Oil Volatility Risk

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Abstract

We show that option-implied oil volatility is a strong negative predictor of economic growth beyond standard financial, macroeconomic, and policy uncertainty measures. A rise in oil volatility also predicts an increase in oil inventories, while oil consumption falls, in line with a propagation channel through the oil sector. We explain these findings within a macro-finance model featuring stochastic uncertainties and precautionary oil inventories: firms increase oil inventories when oil volatility rises, which curbs oil use for production and depresses economic growth. The model makes distinct predictions for aggregate and cross-sectional asset prices, which we confirm empirically.

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1 Introduction

Recent research highlights the important role of economic uncertainty for the macroeconomy and financial markets. The large and growing literature in this area shows that measures of aggregate macroeconomic, policy, and equity market uncertainty negatively predict economic growth several quarters ahead and are a central driver of asset prices.[1] Further, uncertainties related to specific sectors (e.g., Segal 2019), sources (e.g., Croce, Kung, Nguyen, and Schmid 2012; Ai and Kiku 2016; Dou 2017; Bianchi, Kung, and Tirskikh 2019), or markets (e.g., Bretscher, Schmid, and Vedolin 2018; Cremers, Fleckenstein, and Gandhi 2020) play an important role beyond aggregate macro and stock market volatilities.

In this paper, we consider a component of economic uncertainty associated with the *volatility of oil prices*.[2] We find that implied oil variance, constructed from option prices, predicts a statistically and economically significant decline in future economic growth. In fact, implied oil volatility stands out as a strong and robust predictor compared to other financial, macroeconomic, and policy uncertainty measures, and we provide evidence for a separate propagation channel through precautionary oil inventories. Our two-sector macro-finance model explains these empirical findings and connects the volatility effects to equilibrium asset prices. The model predicts that the aggregate equity market is negatively exposed to oil volatility, while the exposure of the oil industry is positive, and the oil variance betas of other industries critically depend on their sensitivity to oil as an input factor. We confirm these predictions in the data, providing additional support to the separate role of oil volatility risk from a financial markets perspective.

In our empirical analysis, we first show that a rise in option-implied oil variance significantly predicts a decline in future output, consumption, investment, and employment. Its univariate

[1] Fernández-Villaverde et al. (2011), Bansal, Kiku, Shaliastovich, and Yaron (2014), Gilchrist, Sim, and Zakrajsek (2014), and Basu and Bundick (2017), among many others, document a negative relation between macroeconomic uncertainty and real economic growth, and Bloom (2009) and Baker, Bloom, and Davis (2016) show a similarly negative effect of equity and policy uncertainty, respectively. Bansal and Yaron (2004), Lettau, Ludvigson, and Wachter (2008), Boguth and Kuehn (2013), and many others underscore the economic effects of volatility fluctuations on asset prices and risk premia.

[2] Throughout the paper, we use the terms oil volatility, oil variance, and oil uncertainty interchangeably and make it precise where necessary. Our benchmark empirical measure for oil volatility is the option-implied oil variance, and using the square-root of this measure does not affect our main economic results.

predictive power is equally strong, if not stronger, compared to other uncertainty measures. In a full multivariate setting, oil volatility 'survives' as a robust predictor and even drives out other uncertainties such as implied equity variance, the Baker, Bloom, and Davis (2016) policy uncertainty index, and macroeconomic total factor productivity (TFP) variance. An increase in oil volatility predicts a significant decline in the growth rate of GDP, consumption, investment, and employment up to 2 quarters ahead, and the predictability extends to 12 quarters ahead when excluding the Financial Crisis. We confirm these results by means of impulse response functions estimated based on vector autoregressions (VARs), which show that following a one-standard-deviation increase in oil variance, output declines by 0.27%, consumption by 0.18%, investment by 1.65%, and employment by 0.29% over the following year. These estimates are based on a conservative VAR ordering in which all variables precede oil volatility and are thus being controlled for, and become even more pronounced when oil volatility precedes other uncertainties.

We next investigate the response of oil sector fundamentals and of total factor productivity (TFP),[3] in search of a distinct propagation channel for oil volatility that explains its enhanced predictive power. We do not find evidence for a negative effect of oil volatility on TFP and also no clear relation to oil production in the short and long run. On the other hand, our results show that an increase in oil variance predicts a significant abrupt increase of oil inventories, and a parallel decline in oil consumption. In particular, both our predictive regressions and impulse responses imply that a one-standard-deviation increase in oil variance predicts a 0.40–0.50% rise in oil inventories, and an oil consumption decline of a similar magnitude. These results reveal that firms stock up precautionary oil inventories in response to increasing oil volatility, reducing the amount of oil effectively used by the economy, which depresses economic growth in all dimensions.

In terms of asset prices, we analyze the exposure of the equity market to oil volatility, on aggregate and in the cross-section. Our results show that aggregate equity valuations have a strong negative exposure to oil volatility at quarterly, annual, and longer-term frequencies.

[3]For *aggregate* uncertainty, David, Hopenhayn, and Venkateswaran (2016) and Bloom et al. (2018) highlight a negative effect on the economy's total factor productivity as an important possible propagation channel.

In the cross-section of industries, the asset price exposures to oil volatility exhibit a distinct pattern: In particular, oil-consuming industries that are particularly sensitive to oil as an input factor have a larger negative oil variance beta. On the contrary, the oil producing industry is one of the industries that is least negatively or even positively exposed to oil variance risks. The cross-sectional patterns in asset price exposures are paralleled by the relation of future dividend growth rates to current oil variance, suggesting that oil volatility has a direct effect on future cash flows. As we show in our economic model, all these results are in line with the effect of increasing oil volatility on precautionary oil inventories, which depresses aggregate growth and asset prices but is rather a positive shock for the oil industry.

Specifically, our macro asset pricing model considers an economy with an oil sector and a general macro sector, with stochastic uncertainties in both sectors. In the oil sector, oil is extracted from existing wells, and the aggregate extraction rate is subject to exogenous fluctuations. On the other side, oil is used in the general macro sector as an essential input for final goods production. Firms rationally manage oil inventories to mitigate the consequences of oil supply fluctuations and decide at each point in time how much oil to hold in storage, which determines how much oil can effectively be used for the production of final goods. In times of high oil-related uncertainty, they increase their inventories as a cushion to potentially large negative oil supply shocks. As a result of this precautionary savings effect, the amount of oil used for production in the general macro sector is reduced, which depresses output, consumption, investment, and employment.

The effect highlighted by the model is exactly in line with our empirical findings on the impact of oil volatility on macro and oil sector fundamentals. In addition, the model also predicts that increasing oil volatility is associated with negative aggregate equity returns as a consequence of the depressed growth, while oil industry valuations can be positively affected through the increased value of oil inventories. We further relate the cross-sectional sensitivities of oil-consuming industries to oil as an input to the elasticity of substitution between oil and other input factors. The model implies that a low elasticity of substitution, and corresponding higher sensitivity to oil as an input factor, results in a larger negative equity return exposure to oil volatility. Altogether, our model underpins that the aggregate and cross-sectional asset price exposures observed empirically directly correspond to and result from the fundamental impact of oil volatility on the real economy.

Finally, we use the model to gauge the quantitative magnitude of oil volatility's distinct impact on the economy and compare it to the effect of other uncertainties. We account for the insight from the existing literature that oil-related shocks are typically amplified by time-varying markups and intermediate sector linkages. The effect of oil volatility shocks produced by our amplified model leads to a drop of 0.25% in output, 0.17% in consumption, 0.63% in investment, and 0.20% in employment—values that are quantitatively consistent with our empirical results. The model therefore confirms that the effect of oil uncertainty through precautionary inventories can be sizeable in magnitude. A final question is whether this distinct channel can explain the strong predictive power of oil price volatility for economic growth beyond other uncertainty measures. We find that, indeed, forward-looking oil price variance dominates equity variance and TFP variance when running multivariate regressions based on simulated data from the model. This result holds under realistic quantitative assumptions for the effects of the different uncertainties, and we show that it can theoretically turn around when considering counterfactual cases.

Related Literature. Our paper contributes to several strands of literature. First of all, we contribute to the literature that identifies uncertainty shocks as a main driver of economic growth and a source of business cycle fluctuations (e.g., Ramey and Ramey 1995; Bloom 2009; Ludvigson, Ma, and Ng 2016; Basu and Bundick 2017; Bloom et al. 2018; Bansal et al. 2019), as well as an important factor for asset prices (e.g., Bansal and Yaron 2004; Bansal et al. 2014; Lettau, Ludvigson, and Wachter 2008; Boguth and Kuehn 2013). We show that oil volatility, implied from option prices, has a strong negative relation to future economic growth and to asset prices, and its predictive power is comparably strong or even stronger compared to widely-used aggregate uncertainty measures. The main message of our paper is similar in spirit to a recent strand of papers highlighting that specific market-implied uncertainty measures are strong predictors of economic activity. For example, Bretscher, Schmid, and Vedolin (2018) and Cremers, Fleckenstein, and Gandhi (2020) show that interest rate volatility implied from Treasury options predicts a number of macroeconomic and financial variables.

Our results also add naturally to the large literature on oil shocks and the macroeconomy (Hamilton 1983; Barsky and Kilian 2004; Kilian 2008; Hamilton 2008) and stock returns (Chen, Roll, and Ross 1986; Huang, Masulis, and Stoll 1996; Jones and Kaul 1996; Driesprong, Jacobsen, and Maat 2008; Ready 2018b). In this literature, most papers focus on oil *price* changes, but it has also been hypothesized that oil-related uncertainty plays a role in addition to 'level' shocks. This idea is often associated with the theory of irreversible investments (see Bernanke 1983; Pindyck 1991), based on which investments are delayed when oil uncertainty rises, predicting an adverse effect on the economy. Empirically, Ferderer (1996), Bredin, Elder, and Fountas (2010), Elder and Serletis (2010), and Jo (2014) find a generally negative relation of *realized* oil volatility to economic activity, but it remains unclear whether this finding results from the fact that periods of high realized macroeconomic volatility are accompanied by both higher oil price volatility and lower economic growth.

We find strong evidence for a separate effect of oil volatility which propagates through precautionary inventories, while the support for delayed oil drilling and production is limited in our data sample. The stocking up of inventories when uncertainty rises echoes the classical *theory of storage*, under which firms rationally maintain commodity inventories as a cushion against large demand or supply shocks. This literature goes back to very early works by Kaldor (1939), Working (1948), Working (1949), and Telser (1958). Modern approaches include Williams and Wright (1991), Deaton and Laroque (1992), Routledge, Seppi, and Spatt (2000), Gorton, Hayashi, and Rouwenhorst (2013), David (2019), and Baker (2019). Closest to our paper is Pirrong (2011), who presents a dynamic theoretical model highlighting the rational increase of precautionary inventories in response to uncertainty shocks. Surprisingly, the large related literature has so far been silent on the implications of uncertainty-driven inventory holdings for the macroeconomy and for stock returns.

The propagation channel of oil-related uncertainty complements other real option mechanisms considered in theoretical macro models (see Ai and Kiku 2016; Dou 2017; Kim and Kung 2017; Alfaro, Bloom, and Lin 2018). Interestingly, our precautionary inventory channel directly yields the empirically observed co-movement of consumption and investment after uncertainty shocks, which is a challenge to many general equilibrium models in this literature (e.g., Arellano, Bai, and Kehoe 2012; Gilchrist, Sim, and Zakrajsek 2014; Bloom et al. 2018).[4] We show that in the data and in our model, increased oil-related uncertainty and the stocking up of oil inventories have an immediate effect on economic output, such that consumption, investment, and other macro quantities drop simultaneously. Our asset pricing evidence—which shows a negative exposure of aggregate equity returns to oil volatility, but a rather positive exposure of the oil sector—provides further support for this channel from a financial markets perspective.

