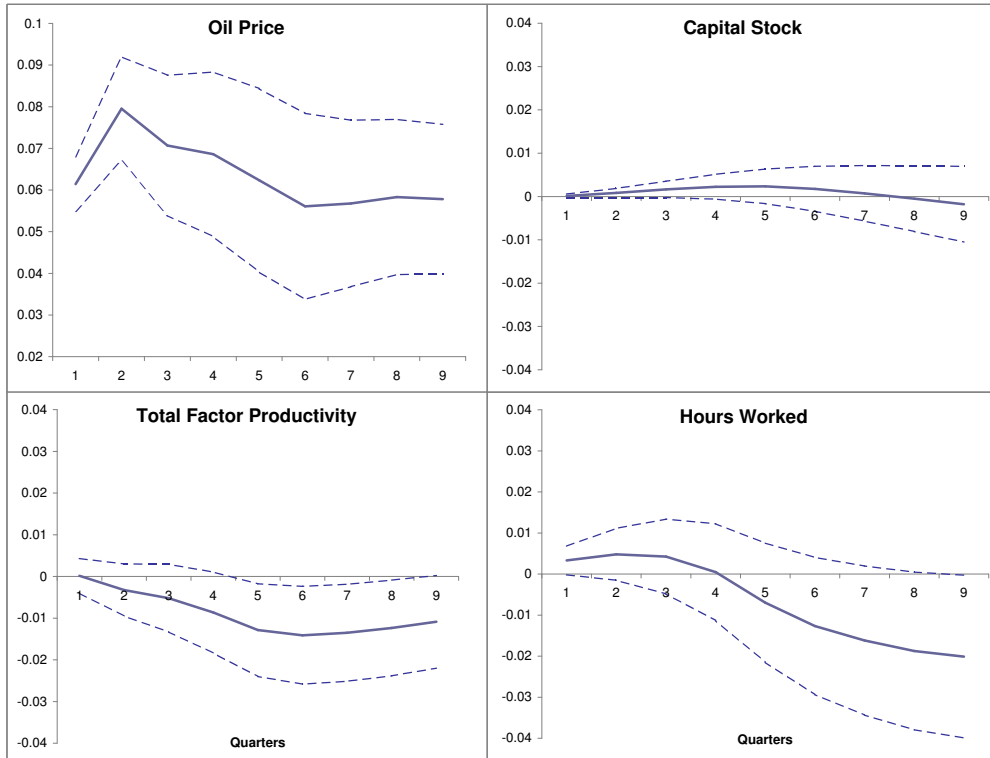
**Figure 5: Approximating the Spot Price of Oil with Consumption**

Predicted prices are the predicted value from the regression  $p_t = \beta_0 + \beta_1 x_t^1 + \beta_2 x_t^2 + \epsilon_t$ , where  $p_t$  is the log of the WTI spot price adjusted by CPI excluding energy costs and of the mpg of the U.S. passenger car fleet. The household oil use and aggregate oil line is the predicted value when household oil consumption and the CES aggregation of the stock of durable consumption and expenditure on nondurable consumption (excluding energy goods) are on the right hand side of the regression. The total oil use and GDP line uses product supplied and real GDP on the right hand side of the regression. Household oil consumption is adjusted by the MPG of the U.S. passenger car fleet.