Thus, the theory and empirical results of this paper finally contribute to the literature on asset pricing in general equilibrium production models (Cochrane 1991, 1996; Rouwenhorst 1995; Jermann 1998; Boldrin, Christiano, and Fisher 2001) and its cross-sectional implications (e.g., Gomes, Kogan, and Zhang 2003; Gomes, Kogan, and Yogo 2009). Our two-sector model particularly builds on recent work in this area that focuses on the interactions of the oil sector with the broader macroeconomy (Hitzemann 2016; Casassus, Collin-Dufresne, and Routledge 2018; Ready 2018a). This paper is the first one to propose a macro-finance model that allows us to investigate the effect of oil-related uncertainty fluctuations, its propagation through oil inventories, and its implications for economic growth and asset prices beyond other uncertainties, providing a strong theoretical foundation for our empirical results.

[4]Empirically, an increase in uncertainty typically leads to a drop of both consumption and investment in the short run. However, in general equilibrium models consumption has to go up when investment falls, and vice versa (see also Bloom 2014), unless the uncertainty shock has an immediate effect on output. The literature proposes different mechanisms to obtain the empirically observed co-movement, such as price and wage rigidities (Christiano, Motto, and Rostagno 2014) or capital flight for the case of small open economies (Fernández-Villaverde et al. 2011). Other papers emphasize that in the long run, a rise in uncertainty might actually have a positive effect as a result of growth options (see Gilchrist and Williams 2005; Jones et al. 2005), without focusing on the empirical short-term dynamics.

2 Empirical Analysis

2.1 Data

In our empirical analysis we use data on quantities and prices in the aggregate economy and in the oil sector. Most importantly, our oil price uncertainty measure is the 30-day ex-ante implied variance constructed from oil option prices using the approach in Bakshi, Kapadia, and Madan (2003); see Appendix A.1 for details. We include several other measures to help control for and disentangle the effects of general macroeconomic, policy, and financial uncertainties. We use the squared volatility index VIX, constructed from S&P 500 index option prices, as a model-free estimate of the equity market variance. We use the Baker, Bloom, and Davis (2016) index to capture economic policy uncertainty. Finally, we apply an AR(1)-GARCH(1,1) filter to U.S. total factor productivity (TFP) growth to construct a measure of macroeconomic variance.[5] Our sample runs quarterly from 1990Q1 to 2014Q1, with the start date being determined by the availability of the options data.

We investigate the effect of oil uncertainty shocks by analyzing aggregate macroeconomic data for the United States as a major oil-dependent economy. These data include GDP, nondurable consumption (comprised of expenditures on nondurable goods and services), private domestic investment, and employment. The data come from the Bureau of Economic Analysis (BEA). Quarterly TFP data are provided by the San Francisco Fed, including utilization adjustments as proposed by Basu, Fernald, and Kimball (2006). All macroeconomic data are real and seasonally adjusted. The oil quantity data for our study come from the U.S. Energy Information Administration.[6] In line with the global nature of the oil market, we use oil data for the largest geographical coverage that is available. For oil production, worldwide quantities are available, and for oil inventories and consumption we rely on data of total petroleum stocks and usage for the OECD countries. In terms of price data, we use crude

[5] Measuring and controlling for macroeconomic variance based on a GARCH filter on other macro variables, such as U.S. GDP growth or global GDP growth, does not affect our key economic results on the effects of oil volatility.

[6] The data are available at http://www.eia.gov/.

oil futures and options data from the Commodity Research Bureau (CRB). Equity return data for the market and portfolios of interest come from CRSP.

The key summary statistics for our data are reported in Table 1, and we show the time series of returns and uncertainty measures in Figure 1. While the volatility measures share some similarities, they also exhibit distinct patterns in relation to the aggregate economy and financial markets. The largest spike in equity volatility corresponds to the Great Recession at the end of 2008, while the largest increase in oil volatility happens in the Gulf War of the 1990s. Equity volatility is also elevated during the LTCM crisis of 1998 and the dotcom crash between 2000 and 2002, but the impact of these events on oil volatility appears limited. Policy uncertainty spikes at the 9/11 terrorist attacks and stays persistently elevated after its increase in the Financial Crisis, which is also when macro variance has its most pronounced increase in addition to the time after the 1990s recession. Overall, the quarterly correlations between oil variance and the other uncertainties are between 0.16 (with macro variance) and 0.57 (with equity variance).

Turbulent market periods are associated with a significant decline in equity prices, as reflected by negative correlations of all uncertainty measures with contemporaneous equity returns. Implied oil variance, in particular, has a sample correlation of -0.31 (-0.64) with contemporaneous equity returns at quarterly (annual) frequency, compared to -0.57 (-0.71) between implied equity variance and equity returns. On the other hand, there is no clear relation between oil variance and oil price changes: The quarterly correlation between the two is -0.21 overall and exactly 0.00 outside of the Financial Crisis (see Appendix Table A.1). A rise in oil volatility can in fact be associated with either sharp increases in the underlying oil prices as in the Gulf War of 1990, or decreases in oil prices as in the Great Recession in 2008.

The negative relation of the uncertainty measures to equity returns is paralleled by negative contemporaneous correlations between uncertainties and macroeconomic fundamentals, and Table 1 shows that GDP, consumption, investment, and employment significantly decline at times of high volatility for all uncertainty measures. Interestingly, the relation of oil variance to economic growth variables is often stronger than for the other considered uncertainties.

For instance, the correlation of oil variance with real GDP growth reaches -0.55, while it is -0.40, -0.39, and -0.32 for equity variance, policy uncertainty, and macro variance, respectively. These findings are robust to excluding the recent Financial Crisis, which features abnormally large volatility movements. The observed correlation patterns provide an additional motivation for our detailed analysis of the relationship between oil volatility, aggregate growth, and asset prices in the next sections.

2.2 Oil Volatility and Aggregate Growth

We analyze the predictive relation of option-implied oil variance to economic growth variables, especially in comparison to and when competing against other important uncertainty measures in a multivariate setting. In particular, we consider implied equity variance, the Baker-Bloom-Davis policy uncertainty index, and macro variance as estimated from a GARCH-filter on TFP growth rates. Our analysis includes predictive regressions over different horizons as well as impulse response functions based on vector autoregressions.

2.2.1 Predictive Regressions

We examine a predictive relation of oil volatility and the other uncertainty measures to future aggregate growth. The regressions take the form

$$\sum_{j=1}^{h} y_{t+j} = const + \beta_h' Z_t + \gamma_h' x_t + \epsilon_{t,t+h}, \tag{2.1}$$

where y is the macroeconomic growth variable of interest, Z is the vector of uncertainty variables, and x stands for contemporaneous controls. For ease of interpretation, we standardize each uncertainty series to have a mean of zero and a variance of one, which allows us to interpret and compare the slope coefficients across various measures.

To set the stage, we consider univariate regressions for each of the volatility measures separately. The results in Table 2 show that all measures considered predict economic growth negatively, with some variation in the magnitude and significance of effects and the horizon of predictability. In particular, the negative effect of equity variance with significance up to about 2–4 quarters ahead is in line with Bloom (2009), and economic policy uncertainty has predictive power over similar horizons, as shown by Baker, Bloom, and Davis (2016). Macro variance predicts consumption growth negatively, but the picture is less clear for the other economic growth variables. For oil volatility, our results show that oil variance implied from option prices predicts growth rates in output, consumption, investment, and employment with a clear negative sign, significant up to at least 4 quarters horizon. For example, a one-standard-deviation increase in implied oil variance leads to a significant decline in output of 0.39% and in investment of 2.25% over the next 2 quarters. These motivating results add to the literature that documents a generally negative relation of *realized* oil volatility to economic activity in similar univariate settings.[7] Interestingly, our comparison to the other uncertainties reveals that the univariate predictive power of implied oil variance for economic growth is similarly strong, if not stronger, compared to the other measures, both with respect to the magnitude and significance of coefficients and the horizon of predictability.

Based on this motivation, our goal is to analyze the partial contributions of the different uncertainty measures, and in particular of implied oil variance, when directly competing with each other in a predictive setting. To this end, we consider several approaches to separate and compare the roles of the uncertainties on economic fundamentals at different horizons. We start with a multivariate regression setting according to (2.1), including all the uncertainty variables (implied oil and equity variance, policy uncertainty, and macroeconomic variance) into the vector Z. The control variables x include the current value of y and the oil return. In the multivariate setting, each slope coefficient β_h measures a partial effect of the corresponding uncertainty measure on future growth, controlling for the effects of other uncertainties and the ex-ante indicators in x. As before, all the uncertainty measures are standardized to help compare their magnitudes across the series.

[7] For example, Ferderer (1996) reports that oil price volatility, as measured by the realized standard deviation of oil prices, "has a negative and significant impact on output growth that occurs immediately and then again beginning at eleven months." Bredin, Elder, and Fountas (2010), Elder and Serletis (2010), and Jo (2014) extend these findings in univariate settings using GARCH-in-mean models and an oil volatility measure based on forecasting errors, respectively.

Table 3 reports the multivariate predictive regression results. Notably, in this setting the predictive power of implied equity variance, policy uncertainty, and macro variance is rendered insignificant for the majority of variables and predictive horizons.[8] For example, while policy uncertainty is a strong negative predictor of consumption growth up to 4 quarters ahead in the univariate regression, this predictability does not survive in the multivariate setting. Implied equity variance also has strong predictive power for consumption and employment growth univariately, but it is driven out by the other measures in the multivariate setting as well. In contrast, a rise in implied oil variance is clearly associated with a decline in future growth rates of GDP, consumption, investment, and employment. The slope coefficients are negative at all horizons and significant up to about 2 quarters ahead, which is remarkable given the high hurdle imposed by our multivariate setting.[9] Even more remarkably, Table 4 shows that the predictability extends to 12 quarters ahead when excluding the Financial Crisis episode from our sample, in line with the intuition that oil uncertainty did not play a major role during this period. Quantitatively, the estimated negative effects of oil volatility are in most cases equally large or larger than those for the other volatility variables. For example, output declines by 0.16% and investment declines by 1.31% over the next 2 quarters following a one-standard-deviation increase in oil variance, according to our more conservative results based on the whole sample period.

Given its success in the multivariate setting, we argue that oil volatility contains an economically important uncertainty component in addition to capturing parts of the common economy-wide uncertainty, which we control for. Table 3 also reveals that this component is not characterized by a negative effect on TFP, as the regression coefficients are insignificant and mostly positive. On the other hand, policy uncertainty and macroeconomic variance are contractionary with respect to future TFP according to the multivariate results, consistent with Bloom et al. (2018). We point out in Section 2.3 that there is a separate propagation

[8] This result and our other findings do not depend on whether or not we include the oil return as a control variable. Appendix Table A.2 reports the results without controlling for the oil return, which are very similar. We control for the oil return in our benchmark results to separate oil volatility effects from the effect of oil price (level) changes.

[9] In comparison, the seminal paper by Bloom (2009) shows a significant negative effect of equity volatility on production and employment up to 2 quarters ahead, in a VAR with several macro variables and the stock market return but no other uncertainty measures. We consider impulse responses based on VARs in Section 2.2.2.

channel of oil volatility through precautionary oil inventories, which amplifies the predictive power of oil variance and makes it a successful predictor in the multivariate setting.

In the presented analysis, we separate the partial effects of all four uncertainty variables. A more parsimonious approach is to evaluate the information content of oil volatility relative to a common component of the other uncertainty measures. Therefore, we also implement the specification (2.1) in which the volatility variables Z include implied oil variance and aggregate variance, defined as the first principal component of the other three uncertainty measures. This approach reduces the number of estimated parameters and concentrates the predictive power of the macro measures. The results are reported in Appendix Table A.3. They are similar to the benchmark evidence: oil variance has a strong and negative impact on all measures of economic activity, apart from aggregate productivity, for the whole sample and even more strongly when excluding the Great Recession. On the other hand, the partial effect of aggregate variance is significantly negative only for consumption growth 1 to 2 quarters ahead, while it is insignificant or even positive for other macroeconomic growth variables and horizons.

2.2.2 Impulse Response Functions

We continue our analysis by investigating impulse response functions based on vector autoregressions (VARs). While the predictive regression results can themselves be interpreted as impulse responses by means of local projections (see Jordà 2005), one approach may provide a better identification than the other one depending on the particular properties of the data sample.[10] We make sure to interpret our empirical results conservatively by building only on findings that are robust both under the predictive regression setup and with respect to the VAR-based impulse response functions.

We consider a VAR(1) fitted to the different macro series, change in oil prices, and uncertainty variables. For computing impulse responses, it is well-known that identification depends on the assumed order of variables in the system under the Cholesky approach. To this end, we

[10] Plagborg-Møller and Wolf (2019) show that both approaches are theoretically equivalent under certain conditions and highlight the "bias-variance trade-off" between both approaches in practice.

consider two schemes: In the first approach, we let implied oil variance follow the considered macro series and the oil return, but be the first among the uncertainty variables. This approach controls for lagged values of the other uncertainties when identifying oil volatility shocks, setting the hurdle higher than existing papers that do not include other uncertainty measures (e.g., Bloom 2009; Jurado, Ludvigson, and Ng 2015). In our second, even more conservative approach, we order implied oil variance as the last among all variables. In this case, contemporaneous and lagged shocks to the considered macro variable, oil prices, and the other uncertainty measures are being controlled for when identifying the response to oil volatility shocks. In reality, the oil volatility shock is likely somewhere in between both specifications, such that we attempt to bracket its impact on fundamentals.

Figure 2 shows impulse responses under the first ordering, for a specification that includes implied oil variance and aggregate variance. As defined in the previous section, aggregate variance is the first principal component of implied equity variance, policy uncertainty, and macro variance. The responses of all macroeconomic variables, apart from TFP, to oil variance shocks are negative and significant over 20 quarters horizon. Quantitatively, after a one-standard-deviation increase in oil variance, the estimated decline in output growth is 0.32% after 1 year; it is 0.26% for consumption, 1.92% for investment, and 0.32% for employment. The estimated response of TFP growth to oil variance shocks is, in fact, positive, confirming that the observed effect does not propagate through a TFP channel. All these results are confirmed when considering the most conservative VAR ordering, as Figure 4 shows. The responses of macro variables to oil variance shocks are only marginally less negative than under the first identification scheme, with a decline in output growth of 0.27%, consumption of 0.18%, investment of 1.65%, and employment of 0.29% after 1 year. These numbers are in a similar magnitude as our estimates from the predictive regressions. It is remarkable that for the aggregate uncertainty component, on the other hand, only consumption growth shows a significantly negative response even if we account for a contemporaneous effect of aggregate variance on oil variance but not the other way round.

We have considered several additional specifications for further robustness: Appendix Figures A.1–A.6 report impulse responses for VARs with oil variance and each of the other uncertainty measures separately (instead of their first principal component). The figures show the most conservative specifications, where implied oil variance is ordered last after the other considered uncertainty measure. All variables' responses to oil variance are very similar to our benchmark results. The setting with oil variance and equity variance (Appendix Figure A.1) also confirms that we are able to recover a significant effect of equity variance, in line with the literature, for the case that equity variance is ordered first among the uncertainties. We have furthermore considered an extended specification which includes all four volatility variables at the same time. Such "many variables" specifications are often avoided in VAR setups due to the quadratically increasing number of estimated coefficients, which leads to large estimation errors and sets the bar for significant results very high. Nevertheless, the results are very similar to the benchmark ones in our case despite the somewhat larger standard errors, as Appendix Figure A.7 shows.

2.3 Oil Volatility and the Oil Sector

The results in the previous section suggest that increased oil volatility has a negative effect on economic growth that goes beyond the effect captured by other uncertainty measures, and it is unrelated to negative TFP effects. In this section, we analyze a possible propagation through oil sector fundamentals that explains this amplified impact. A number of different potential channels are suggested by real options theory: increasing oil volatility should theoretically lead to a stocking up of oil inventories, a delay of irreversible oil drilling investments, and to holding back extraction from existing oil wells, all with negative effects on the overall economy. We investigate the empirical relevance of these channels on a macro level, using the statistical tools of the last section to understand the relation between implied oil variance and oil sector fundamentals.

Table 2 documents the evidence for univariate predictive regressions with respect to growth rates of oil production, inventories, and consumption. In the univariate setting, we find no significant predictive relation of oil variance to oil production growth rates at any of the horizons. In contrast, a one-standard-deviation increase in oil variance predicts an abrupt increase of 0.48% in oil inventories with significance up to 2 quarters ahead, and a decline of oil consumption by 0.35%. This finding is consistent with the idea that agents stock up precautionary inventories in times of high uncertainty, effectively reducing oil consumption. Our further analysis confirms that this result is very robust under different specifications: In particular, the effect is confirmed in our multivariate setting with and without the Financial Crisis, see Tables 3 and 4. VAR-based impulse responses, as reported in Figures 3 and 5, also show a significantly negative response of oil consumption to a rise in oil variance, and a significantly positive response of oil inventories.[11]

Our results thus uncover an effect at the macro level that is at the heart of the *theory of storage*: high uncertainties lead to a stocking up of inventories. Surprisingly, the large and important literature on this topic has not connected this channel with implications for economic growth and asset prices. Our macro-finance model in Section 3 shows that the precautionary inventory effect depresses economic growth and asset prices as observed empirically, and explains the amplified performance of oil variance as a predictor.

While we do not claim that the other suggested real option effects are irrelevant, our evidence for the inventory channel is by far the strongest. A significant relation of oil variance to oil production growth at 12 quarters ahead in the multivariate setting (see Table 3) could be interpreted as weak evidence of reduced long-run oil production due to delayed drilling. While our VAR analysis does not provide additional support for this effect (see Figures 3 and 5), Kellogg (2014) presents evidence of delayed drilling based on micro-level data for Texas-based oil wells, and the effect has been popularly discussed by Bernanke (1983) as a theoretical example.[12] Such a delayed drilling effect would endogenously lead to reduced oil inventories, such that observing actually increasing inventories implies an even more pronounced precautionary inventory effect.

In all, we find strong evidence for a stocking up of oil inventories and a reduction in oil consumption when oil volatility rises, while our evidence for a decline in oil production is

[11] As in the previous section, we consider a number of alternative VAR specifications for robustness, see Appendix Figures A.2, A.4, A.6, and A.8.

[12] The idea of holding back oil extraction is furthermore used in the model of Litzenberger and Rabinowitz (1995).

limited. Note that the other uncertainty variables do not exhibit a similar type of relation to oil sector variables (see Tables 2 and 3). The coefficients for equity variance and policy uncertainty are insignificant for the most part, and macro variance rather predicts increased oil production and consumption. Our VAR analysis (see Figures 3 and 5) also shows no significant effect of aggregate variance on oil sector variables.

2.4 Oil Volatility and Asset Prices

We finally examine the relation between oil volatility and asset valuations. As Table 1 shows, implied oil variance exhibits a strong negative contemporaneous correlation with equity returns (−0.64 at annual frequency), similar to equity variance (−0.71) and larger in absolute value than policy uncertainty (−0.25) and macro variance (−0.40). On the other hand, the correlation of oil variance and oil returns is close to zero especially outside the Financial Crisis (see Table A.1).

We investigate the exposure of equity returns to oil variance in more detail, using a multivariate setting with the other uncertainty measures and considering different frequencies. Aggregating equity returns to lower frequency can help better identify the exposures to persistent risk factors. We consider the following specification:

$$\sum_{j=1}^{h} r_{t+j} = const + \beta_h' Z_{t+h} + \gamma_h' x_t + \epsilon_{t,t+h}, \tag{2.2}$$

where r is the return of interest, Z is the vector of all four uncertainty variables and the oil return, and x is the vector of control variables which include the current value of all the variables in Z and the asset return r. The vector β_h thus captures the exposure of cumulative asset returns to the uncertainty measures and to oil price changes, controlling for the ex-ante indicators.[13]

[13] The results are similar when adding other risk factors, such as consumption or GDP growth, or including the market return for the subsequent cross-sectional analysis.

We are particularly interested in the role of oil volatility for the aggregate market and for the oil sector's equity returns, as well as for the cross-section of oil-consuming industries with different oil sensitivities. Our previous empirical results suggest that a rise in oil variance has a negative effect on the economy through increased precautionary oil inventories and a reduced effective oil supply to oil-dependent industries. This channel would imply a negative oil variance exposure of the aggregate market and of oil-consuming industries, where the exposure becomes more negative with the industries' sensitivity to oil as an input. Oil producers, on the other hand, should be less negatively or even positively exposed to oil variance according to this channel.

Figure 6 illustrates the oil variance exposures of the aggregate market and of the 30 Fama-French industry portfolios over 1, 2, 4, and 12 quarters, and also relates them to oil price betas based on their oil return exposures. At all frequencies, the market's oil variance beta is clearly negative even after controlling for the other uncertainties and for the oil return. On the other hand, Figure 6 also reveals that the oil industry is one of the least negatively exposed industries to oil variance at 1, 2, and 4 quarters, and even has a positive oil variance beta at 12 quarters frequency. The vast majority of the other 29 industries, which are all consumers of oil as part of their production processes, have a negative oil variance beta.[14] Interestingly, the industries that are highly sensitive to oil as an input factor, as measured by a large negative oil *price* beta, also show a particularly large exposure to oil volatility risk. The strong relation between oil price risk and oil volatility risk is remarkable at annual or 3-year frequencies, at which the correlations between the estimated oil price beta and oil variance beta reach 65% and 90%.[15] Overall, all these results are consistent with the effect of oil volatility risk on macroeconomic and oil sector fundamentals, and reveal its importance for the cross-section of asset prices.

[14] One exception is the coal industry, which has a positive oil variance beta at annual and 3-year frequencies. Oil and coal are direct substitutes as energy inputs, such that a higher precautionary demand for oil similarly translates to the coal industry.

[15] Recall that the correlation between oil variance and oil returns is low and, if anything, negative in our sample (see Table 1), and that we compute oil variance betas and oil price betas from the same multivariate regression (2.2). Therefore the observed positive relation between oil variance betas and oil price betas cannot arise mechanically. The results are robust to using a bigger (or smaller) cross-section of portfolios, such as the 49 (or 17) Fama-French industries.

We round off our analysis by showing that the risk exposures of the market and the cross-section of industry returns reflect the risk exposures of their dividend payments. Such evidence confirms the effect of oil volatility on firms' cash flows, as our previous results suggest. Table 5 shows that, indeed, oil variance negatively predicts aggregate market dividends, with significance at 2 to 4 quarters, suggesting an important role of cash-flow effects. We examine this relation in detail by sorting the industries into quintiles based the oil variance betas of their equity returns at 4-quarter frequency, measured over the full sample (as depicted in Figure 6). The lowest quintile contains the industries with the strongest negative return exposure to oil volatility, and Table 5 reveals that the exposure of future dividends is both larger in magnitude and significant over longer horizons for these industries. In the three medium quintiles, oil variance negatively predicts future dividends, but the relation is significant only at a 2-quarter horizon. Finally, the highest quintile contains industries that have oil variance betas close to or even greater than zero, and especially includes the oil sector. We find that the overall negative effect of oil volatility on dividends is not present for these industries, as the related coefficients are all insignificant and rather positive over 1 to 4 quarters horizon.

Altogether, these results show that the differential equity return exposures to oil variance across industries correspond to exposures of future dividends, in line with a cash-flow effect of oil volatility risk. This finding is consistent with the channel of increased precautionary oil inventories, which depress the effective oil supply to productive industries and thereby their output and cash flows. The effect is particularly severe for highly oil-sensitive industries, while oil producers themselves are not negatively affected, as our asset pricing results confirm. In the next section, we develop an economic framework that explains our results on the role of oil volatility for macro variables, oil sector quantities, and asset prices.