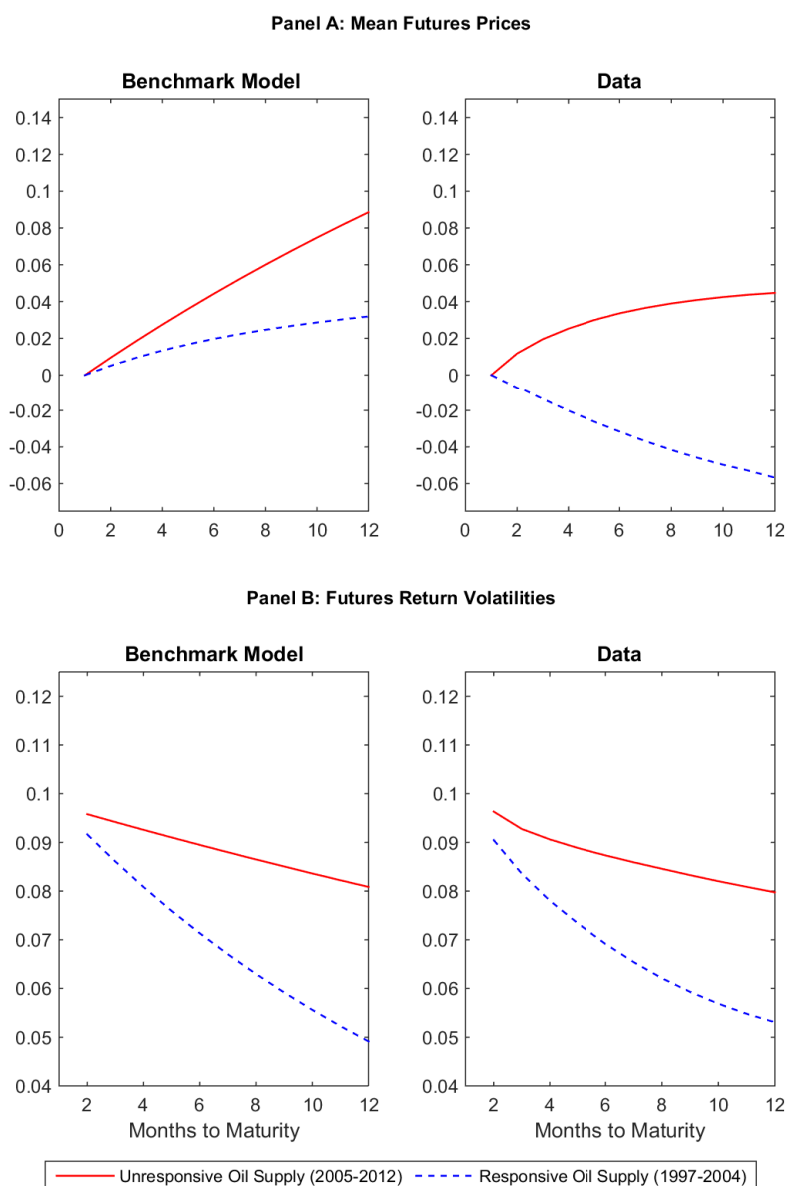
**Figure 6: Response of Components of Output to Change in Oil Price**

This figure plots the cumulative orthogonalized impulse response functions of a four-variable VAR on the growth rates of the log of real oil prices, hours worked, capital stock, and total factor productivity. Data for components of output are from the San Francisco Federal Reserve. The data are quarterly and the VAR is estimated with four lags. 95% confidence intervals shown in dashed lines.



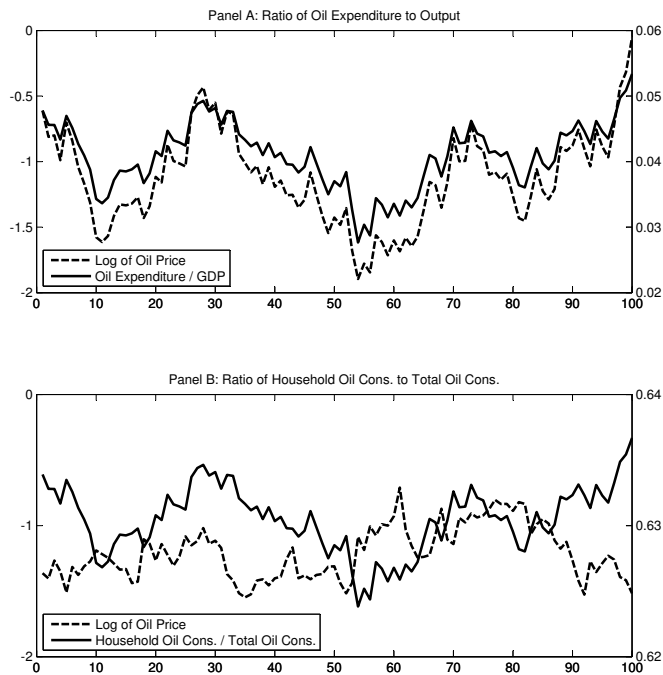
**Figure 7: Model Future Prices and Returns**

This figure shows average future prices, returns, and return volatilities for the model with both an unresponsive and responsive supply. The two regimes differ in their values of  $\kappa$  and  $\rho_w$  as described in Table 4. The model is simulated for 100 simulations of 480 months, and moments are calculated as the average means or standard deviations of the last 360 months of each simulation. Future prices are shown in logs and normalized so  $E[f_1] = 0$ . Future returns means and standard deviations are monthly.