3 Model

We assess the role of oil volatility within a quantitative macro-finance model with an oil sector and a general macro sector, featuring stochastic uncertainty in both sectors.[16] In the model, oil is a critical production input for the macro sector, and firms rationally hold oil inventories to smooth out oil supply shocks. When oil supply uncertainty rises, agents stock up their oil inventories in line with a *precautionary savings* motive, reducing the availability of oil as a production input. The oil uncertainty shock consequently propagates to the macro sector and depresses output, consumption, investment, and employment, as well as aggregate equity prices. This effect is separate from other uncertainty channels and quantitatively large under standard amplification mechanisms, giving rise to the strong performance of oil price volatility in multivariate regressions.

3.1 Setup

Final goods production In the macro sector of our model, a representative firm produces final goods using labor, capital, and oil as input factors. The production function follows the Cobb-Douglas form

$$Y_t = (A_t N_t)^{1-\alpha}[(1-\tilde{\iota})K_t^{1-\frac{1}{o}} + \tilde{\iota} J_t^{1-\frac{1}{o}}]^{\frac{\alpha}{1-\frac{1}{o}}} \tag{3.1}$$

with total factor productivity A_t, combining labor N_t and a constant elasticity of substitution (CES) aggregate of capital K_t and oil J_t. The labor share of production is $1-\alpha$, such that α is the joint share of capital and oil. The parameter o specifies the constant elasticity of substitution between oil and capital, and $\tilde{\iota} = \iota^{\frac{1}{o}}$ determines the oil intensity of production.

[16] Our model builds on recent works such as Hitzemann (2016), Casassus, Collin-Dufresne, and Routledge (2018), and Ready (2018a), who explore the connection of the oil sector, the macroeconomy, and asset prices in two-sector models. In the macroeconomics literature, Kim and Loungani (1992) and Backus and Crucini (2000), among others, consider the role of energy input in real business cycle models. None of these papers explores the effects of oil volatility shocks on oil inventories, economic growth, and asset prices. The appendix of Ready (2018a) shows that his main results are robust to introducing stochastic oil supply volatility and oil storage into his baseline model.

The general capital stock K_t is maintained by the firm in line with the classical real business cycle framework, following the capital accumulation equation

$$K_{t+1} = (1-\delta)K_t + I_t - G_t K_t, \tag{3.2}$$

where δ is the depreciation rate, I_t is physical capital investment, and G_t is an adjustment cost function. We employ adjustment costs as proposed by Jermann (1998):

$$G_t(I_t/K_t) = I_t/K_t - (a_0 + \frac{a_1}{1-\frac{1}{\xi}}(I_t/K_t)^{1-\frac{1}{\xi}}). \tag{3.3}$$

The adjustment cost parameter ξ determines how flexibly capital can be reallocated for investment and consumption purposes. As usual, we set the parameters a_0 and a_1 in such way that adjustment costs G_t and their first derivative G'_t are zero in the model's deterministic steady state.

The final goods producer generates revenues of $Y_t - I_t$, selling the part of the final output to the households that is not used for investment. On the other hand, the oil input J_t enters the cost side at market price P_t, and workers are paid wages W_t^N for their hours worked N_t. Overall, the final goods producer maximizes the expected sum of discounted cash flows

$$\mathbb{E}_t \sum_{s=0}^{\infty} M_{t+s}(Y_{t+s} - I_{t+s} - P_{t+s}J_{t+s} - W_{t+s}^N N_{t+s}), \tag{3.4}$$

where M_{t+s} is the s-period stochastic discount factor at time t.

Oil inventories On the other side, we consider a representative oil inventory holder who actively manages the oil stock of the economy. In practice, an economy's oil stock includes both input and output inventories held by oil producers, refineries, and oil consumers, as well as inventories held by oil traders as part of commodity carry trades. The overall oil inventories in our economy evolve as

$$S_{t+1} = (1-\omega)S_t + E_{t+1} - D_{t+1} - \Pi_t A_t \tag{3.5}$$

with inventory cost ω, where E_t is the newly extracted oil from active oil wells, D_t is the amount of oil provided for final goods production, and Π_t is a stock-out cost function. At each point in time, the inventory holder decides how much oil to supply for final goods production and how much to store. An important restriction is that inventories cannot become negative, which gives rise to a precautionary savings motive that is at the center of the economic mechanism studied in this paper. Technically, we approximate the non-negativity condition by a smooth stock-out cost function

$$\Pi_t(S_t/A_t) = \frac{\pi}{2}(S_t/A_t)^{-2} \tag{3.6}$$

with parameter π, as proposed by Hitzemann (2016). When aggregate oil inventories are low, stock-out costs are very high due to local shortages, increasing transportation costs, and other disruptions resulting from low economy-wide oil stocks.[17]

Keeping the model as simple as possible, we focus on the oil inventory holder's decision and take oil drilling and extraction as exogenous. In particular, we assume that oil is extracted from productive oil wells U_t at a stochastic extraction rate κ_t:

$$E_t = \kappa_t U_t. \tag{3.7}$$

The overall amount of oil contained in productive oil wells evolves as

$$U_{t+1} = (1 - \kappa_t)U_t + A_t\bar{Z}, \tag{3.8}$$

assuming that the economy is endowed with an amount of land $\bar{Z}$ on which at each point in time new oil wells are created according to the total factor productivity A_t.

[17] The commodities literature often models an explicit constraint at zero inventories (e.g., Routledge, Seppi, and Spatt 2000), but also acknowledges that such complete stock-outs are rarely observed on aggregate (Casassus, Collin-Dufresne, and Routledge 2018). In contrast, stock-out cost functions in line with our specification are a standard choice in macroeconomic models with inventory dynamics (see, e.g., West 1990), accounting for costs arising from local shortages and frictions when aggregate stocks are low but still positive.

Given these ingredients, oil inventory holders maximize the expected discounted cash flows from oil sales to the final goods producing firm, which are given by

$$\mathbb{E}_t \sum_{s=0}^{\infty} M_{t+s} P_{t+s} D_{t+s}. \tag{3.9}$$

Oil and macro productivity risk In our model, both the general macro sector and the oil sector are subject to productivity risk. The productivity risk in the oil sector stems from fluctuations in the extraction rate from existing oil wells given by

$$\kappa_{t+1} = \eta(1-\chi) + \chi\kappa_t + e^{v_t}\eta\varepsilon^{\kappa}_{t+1}, \tag{3.10}$$

with mean η, mean-reversion rate χ, and oil supply level shocks $\varepsilon^{\kappa}_t \sim N(0, \sigma^2_{\kappa})$. As an important ingredient of our model, the volatility of oil supply itself is stochastic, driven by the process

$$v_t = \rho_v v_{t-1} + \varepsilon^v_t \tag{3.11}$$

with mean-reversion rate ρ_v and oil supply uncertainty shocks $\varepsilon^v_t \sim N(0, \sigma^2_v)$.

For the productivity of the macro sector, we exactly follow the specification of Croce (2014), including a long-run component x_t and macroeconomic uncertainty fluctuations w_t:

$$A_{t+1} = A_t \exp\{\mu + x_t + e^{w_t}\varepsilon^A_{t+1}\}, \tag{3.12}$$

$$x_t = \phi x_{t-1} + e^{w_t}\varepsilon^x_t, \tag{3.13}$$

$$w_t = \rho_w w_{t-1} + \varepsilon^w_t. \tag{3.14}$$

Overall, the total factor productivity A_t exhibits a fixed growth trend μ and a long-run component x_t, in addition to short-run productivity shocks $\varepsilon^A_t \sim N(0, \sigma^2_A)$. The long-run component with shocks $\varepsilon^x_t \sim N(0, \sigma^2_x)$ is not critical for our results from a qualitative perspective, but improves the quantitative fit of the model to important asset pricing moments. Both the short-run and long-run productivity shocks are subject to stochastic uncertainty

w_t, with macro uncertainty shocks $\varepsilon_t^w \sim N(0, \sigma_w^2)$. All shocks considered in our model are i.i.d. and mutually independent in our baseline specification.[18]

Market-based uncertainties, especially oil price variance and equity variance, are endogenously derived in our model based on equilibrium oil and equity returns. The model therefore allows us to first characterize the economy's precise response to fundamental uncertainty shocks, and then to investigate the role of different uncertainty measures in a multivariate setting. Oil price variance naturally loads highly on fundamental oil supply uncertainty in our calibrated model.

Household Finally, the representative household is specified in line with recent macro asset pricing models, maximizing Epstein and Zin (1991) utility

$$V_t = \left[(1-\beta)\tilde{C}_t^{1-\frac{1}{\psi}} + \beta \mathbb{E}_t \left[V_{t+1}^{1-\gamma} \right]^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right]^{\frac{1}{1-\frac{1}{\psi}}} \tag{3.15}$$

over a consumption bundle $\tilde{C}_t$, with subjective discount factor β, risk aversion γ, and intertemporal elasticity of substitution ψ. The consumption bundle

$$\tilde{C}_t = \left[\tau C_t^{1-\frac{1}{\xi_L}} + (1-\tau)(A_{t-1} L_t)^{1-\frac{1}{\xi_L}} \right]^{\frac{1}{1-\frac{1}{\xi_L}}} \tag{3.16}$$

is composed of final consumption goods C_t and leisure L_t, with constant elasticity of substitution ξ_L between consumption and leisure and a goods consumption share of τ.

3.2 Equilibrium

To calculate the model equilibrium, we derive the firms' and the household's first order conditions.[19] As a result, we obtain intratemporal conditions for the oil price and for labor

[18] In Sections 3.6 and 3.7, we also consider the case of a negative exogenous correlation between macro uncertainty shocks and short-run total factor productivity shocks to account for a Bloom et al. (2018) type effect.

[19] The household's first order conditions are the same as in an endowment economy with the same consumption goods. For the derivation of the firms' first order conditions, see Appendix A.2.

wages as well as intertemporal conditions for the different asset returns in the economy. Together with the dynamics of the different model variables specified above and the market clearing conditions, we can solve the model numerically.

Oil price and labor wages The intratemporal conditions for the oil price and for labor wages result as

$$P_t = \alpha\tilde{\iota}\frac{Y_t}{J_t^{\frac{1}{o}}[(1-\tilde{\iota})K_t^{1-\frac{1}{o}} + \tilde{\iota}J_t^{1-\frac{1}{o}}]} \qquad \text{and} \qquad W_t^N = (1-\alpha)\frac{Y_t}{N_t} = \frac{\partial\tilde{C}_t}{\partial L_t}/\frac{\partial\tilde{C}_t}{\partial C_t}. \tag{3.17}$$

In particular, the final goods producer's problem yields that the oil price is equal to the marginal product of oil input J_t, and wages equal the marginal product of labor N_t. Labor wages also have to be equal to the marginal rate of substitution between final goods consumption and leisure, as obtained from the household's problem.

Asset pricing conditions With the pricing kernel

$$M_{t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\frac{1}{\xi_L}}\left(\frac{\tilde{C}_{t+1}}{\tilde{C}_t}\right)^{\frac{1}{\xi_L}-\frac{1}{\psi}}\left(\frac{V_{t+1}}{\mathbb{E}_t\left[V_{t+1}^{1-\gamma}\right]^{\frac{1}{1-\gamma}}}\right)^{\frac{1}{\psi}-\gamma}, \tag{3.18}$$

the intertemporal Euler condition

$$\mathbb{E}_t\left[M_{t+1}R_{t+1}\right] = 1 \tag{3.19}$$

holds for the returns of all assets traded in the economy. The asset pricing equation applies to the return on investment in the general macro sector R_{t+1}^I, and to the return on oil inventories R_{t+1}^S. We show in Appendix A.2 that these returns are given by

$$R_{t+1}^I = \frac{\alpha(1-\tilde{\iota})\frac{Y_{t+1}}{K_{t+1}^{\frac{1}{o}}[(1-\tilde{\iota})K_{t+1}^{1-\frac{1}{o}}+\tilde{\iota}J_{t+1}^{1-\frac{1}{o}}]} + ((1-\delta) + G_{t+1}{}'\frac{I_{t+1}}{K_{t+1}} - G_{t+1})Q_{t+1}^I}{Q_t^I}, \tag{3.20}$$

in which $Q_t^I = \frac{1}{1-G_t'}$ is the final goods producer's Tobin's Q, and

$$R_{t+1}^S = \frac{(1-\omega-\Pi_t')P_{t+1}}{P_t}. \tag{3.21}$$

Based on the two sectoral returns, we can define the overall unlevered equity market return R_{t+1} as the weighted average of these returns:

$$R_{t+1} = \frac{K_t Q_t^I R_{t+1}^I + S_t P_t R_{t+1}^S}{K_t Q_t^I + S_t P_t}. \tag{3.22}$$

We are now able to compute unlevered excess equity returns on the market as $R_{ex,t+1} = R_{t+1} - R_t^f$, with risk-free rate $R_t^f = \frac{1}{\mathbb{E}_t[M_{t+1}]}$, and we define the sectoral excess returns R_{ex}^I and R_{ex}^S analogously. We follow Croce (2014) and specify *levered* excess equity returns in a reduced-form way as

$$R_{ex,t+1}^{LEV} = (1+\overline{DE})R_{ex,t+1} + e^{u_t}\varepsilon_{t+1}^d, \tag{3.23}$$

incorporating an average debt-to-equity ratio $\overline{DE}$ of 1 and idiosyncratic cash-flow shocks $\varepsilon_{t+1}^d \sim N(0,\sigma_d^2)$ that affect the equity volatility but are not priced by the market. We account for a time-varying volatility u_t of the cash-flow shocks, which follows the process

$$u_t = \rho_u u_{t-1} + \varepsilon_t^u \tag{3.24}$$

with mean-reversion rate ρ_u and volatility shocks $\varepsilon_t^u \sim N(0,\sigma_u^2)$.[20]

Market clearing conditions Finally, there are three market clearing conditions: The labor supply constraint

$$N_t + L_t = 1 \tag{3.25}$$

[20] As in Croce (2014), the idiosyncratic cash-flow shocks do not affect the model equilibrium, but are an exogenous unpriced source of equity volatility (see also Johnson and Lee 2014; Herskovic et al. 2016; Schorfheide, Song, and Yaron 2018). Our model results in Sections 3.4 and 3.5 are therefore completely identical to a model variant without these shocks. In Section 3.6, we show that such component of equity volatility that is unrelated to aggregate fundamentals is an important reason why equity volatility does not drive out oil volatility as a predictor of economic activity. We set the volatility σ_d of the cash-flow shocks to 6.5% annualized (see Croce 2014), and its mean-reversion and volatility parameters ρ_u and σ_u to 0.81 and 21% according to our own estimates.

as well as the resource constraints for final goods and oil,

$$C_t + I_t = Y_t \qquad \text{and} \qquad D_t = J_t. \tag{3.26}$$

Solution approach Having all conditions, we can reformulate the model as a central planner's problem according to the welfare theorems. We solve this problem numerically by a third-order approximation, using perturbation methods as provided by the `dynare` package. In particular, we apply the pruning scheme proposed by Andreasen, Fernández-Villaverde, and Rubio-Ramírez (2018). This approach is particularly useful for our purposes as it allows us to reliably compute impulse response functions to uncertainty shocks at the model's ergodic mean, based on closed-form expressions obtained under the given pruning scheme. Model-endogenous uncertainty measures are computed based on a large number of draws for the shocks in our model. In particular, we compute forward-looking oil price variance $\sigma_t^2(\Delta p_{t+1})$ based on 5000 one-step ahead draws of the log oil return $\Delta p_{t+1} = \log(P_{t+1}/P_t)$ as computed from (3.17). Similarly, equity variance $\sigma_t^2(r_{ex,t+1}^{LEV})$ is calculated based on the forward-looking one-step ahead variance of simulated log equity returns $r_{ex,t+1}^{LEV} = \log(R_{ex,t+1}^{LEV})$ given by (3.23). Macroeconomic total factor productivity variance $\sigma_t^2(\Delta a_{t+1})$ is defined as the variance of $\Delta a_{t+1} = \log(A_{t+1}/A_t)$ across 5000 independent draws.

3.3 Calibration

We calibrate the model and demonstrate its broad consistency with important macroeconomic and asset price moments. We begin with a straightforward calibration of the presented baseline model, which successfully generates the negative effect of increased oil uncertainty on the macroeconomy through precautionary inventory stock-ups, in line with our empirical results.

Table 6 shows the parameters of the baseline calibration. Following the recent consumption- and production-based macro asset pricing literature (Bansal and Yaron 2004; Croce 2014), we set the relative risk aversion γ to 10 and the intertemporal elasticity of substitution ψ to 2, such that households in our model have a preference for the early resolution of uncertainty. The subjective discount factor β is set to 0.96 annualized. In a similar vein, we choose the parameters α, δ, μ, ξ, τ, ξ_L, σ_A, ϕ, σ_x, ρ_w, and σ_w describing the general macroeconomy in line with standard values based on recent production-based asset pricing papers (e.g., Ai, Croce, and Li 2013, Croce 2014, Kung and Schmid 2015).

For the oil sector, we ensure that the economy's oil consumption (in monetary units) amounts to 4% of its general consumption, as in the data, by calibrating the oil intensity parameter ι to match this ratio (see Table 7). The economy's sensitivity to oil input is further driven by the elasticity of substitution o between oil and physical capital, for which values in the literature vary widely.[21] We start with a modest value of 0.4 in our baseline calibration and demonstrate subsequently that a lower o amplifies the effect of oil uncertainty shocks. Oil inventory costs ω as well as the mean η and the mean-reversion χ of the oil production rate are chosen according to the benchmark calibration of Hitzemann (2016). The oil inventory stock-out cost parameter π is calibrated such that the model matches the level of oil inventories relative to yearly oil production. Finally, we calibrate the oil supply uncertainty's parameters σ_k, ρ_v, and σ_v such that the mean oil price variance produced by the model as well as its volatility and mean-reversion rate are in line with the data.

Table 7 reports the price and quantity moments produced by our model. The model indeed matches very precisely the average level and the dynamics of oil price variance, in line with our calibration approach. We also obtain a very low model-endogenous correlation of 0.12 between oil price variance and oil returns, indicating that oil volatility and oil price effects are distinct in the model. This is an important feature of the data, where the corresponding empirical moment is slightly negative over the whole sample and exactly 0.00 when excluding the Financial Crisis period. Our model additionally produces oil inventory fluctuations relative to oil production that are in a similar magnitude as in the data.

On the macro side, the model achieves a good fit to the main price and quantity moments too, and deviations are in line with general equilibrium asset pricing models without an oil

[21] For example, Kim and Loungani (1992) consider an elasticity of substitution of 0.6, while Backus and Crucini (2000) and Hitzemann (2016) use a value of 0.09. Ready (2018a) calibrates the CES to a value of 0.225.

sector. For example, the investment-output ratio in our baseline model is 27.37% and therefore greater than in the data (15.88%), but this deviation is in line with the most successful state-of-the-art macro asset pricing models (e.g., Croce 2014). Similarly, the model matches very nicely the volatility of final goods consumption relative to output, but underestimates investment volatility. Our model results might therefore provide rather conservative quantitative estimates on the response of investment to oil volatility shocks. In terms of general asset pricing moments, the model generates a low average risk-free rate and reproduces its volatility very well, and we obtain an equity premium of 3.27% in the model as a result of long-run risks, which is much more sizeable than in standard macro models.[22]

3.4 Effect of Oil Uncertainty Shocks

Our model highlights the precautionary inventory channel through which an increase of uncertainty in the oil sector depresses macroeconomic growth. The mechanism is illustrated by the impulse response functions for an oil supply uncertainty shock based on our model, as presented by Figure 7. We see that a rise in uncertainty regarding oil supply leads to a stocking up of oil inventories. The reason is that a positive shock to oil supply uncertainty makes large negative and positive oil supply (level) shocks more likely. To alleviate the probability of large stock-out costs in case of potentially large negative oil supply shocks, oil inventory holders need to increase the amount of oil held in storage. As a result of this *precautionary savings effect*, less oil is effectively available for the production of other goods.

In particular, the reduced effective oil supply negatively affects the output of the final goods producer in the general macro sector, for which oil is an important input factor. Therefore, the precautionary inventory effect spills over to the general macroeconomy. In consequence of the declining output, aggregate consumption and investment also decrease, and employment declines as well. The magnitude of the effect of oil supply uncertainty shocks on the macro sector strongly depends on the substitutability of oil, as specified by the CES parameter o.

[22]The model produces an even larger equity premium, in line with Croce (2014), if we simply simulate it at a monthly frequency. We use a quarterly time frequency in line with our data, but it is known that the longer decision horizon directly translates to a lower market price of risk for long-run shocks (see Bansal, Kiku, and Yaron 2010).

This becomes evident when we vary the value of o, as shown by Figure 8. In the case of a lower o, the impact on the macro sector is clearly more pronounced than in the baseline calibration, while it is the other way round for a higher o.

The model makes distinct predictions on the exposure of equity returns to oil uncertainty shocks, as presented by the three impulse responses on the lower right-hand side of Figure 7. As a result of the depressing effect on output, consumption, and investment, there is also a negative impact on aggregate equity returns r_{ex}, in line with what we see in the data. Considering the cross-section of different industries reveals that this negative effect is present in the returns of the final goods producing macro sector, r_{ex}^{I}, but not for the return of oil firms, r_{ex}^{S}. The oil firm's return is actually positive, in line with a higher value of inventories according to the real options effect. These predictions are confirmed by our empirical results, where the exposure of aggregate equity to increasing oil price volatility is clearly negative, but there is no such relation (or even a positive one) for the oil industry (see Section 2.4).

While we do not explicitly model a cross-section of oil-consuming industries that differ with respect to their oil sensitivity, the model outcomes for different o values presented in Figure 8 provide a good intuition. The figure reveals that the negative response of the macro sector's equity returns to oil volatility shocks is much more pronounced for the low o case, in which the productive sector is highly sensitive to oil as an input. This intuition aligns nicely with our empirical result that industries that are more sensitive to oil prices also have greater oil variance betas.

3.5 Quantitative Results and Amplification

We ask whether this separate channel for the propagation of oil uncertainty can quantitatively account for the strong relation of oil volatility to macro variables and asset prices that we observe empirically. As discussed, the elasticity of substitution o between oil and general capital in the productive sector is a crucial determinant of the effects' quantitative magnitude. In addition, it is well-known from the literature on oil supply *level* shocks that different amplification mechanisms are important for quantifying the impact of oil-related shocks properly. To this end, Rotemberg and Woodford (1996) show that the effect of oil shocks is amplified by imperfect competition and time-varying markups, and Baqaee and Farhi (2019) demonstrate the amplification through input-output relations of intermediate goods sectors.[23]

We incorporate these mechanisms in a simplified way by introducing exogenously time-varying markups into our model together with an intermediate goods multiplier as in Jones (2011). These ingredients formally result from an extension of our model that features an interlinked and imperfectly competitive intermediate goods sector (see also Hitzemann and Yaron 2016). Both channels amplify the impact of oil uncertainty shocks: Increasing markups in times of low effective oil supply reduce macroeconomic output even further, and linkages of intermediate goods sectors are an additional multiplier for this effect. Technically, accounting for these channels requires slight adjustments of the aggregate production function (3.1) as well as of the first order conditions (3.17) and the macro sector return (3.20). We provide the modified equations and calibration details in Appendix A.3.

Figure 7 shows the impulse response functions for the amplified model. We see that when accounting for the described channels, the effect of oil uncertainty shocks on the economy is very similar in magnitude to the empirical response after implied oil variance increases. In particular, we obtain a decrease in output by 0.25% and a fall in consumption by 0.17% on a one-standard-deviation increase of oil supply uncertainty. Investment declines by 0.63%, and employment is reduced by 0.20%. These results are, for all variables, quantitatively consistent with the empirical response to oil variance shocks documented in Figures 2 and 4.