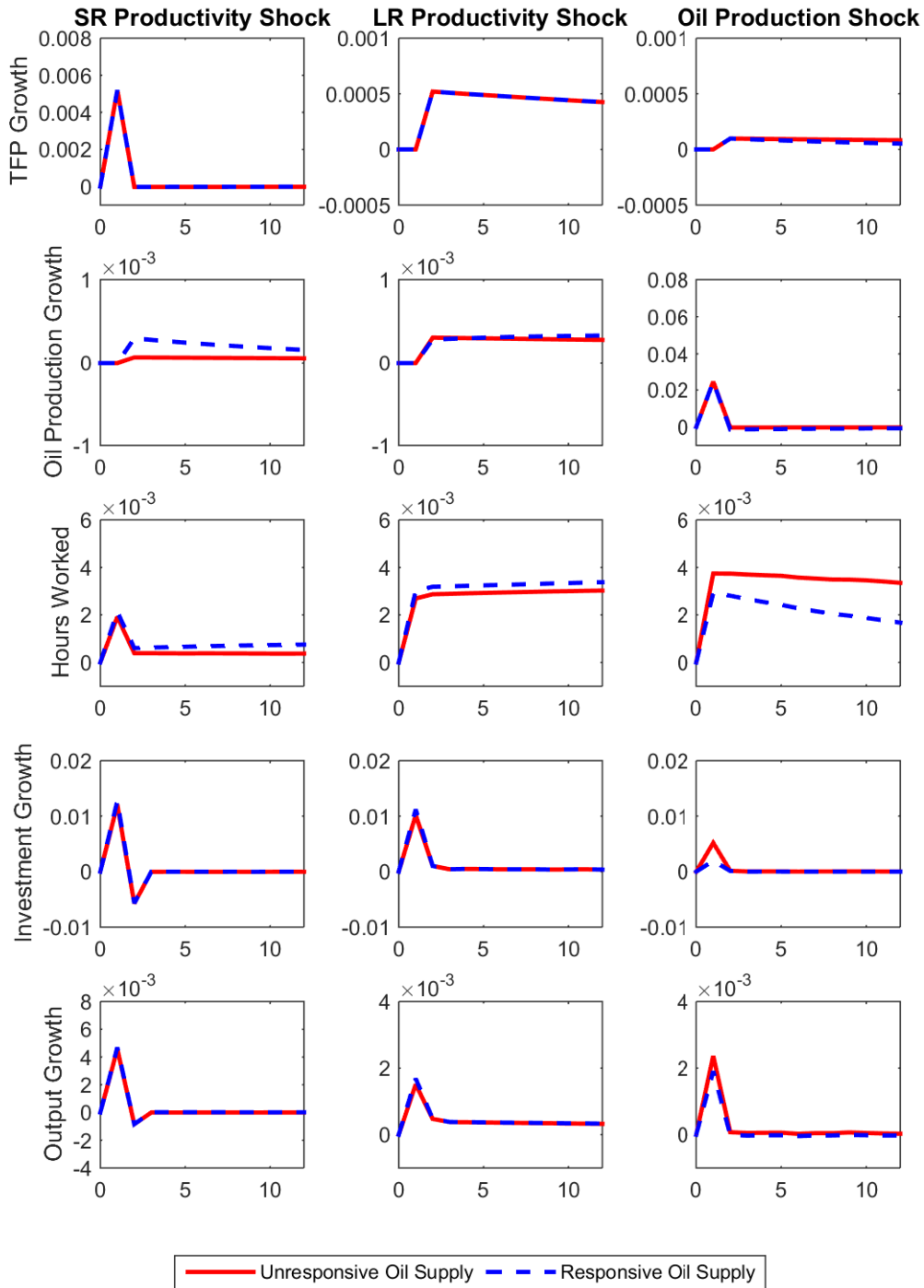
**Figure 8: Model Expenditure Ratios**

This figure plots time series of oil prices and expenditure ratio from a single simulation of the Benchmark Model with a responsive oil supply. Panel A plots the log of the oil price and the ratio of total oil consumption to aggregate output, calculated as  $\frac{P_t(O_t+G_t)}{Y_t}$ . Panel B plots the log of the oil price and ratio of household consumption of oil to total consumption of oil, calculated as  $\frac{G_t}{G_t+O_t}$ .