A difference between the model-based impulse responses for oil uncertainty shocks and the empirical results is that the effects are less persistent in the model than in the data. The main reason is that our model abstracts for simplicity from different frictions that are present in the real world. First, there are potential lags for the adjustment of inventories in the real world due to physical frictions, which lead to a slower increase (and subsequent decrease)

[23]Moreover, Finn (2000) emphasizes the role of energy-dependent capacity utilization. We do not incorporate this channel, however, due to the doubts on its robustness highlighted by Kormilitsina (2016). In a recent paper, Ready, Roussanov, and Zurowska (2019) highlight an additional amplification channel of oil shocks costs through commuting costs, which affect labor supply and R&D activity.

of inventories compared to the model. Second, similar lags as well as rigidities that exist in the macro sector are not incorporated into our model. Finally, it is possible that the agents' estimate of the oil production volatility's mean-reversion rate ρ_v deviates from our calibrated value, which is inferred from the persistence of implied oil price variance. A higher value of ρ_v indeed translates directly to a higher persistence of the response of macroeconomic variables, as illustrated by Figure 7.

3.6 Multivariate Regressions for Simulated Samples

The previous sections explain the separate channel through which fundamental oil uncertainty propagates and affects economic growth and asset prices. We take the analysis one step further by running multivariate regressions based on simluated samples, in which oil price variance competes with other uncertainty measures. To this end, we simulate 96 quarters as in the data, for 100 sample economies. At each point in time, we compute forward-looking oil variance, equity variance, and macroeconomic TFP variance as described in Section 3.2.[24] Based on these simulations, we estimate regressions

$$y_{t+1} = const + \beta' Z_{t+1} + \gamma' x_t + \epsilon_{t,t+1}, \tag{3.27}$$

where y is the macroeconomic variable of interest, Z is the vector of uncertainty variables, and x includes controls. As the response to oil volatility shocks is immediate in the model, we specify the uncertainty variables Z as contemporaneous variables and also add oil production growth to Z to control for the endogenous effect of oil supply shocks on oil price variance.[25] The control variables x include the current value of y, the oil return, and the current value of the variables in Z.

[24] These variances correspond to the uncertainty measures considered in our empirical analysis, except that there is no analogue to the policy uncertainty measure in our model.

[25] The model generates a negative contemporaneous relation between oil production and oil price variance in line with the data (see Table 1), which arises endogenously as low oil supply translates to low inventories and higher oil price variance due to the stock-out constraint. Adding oil production growth to Z separates this effect from the impact of exogenous oil volatility shocks. In the data, the two effects are naturally separated as variables respond to oil volatility shocks with a lag.

Tables 8 and 9 report the model-based regression results. In univariate regressions, both oil variance and equity variance have a strong and significant negative effect on macro variables.[26] For macroeconomic variance, we obtain a positive exposure of investment, which is in line with the agents' precautionary motive to raise the capital stock as a cushion against large negative future productivity shocks (see Croce 2014). We also consider a model variant that captures a negative effect of macro uncertainty on TFP levels along the lines of Bloom et al. (2018), by imposing a negative correlation of -0.35 between macroeconomic volatility shocks and TFP shocks. This case translates to mildly negative exposures of macro variables such as output and employment growth to macroeconomic variance in the model-based univariate regression.

When including all three uncertainty measures in multivariate regressions (see Table 9), the model nicely reproduces the pattern observed empirically: oil variance stands out with a clear negative relation to macro variables, in contrast to the other uncertainties. In particular, the coefficients for equity variance are rendered insignificant, and the role of macro variance remains modest with partly positive coefficients. The model results parallel our empirical findings in Table 3 down to the very details: There, it is also the case that the coefficients of equity variance are largely insignificant in the multivariate setting, while we obtain positive coefficients for macro variance, especially for the effect on investment and employment. The coefficients estimated based on our simulated samples are furthermore of a similar magnitude as the empirical estimates for 1 to 2 quarters horizon.

In addition to the exposure of macro variables, the model is also consistent with our empirical results for oil sector variables and asset prices. Oil inventories have a significant positive exposure to oil price variance in line with the emphasized precautionary channel, and oil consumption is negatively exposed with a slope of similar magnitude. The oil sector variables show, on the other hand, no significant exposure to the other uncertainty measures in the multivariate setting. In terms of asset prices, the regression coefficients reflect the highlighted

[26] We compute Newey-West standard errors as in our empirical analysis for each simulated sample, and call a result significant if the estimated coefficient is statistically significant at the 10% level for the median simulated economy.

negative exposure of the overall market as well as the outstanding role of the oil industry which has a positive oil variance beta, in accordance with our empirical results.

Finally, the model allows us to gain a deeper understanding of the power of oil variance as a predictor of macroeconomic aggregates when compared to other uncertainty measures. In principle, one might expect that especially equity variance could drive out oil price variance, as it endogenously captures oil supply uncertainty in addition to other fundamental uncertainties as well. However, equity variance is also strongly influenced by idiosyncratic cash-flow shocks that are unrelated to fundamentals (see equation (3.23)), which account for a sizeable part of overall equity volatility (see also Croce 2014; Herskovic et al. 2016; Schorfheide, Song, and Yaron 2018). These shocks make equity variance a more noisy measure of fundamental uncertainties and are a main reason why equity variance is driven out by oil price variance in the multivariate setting. Indeed, if we consider a counterfactual model variant without non-fundamental shocks to equity in Table 10, the result turns around and equity variance captures the negative effect on macroeconomic variables, while the coefficients of oil variance turn positive. Macro variance, on the other hand, does not capture the effect of oil uncertainty shocks and affects the economy through a different channel, as described. Accordingly, the second panel of Table 10 reveals that when the correlation between macro variance and TFP level shocks is highly negative, macro variance is strongly negatively related to economic growth variables in the multivariate setting, but this does not weaken the predictive power of oil variance. Overall, our model shows that oil variance particularly stands out as the most robust and strong predictor when equity variance is affected by non-fundamental payout shocks and when the negative effect of macro variance on TFP levels is not excessively large, which both is the case empirically.

3.7 Distinction from Other Shocks and Further Robustness

To conclude our analysis, we use our model to compare the effect of oil uncertainty shocks to other types of shocks from a theoretical perspective, in particular to oil supply (level) shocks and to macroeconomic volatility shocks. The analysis shows that these other shocks are conceptually different in terms of their effect on quantities and asset prices, confirming the message that our empirical results can be explained by the effect of oil uncertainty shocks, but not by other effects.

Appendix Figure A.9 depicts the economy's response to a negative oil supply shock ε_t^{κ}. Like oil uncertainty shocks, oil supply level shocks have a considerable negative effect on the main macroeconomic aggregates. In stark contrast to oil uncertainty shocks, however, oil supply shocks lead to a *fall* in oil inventories due to the lower actual oil supply. This overall behavior is in line with the findings of a long-standing literature on the effect of oil shocks on the macroeconomy, for example Hamilton (1983), Barsky and Kilian (2004), Hamilton (2008), and Hitzemann and Yaron (2016). Therefore, the response of oil inventories provides a clear distinction of oil supply (level) shocks and oil uncertainty shocks, as inventories rise due to increased precautionary demand for the latter ones, lowering the *effective* oil supply to the economy even if oil production is unchanged.

In Appendix Figure A.10 we show the economy's response to general macroeconomic uncertainty shocks, ε_t^{w}. As explained in the previous section, we consider both the case where macro volatility shocks and TFP level shocks are uncorrelated, and the case of a negative correlation of -0.35 to incorporate a Bloom et al. (2018) type effect. In the former case, it is clear ex-ante that consumption and investment cannot both negatively respond to these shocks due to the resource constraint. The figure reveals that in our setting, agents increase current investment at the expense of current consumption, which is in line with the results of Croce (2014). The economic reason behind this effect is a precautionary savings motive in the macro sector: by raising the capital stock, agents have an additional cushion against potentially large negative productivity shocks in the future. With a negative correlation between macro volatility and TFP level shocks, an increase in macro uncertainty materializes predominantly as a negative growth shock, leading to lower output, consumption, investment, employment, and negative equity returns in all sectors including the oil sector. Furthermore, both oil inventories and oil consumption decline in the longer run as the reduced economic growth also negatively affects the drilling of new oil wells.

Finally, we analyze whether the demonstrated effect of oil uncertainty shocks in our model hinges on particular model assumptions. To this end, we consider an additional model variant in which the intertemporal elasticity of substitution (IES) is lower than in our benchmark model. We are especially interested in the case of an IES smaller than 1, and choose a value of 0.9 for this robustness check. Second, we consider a model variant with fixed labor supply. Considering this variant sheds light on the question whether the flexibility of labor supply is a critical ingredient for our results, as one could imagine a mechanism in which output decreases in response to oil uncertainty shocks not only due to increasing oil inventories, but also due to a decrease of labor. Appendix Figure A.11 presents the effect of oil uncertainty shocks for these two alternative model specifications. As one can directly observe, the economy's response is in both cases very similar to our baseline model, suggesting that both the particular value of the IES and the flexibility of labor supply are not critical for our results.

4 Conclusion

We present empirical evidence that forward-looking oil price volatility captures significant information about economic growth and asset prices. An increase in option-implied oil variance predicts a decline in current and future growth rates of output, consumption, investment, and employment, controlling for the current growth rate in the corresponding variables, current oil returns, and other widely-used uncertainty measures. Oil variance also has a significant positive effect on oil inventories and a negative impact of similar magnitude on oil consumption. Moreover, we show that the market equity price drops at times of high oil uncertainty and the effect is most pronounced for oil-sensitive industries in the cross-section, while there is no such negative impact on the oil sector.

We provide a two-sector macro asset pricing model to explain these empirical findings. In the model, oil inventory holders manage the oil stock of the economy to mitigate the consequences of oil supply shocks. In times of high oil supply volatility, they increase their inventories to alleviate the probability of a stock-out. As a result of this precautionary savings effect, the amount of oil available for production in the general macro sector is reduced, and production, consumption, and investment decrease, accompanied by employment. The effect explains the observed asset price exposures to oil variance, can be quantitatively large, and gives rise to the enhanced predictive power of forward-looking oil variance that we find empirically.

Table 1: **Summary Statistics**

				Quarterly Correlations with				Annual Correlations with			
	Mean	Std Dev	AR(1)	Oil Var	Eq Var	Pol Unc	Macro Var	Oil Var	Eq Var	Pol Unc	Macro Var
GDP growth	1.38	1.26	0.42	-0.55	-0.40	-0.39	-0.32	-0.62	-0.57	-0.48	-0.62
Consumption growth	1.36	0.78	0.52	-0.49	-0.35	-0.50	-0.32	-0.43	-0.41	-0.53	-0.57
Investment growth	1.95	6.38	0.42	-0.49	-0.37	-0.18	-0.21	-0.62	-0.53	-0.21	-0.48
Employment growth	1.02	1.11	0.90	-0.55	-0.49	-0.36	-0.40	-0.40	-0.45	-0.32	-0.47
Util.-adj. TFP growth	0.96	1.45	0.01	0.09	0.15	-0.10	-0.02	-0.03	0.06	-0.16	-0.24
Oil production growth	0.11	2.77	0.27	-0.28	-0.17	-0.06	0.05	-0.41	-0.18	-0.04	-0.02
Oil inventory growth	0.53	3.21	0.33	-0.02	-0.02	-0.05	-0.06	0.20	-0.07	-0.12	-0.05
Oil consumption growth	-0.22	2.66	-0.01	-0.38	-0.05	-0.02	-0.02	-0.75	-0.59	-0.03	-0.37
Excess oil return	6.34	37.77	-0.09	-0.21	-0.15	-0.10	-0.12	-0.20	-0.30	-0.17	-0.23
Excess equity return	6.13	17.20	0.05	-0.31	-0.57	-0.23	-0.11	-0.64	-0.71	-0.25	-0.40
Risk-free rate	0.58	0.86	0.94	-0.09	-0.22	-0.57	-0.32	-0.00	-0.25	-0.55	-0.36
Oil variance	341.01	667.91	0.50	1.00	0.57	0.34	0.16	1.00	0.72	0.26	0.39
Equity variance	115.17	194.18	0.48	0.57	1.00	0.45	0.16	0.72	1.00	0.35	0.40
Policy uncertainty	108.98	72.73	0.69	0.34	0.45	1.00	0.34	0.26	0.35	1.00	0.35
Macro variance	0.54	0.34	0.81	0.16	0.16	0.34	1.00	0.39	0.40	0.35	1.00

The table reports summary statistics for the macroeconomic, oil sector, asset price, and uncertainty variables. Means and standard deviations are annualized. Data are quarterly from 1990Q1 to 2014Q1.

Table 2: **Univariate Predictability Evidence**

	Oil Var			Equity Var			Pol Unc			Macro Var		
	Slope	SE	Adj. R^2	Slope	SE	Adj. R^2	Slope	SE	Adj. R^2	Slope	SE	Adj. R^2
GDP Growth:												
1q ahead	**-0.28**	**(0.07)**	0.19	-0.16	(0.12)	0.05	**-0.19**	**(0.08)**	0.08	-0.09	(0.08)	0.01
2q ahead	**-0.39**	**(0.12)**	0.13	-0.28	(0.19)	0.06	**-0.32**	**(0.14)**	0.08	-0.14	(0.14)	0.01
4q ahead	**-0.45**	**(0.14)**	0.05	-0.29	(0.27)	0.02	**-0.37**	**(0.21)**	0.03	-0.14	(0.22)	-0.00
12q ahead	-0.48	(0.43)	0.01	-0.08	(0.68)	-0.01	-0.05	(0.97)	-0.01	0.54	(0.69)	0.01
Consumption Growth:												
1q ahead	**-0.19**	**(0.04)**	0.24	**-0.14**	**(0.05)**	0.12	**-0.16**	**(0.04)**	0.15	**-0.11**	**(0.05)**	0.07
2q ahead	**-0.29**	**(0.10)**	0.17	**-0.22**	**(0.11)**	0.09	**-0.28**	**(0.09)**	0.16	**-0.18**	**(0.10)**	0.06
4q ahead	**-0.43**	**(0.14)**	0.11	-0.31	(0.21)	0.05	**-0.47**	**(0.16)**	0.14	-0.28	(0.19)	0.04
12q ahead	-0.45	(0.35)	0.01	-0.10	(0.55)	-0.01	-0.51	(0.78)	0.01	-0.20	(0.63)	-0.01
Investment Growth:												
1q ahead	**-1.47**	**(0.51)**	0.20	-0.95	(0.68)	0.08	-0.65	(0.47)	0.03	-0.14	(0.59)	-0.01
2q ahead	**-2.25**	**(0.89)**	0.16	-1.69	(1.17)	0.09	-0.82	(0.87)	0.01	0.04	(0.95)	-0.01
4q ahead	**-1.81**	**(0.91)**	0.03	-1.53	(1.32)	0.02	-0.08	(1.13)	-0.01	1.39	(1.10)	0.01
12q ahead	-0.25	(2.09)	-0.01	1.45	(3.40)	-0.01	5.71	(4.10)	0.07	**7.65**	**(2.61)**	0.20
Employment Growth:												
1q ahead	**-0.35**	**(0.11)**	0.38	**-0.30**	**(0.11)**	0.29	**-0.20**	**(0.09)**	0.12	-0.16	(0.11)	0.08
2q ahead	**-0.66**	**(0.21)**	0.36	**-0.58**	**(0.22)**	0.28	**-0.36**	**(0.20)**	0.10	-0.24	(0.22)	0.04
4q ahead	**-1.03**	**(0.36)**	0.24	**-0.97**	**(0.36)**	0.21	-0.50	(0.38)	0.05	-0.18	(0.42)	-0.00
12q ahead	**-1.14**	**(0.63)**	0.05	-1.10	(0.75)	0.04	0.25	(0.90)	-0.01	**1.39**	**(0.81)**	0.08
Utilization-adjusted TFP Growth:												
1q ahead	**0.20**	**(0.09)**	0.06	**0.20**	**(0.08)**	0.06	0.05	(0.07)	-0.00	-0.07	(0.10)	-0.00
2q ahead	**0.36**	**(0.16)**	0.11	**0.40**	**(0.11)**	0.14	0.09	(0.13)	-0.00	-0.15	(0.19)	0.01
4q ahead	0.35	(0.26)	0.04	**0.58**	**(0.18)**	0.13	-0.01	(0.20)	-0.01	-0.43	(0.32)	0.07
12q ahead	-0.13	(0.26)	-0.01	0.65	(0.55)	0.03	-0.89	(0.67)	0.06	-0.79	(0.60)	0.07
Oil Production Growth:												
1q ahead	0.03	(0.21)	-0.01	0.04	(0.12)	-0.01	-0.01	(0.13)	-0.01	0.14	(0.15)	0.00
2q ahead	-0.02	(0.23)	-0.01	0.15	(0.24)	-0.01	0.05	(0.22)	-0.01	**0.40**	**(0.24)**	0.02
4q ahead	-0.18	(0.20)	-0.01	0.06	(0.37)	-0.01	0.19	(0.35)	-0.01	**0.88**	**(0.42)**	0.07
12q ahead	0.10	(0.61)	-0.01	1.16	(1.03)	0.04	**1.99**	**(0.71)**	0.11	**2.87**	**(0.64)**	0.37
Oil Inventory Growth:												
1q ahead	**0.33**	**(0.16)**	0.04	0.20	(0.16)	0.01	0.15	(0.19)	-0.00	-0.02	(0.16)	-0.01
2q ahead	**0.48**	**(0.22)**	0.03	0.33	(0.26)	0.01	0.23	(0.35)	-0.00	-0.13	(0.24)	-0.01
4q ahead	0.24	(0.27)	-0.01	0.31	(0.35)	-0.00	0.09	(0.59)	-0.01	-0.33	(0.48)	-0.00
12q ahead	-0.34	(0.43)	-0.01	-0.54	(0.84)	0.00	-0.56	(0.85)	-0.00	-0.99	(0.76)	0.04
Oil Consumption Growth:												
1q ahead	**-0.35**	**(0.17)**	0.06	**-0.28**	**(0.13)**	0.04	-0.11	(0.13)	-0.00	0.09	(0.12)	-0.01
2q ahead	-0.24	(0.24)	0.01	-0.29	(0.18)	0.01	0.01	(0.19)	-0.01	0.30	(0.23)	0.02
4q ahead	-0.02	(0.19)	-0.01	-0.26	(0.21)	0.00	**0.50**	**(0.23)**	0.03	**0.81**	**(0.34)**	0.10
12q ahead	**0.92**	**(0.53)**	0.05	**1.42**	**(0.76)**	0.12	**2.68**	**(0.71)**	0.35	**2.34**	**(0.63)**	0.40

The table reports the results for the univariate predictability of future macroeconomic and oil sector variables by implied oil and equity variances, policy uncertainty, and macroeconomic variance, respectively. Newey-West standard errors are in parentheses. Bold numbers indicate statistical significance at the 10% level. Data are quarterly from 1990Q1 to 2014Q1.

Table 3: **Multivariate Predictability Evidence**

	Oil Var		Equity Var		Pol Unc		Macro Var		
	Slope	SE	Slope	SE	Slope	SE	Slope	SE	Adj. R^2
GDP Growth:									
1q ahead	**-0.20**	**(0.06)**	0.05	(0.09)	**-0.10**	**(0.05)**	0.01	(0.05)	0.21
2q ahead	**-0.16**	**(0.08)**	0.00	(0.14)	-0.14	(0.10)	0.04	(0.10)	0.20
4q ahead	-0.13	(0.19)	0.06	(0.23)	-0.14	(0.17)	0.09	(0.20)	0.11
12q ahead	-0.16	(0.48)	0.34	(0.48)	0.19	(0.86)	0.83	(0.55)	0.07
Consumption Growth:									
1q ahead	**-0.12**	**(0.03)**	-0.01	(0.04)	-0.04	(0.04)	**-0.05**	**(0.03)**	0.37
2q ahead	-0.13	(0.08)	-0.01	(0.08)	-0.08	(0.07)	-0.05	(0.05)	0.34
4q ahead	-0.12	(0.13)	0.02	(0.15)	-0.15	(0.16)	-0.04	(0.13)	0.29
12q ahead	-0.15	(0.37)	0.44	(0.48)	-0.12	(0.75)	0.12	(0.42)	0.09
Investment Growth:									
1q ahead	**-1.03**	**(0.40)**	0.01	(0.47)	-0.25	(0.28)	0.27	(0.34)	0.22
2q ahead	**-1.31**	**(0.56)**	-0.41	(0.80)	-0.14	(0.49)	0.67	(0.60)	0.19
4q ahead	-0.71	(0.91)	-0.71	(1.19)	0.22	(0.82)	**1.93**	**(0.98)**	0.07
12q ahead	-1.03	(1.51)	0.85	(2.23)	3.67	(2.83)	**7.19**	**(2.11)**	0.23
Employment Growth:									
1q ahead	**-0.07**	**(0.03)**	-0.04	(0.03)	-0.01	(0.02)	**0.04**	**(0.02)**	0.85
2q ahead	**-0.15**	**(0.05)**	-0.09	(0.09)	-0.00	(0.04)	**0.14**	**(0.06)**	0.76
4q ahead	-0.15	(0.12)	-0.24	(0.19)	0.06	(0.11)	**0.45**	**(0.16)**	0.57
12q ahead	-0.34	(0.31)	-0.52	(0.56)	**1.28**	**(0.68)**	**1.98**	**(0.56)**	0.29
Utilization-adjusted TFP Growth:									
1q ahead	0.11	(0.08)	0.14	(0.11)	-0.02	(0.07)	-0.11	(0.07)	0.09
2q ahead	0.19	(0.12)	**0.33**	**(0.12)**	-0.07	(0.10)	**-0.22**	**(0.11)**	0.21
4q ahead	0.06	(0.19)	**0.67**	**(0.21)**	-0.19	(0.18)	**-0.49**	**(0.24)**	0.24
12q ahead	-0.47	(0.32)	**1.73**	**(0.57)**	**-1.50**	**(0.68)**	-0.49	(0.44)	0.25
Oil Production Growth:									
1q ahead	0.12	(0.29)	0.06	(0.16)	-0.10	(0.14)	0.13	(0.15)	0.04
2q ahead	-0.13	(0.31)	0.26	(0.26)	-0.16	(0.21)	**0.43**	**(0.23)**	-0.01
4q ahead	-0.27	(0.25)	0.19	(0.40)	-0.10	(0.32)	**0.90**	**(0.43)**	0.06
12q ahead	**-1.21**	**(0.44)**	1.02	(0.88)	0.57	(0.58)	**2.73**	**(0.65)**	0.42
Oil Inventory Growth:									
1q ahead	**0.29**	**(0.10)**	-0.01	(0.17)	0.09	(0.18)	-0.08	(0.13)	0.14
2q ahead	**0.40**	**(0.22)**	0.05	(0.32)	0.16	(0.37)	-0.25	(0.26)	0.02
4q ahead	0.09	(0.30)	0.26	(0.53)	0.09	(0.64)	-0.41	(0.44)	-0.03
12q ahead	-0.13	(0.51)	-0.35	(0.99)	0.18	(1.07)	**-1.12**	**(0.66)**	0.10
Oil Consumption Growth:									
1q ahead	**-0.39**	**(0.18)**	-0.15	(0.16)	0.00	(0.11)	0.13	(0.12)	0.14
2q ahead	**-0.42**	**(0.26)**	-0.20	(0.31)	0.10	(0.18)	0.31	(0.22)	0.08
4q ahead	0.08	(0.22)	**-0.68**	**(0.34)**	**0.53**	**(0.18)**	**0.68**	**(0.38)**	0.13
12q ahead	-0.23	(0.18)	0.43	(0.40)	**1.64**	**(0.42)**	**1.72**	**(0.36)**	0.52

The table reports the results for the multivariate predictability of future macroeconomic and oil sector variables by implied oil and equity variances, policy uncertainty, and macroeconomic variance, controlling for the current value of the predicted variable and the oil return. Newey-West standard errors are in parentheses. Bold numbers indicate statistical significance at the 10% level. Data are quarterly from 1990Q1 to 2014Q1.