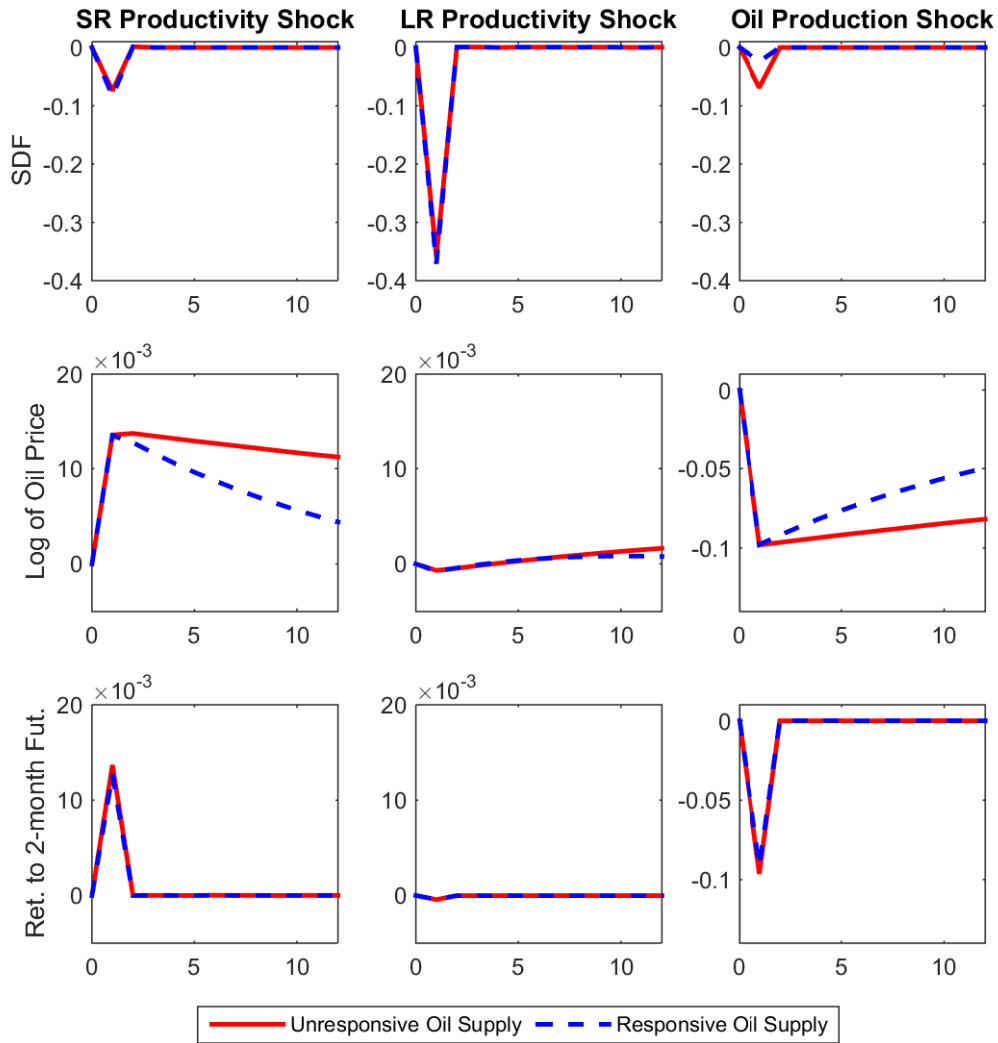
**Figure 9: Model Impulse Response: Output Variables**

Response of model variables to one standard deviation shocks to both short and long-run aggregate productivity as well as the oil supply. Results are shown for the responsive and unresponsive cases of the Benchmark Model described in Table 5.



**Figure 10: Model Impulse Response: Oil Spot and Future Prices**

Response of model variables to one standard deviation shocks to both short and long-run aggregate productivity as well as the oil supply. Results are shown for the responsive and unresponsive cases of the Benchmark Model described in Table 4.



**Figure 11: Futures and Equities (2012 - 2014)**

A plots an measure of the slope adjusted for recent changes in the level of the oil price as well as a measure of persistence. The adjusted slope is the  $\alpha$  from a rolling regression using three years weekly data.

$$Slope_t = \alpha + \beta_p \Delta f_t^1 + \beta_{Slope} Slope_{t-1}$$

Where  $Slope_t = f_t^{12} - f_t^1$  is the difference between logs the 12 and the 1 month future prices. Data are weekly so synthetic constant maturity future contracts are constructed by linearly interpolating the two nearest maturity future prices. The measure of persistence is  $\beta$  from a rolling regression using three years of weekly data.

$$\Delta f_t^{12} = \alpha + \beta \Delta f_t^1$$

Panel B plots the cumulative change in the WTI spot price and the cumulative return to the Oil Characteristic Equity Portfolio described in Table 6.