Table 4: **Multivariate Predictability Evidence Excluding Great Recession**

	Oil Var		Equity Var		Pol Unc		Macro Var		
	Slope	SE	Slope	SE	Slope	SE	Slope	SE	Adj. R^2
GDP Growth:									
1q ahead	**-0.20**	**(0.06)**	**0.18**	**(0.09)**	**-0.12**	**(0.05)**	0.03	(0.05)	0.15
2q ahead	**-0.17**	**(0.07)**	**0.18**	**(0.11)**	**-0.17**	**(0.09)**	0.04	(0.09)	0.14
4q ahead	**-0.32**	**(0.09)**	**0.33**	**(0.14)**	**-0.26**	**(0.14)**	0.01	(0.18)	0.08
12q ahead	**-0.48**	**(0.22)**	0.42	(0.31)	-0.64	(0.51)	0.33	(0.28)	0.04
Consumption Growth:									
1q ahead	**-0.13**	**(0.03)**	0.05	(0.04)	**-0.07**	**(0.04)**	-0.03	(0.03)	0.22
2q ahead	**-0.12**	**(0.06)**	**0.13**	**(0.06)**	**-0.17**	**(0.07)**	0.01	(0.06)	0.21
4q ahead	**-0.18**	**(0.09)**	**0.26**	**(0.11)**	**-0.32**	**(0.14)**	0.01	(0.12)	0.21
12q ahead	-0.26	(0.25)	**0.84**	**(0.32)**	**-0.78**	**(0.42)**	0.04	(0.27)	0.11
Investment Growth:									
1q ahead	**-0.77**	**(0.27)**	**0.78**	**(0.39)**	-0.44	(0.27)	**0.75**	**(0.32)**	0.12
2q ahead	**-1.04**	**(0.32)**	0.80	(0.49)	-0.29	(0.44)	**0.99**	**(0.54)**	0.09
4q ahead	**-1.03**	**(0.41)**	0.62	(0.70)	-0.07	(0.66)	**1.70**	**(0.84)**	0.04
12q ahead	**-1.91**	**(0.95)**	-1.91	(1.74)	1.09	(1.89)	**3.30**	**(0.91)**	0.16
Employment Growth:									
1q ahead	**-0.04**	**(0.02)**	0.01	(0.02)	-0.01	(0.02)	**0.06**	**(0.02)**	0.75
2q ahead	**-0.10**	**(0.05)**	0.01	(0.06)	-0.00	(0.04)	**0.16**	**(0.06)**	0.69
4q ahead	**-0.14**	**(0.08)**	-0.05	(0.15)	0.06	(0.09)	**0.45**	**(0.16)**	0.56
12q ahead	**-0.55**	**(0.31)**	-0.69	(0.49)	**0.85**	**(0.46)**	**1.45**	**(0.29)**	0.38
Utilization-adjusted TFP Growth:									
1q ahead	0.09	(0.08)	0.08	(0.09)	0.01	(0.07)	**-0.20**	**(0.07)**	0.09
2q ahead	0.08	(0.07)	**0.25**	**(0.12)**	-0.00	(0.11)	**-0.37**	**(0.13)**	0.15
4q ahead	-0.06	(0.12)	**0.57**	**(0.24)**	-0.11	(0.17)	**-0.60**	**(0.29)**	0.22
12q ahead	-0.33	(0.27)	**2.45**	**(0.71)**	**-1.37**	**(0.79)**	0.03	(0.56)	0.22
Oil Production Growth:									
1q ahead	0.32	(0.20)	0.18	(0.14)	-0.18	(0.16)	0.28	(0.18)	0.09
2q ahead	0.11	(0.22)	**0.51**	**(0.27)**	-0.26	(0.22)	**0.65**	**(0.28)**	0.03
4q ahead	-0.08	(0.23)	0.43	(0.52)	-0.23	(0.32)	**1.12**	**(0.50)**	0.08
12q ahead	**-0.85**	**(0.38)**	1.51	(1.29)	0.08	(0.69)	**3.09**	**(0.70)**	0.38
Oil Inventory Growth:									
1q ahead	**0.28**	**(0.10)**	0.05	(0.18)	0.04	(0.18)	0.01	(0.15)	0.10
2q ahead	**0.42**	**(0.21)**	0.05	(0.35)	0.07	(0.37)	-0.10	(0.30)	-0.00
4q ahead	0.01	(0.30)	0.05	(0.62)	0.12	(0.65)	-0.58	(0.55)	-0.03
12q ahead	-0.13	(0.56)	0.00	(1.45)	0.58	(1.00)	-0.71	(0.65)	-0.01
Oil Consumption Growth:									
1q ahead	**-0.32**	**(0.18)**	-0.01	(0.18)	-0.03	(0.12)	0.17	(0.14)	0.13
2q ahead	**-0.42**	**(0.19)**	0.29	(0.25)	0.03	(0.19)	**0.55**	**(0.28)**	0.18
4q ahead	0.05	(0.21)	-0.25	(0.24)	**0.41**	**(0.22)**	**0.72**	**(0.42)**	0.16
12q ahead	-0.05	(0.25)	-0.56	(0.74)	**0.93**	**(0.55)**	0.63	(0.48)	0.10

The table reports the results for the multivariate predictability of future macroeconomic and oil sector variables by implied oil and equity variances, policy uncertainty, and macroeconomic variance, controlling for the current value of the predicted variable and the oil return. Newey-West standard errors are in parentheses. Bold numbers indicate statistical significance at the 10% level. Data are quarterly from 1990Q1 to 2014Q1, excluding 2008Q1-2009Q2.

Table 5: **Dividend Predictability Evidence**

	Oil Var		Equity Var		Pol Unc		Macro Var		
	Slope	SE	Slope	SE	Slope	SE	Slope	SE	Adj. R^2
Aggregate Market:									
1q ahead	-1.11	(0.69)	-0.89	(1.38)	1.82	(1.31)	**-1.52**	**(0.88)**	0.49
2q ahead	**-1.30**	**(0.77)**	**-2.10**	**(1.26)**	1.75	(1.49)	**-1.78**	**(0.78)**	0.12
4q ahead	**-1.50**	**(0.64)**	-2.16	(1.65)	2.67	(1.80)	-1.72	(1.18)	0.05
12q ahead	-0.42	(2.50)	-2.88	(3.48)	**8.41**	**(3.02)**	0.89	(2.97)	0.07
				Industry Portfolios Sorted by Oil Variance Beta					
Lowest Quintile (1):									
1q ahead	**-3.66**	**(1.62)**	-1.69	(2.95)	**5.43**	**(3.17)**	-2.79	(1.77)	0.27
2q ahead	**-4.31**	**(2.03)**	-3.51	(3.89)	4.31	(3.78)	-1.52	(2.21)	0.13
4q ahead	-2.49	(2.56)	-3.12	(4.88)	6.07	(4.43)	0.80	(2.74)	0.04
12q ahead	**-6.62**	**(2.17)**	2.39	(6.24)	**22.35**	**(5.06)**	**10.93**	**(4.49)**	0.30
Medium Quintiles (2,3,4):									
1q ahead	-1.18	(0.85)	0.04	(1.35)	1.97	(1.26)	-1.35	(0.84)	0.24
2q ahead	**-2.42**	**(0.83)**	-0.19	(1.25)	1.47	(1.28)	**-1.92**	**(0.81)**	0.20
4q ahead	-0.72	(1.05)	-0.79	(1.21)	1.71	(1.62)	-1.69	(1.23)	0.01
12q ahead	0.33	(3.34)	-1.70	(4.53)	**7.13**	**(4.02)**	-2.93	(3.50)	0.02
Highest Quintile (5):									
1q ahead	1.34	(1.06)	-1.77	(1.32)	-0.18	(1.54)	0.01	(1.20)	0.17
2q ahead	0.66	(1.29)	-1.11	(1.74)	-1.15	(1.84)	0.63	(1.71)	0.03
4q ahead	0.57	(2.99)	0.55	(2.86)	-1.90	(3.18)	-0.30	(3.37)	0.01
12q ahead	-2.27	(4.42)	**10.65**	**(4.76)**	-5.18	(5.41)	1.89	(3.79)	0.05

The table reports the results for the multivariate predictability of future dividends by implied oil and equity variances, policy uncertainty, and macroeconomic variance, controlling for the current dividend growth rate and the oil return. We consider dividends for the aggregate market and for the 30 Fama-French industry portfolios, sorted into five quintiles based on the oil variance exposure of their equity returns at annual frequency. Newey-West standard errors are in parentheses. Bold numbers indicate statistical significance at the 10% level. Data are quarterly from 1990Q1 to 2014Q1.

Table 6: **Model Parameters**

Parameter		Value	
		Baseline	Amplified
Preferences			
Subjective discount factor	β	0.96	
Risk aversion	γ	10	
Intertemporal elasticity of substitution	ψ	2	
General Macroeconomy			
Capital share	α	0.34	
Depreciation rate of capital	δ	0.06	
Average growth rate	μ	1.8%	
Capital adjustment costs	ξ	3.5	4.0
Share of final goods in consumption	τ	0.205	
Elasticity of substitution between leisure and consumption goods	ξ_L	1.2	
Volatility of short-run macro productivity risk	σ_A	3.35%	
Autocorrelation of expected growth	ϕ	0.925	
Volatility of long-run macro productivity risk	σ_x	$0.1\sigma_A$	
Mean-reversion of volatility of macro productivity	ρ_w	0.855	
Volatility of volatility of macro productivity	σ_w	3.46%	
Price markup elasticity	ε_θ	—	−0.1
Share of intermediate goods sector	ν	—	0.5
Oil Sector			
Elasticity of substitution between oil and capital	o	0.400	0.225
Oil intensity parameter ($\tilde{\iota} = \iota^{\frac{1}{o}}$)	ι	0.011	0.6
Oil inventory costs	ω	0.1	
Oil stock-out costs	π	$5 \cdot 10^{-7}$	$2.8 \cdot 10^{-7}$
Average oil production rate	η	0.08	
Mean-reversion of oil productivity	χ	0.87	
Volatility of oil productivity	σ_κ	15.0%	14.4%
Mean-reversion of oil production volatility	ρ_v	0.82	0.56
Volatility of oil production volatility	σ_v	48%	41%

The table reports the parameters of the calibrated model, both for the baseline and the amplified version. Parameters describing the household's preferences as well as the general structure of the macroeconomy and the oil sector are set according to the literature. The oil intensity parameter, the oil stock-out cost parameter, and the parameters describing the volatility of oil supply are calibrated to match the economy's oil share, the oil inventory-production ratio, as well as the mean, volatility, and autocorrelation of oil price variance as reported in Table 7. All parameters are annualized.

Table 7: **Moments**

Quantity Moments			
Statistic	Data	Model	
		Baseline	Amplified
Oil input relative to general consumption			
$\mathbb{E}[P * J/C]$	0.04	0.04	0.04
Oil inventory-production ratio			
$\mathbb{E}[S/E]$	0.29	0.29	0.29
Relative volatility of oil inventories and oil production			
$\sigma(\Delta s)/\sigma(\Delta e)$	1.16	0.61	1.32
Investment-output ratio			
$\mathbb{E}[I/Y]$ [%]	15.88	27.37	20.68
Relative volatility of general investment and output			
$\sigma(\Delta i)/\sigma(\Delta y)$	5.06	2.70	2.72
Relative volatility of general consumption and output			
$\sigma(\Delta c)/\sigma(\Delta y)$	0.62	0.61	0.63

Price Moments			
Statistic	Data	Model	
		Baseline	Amplified
Mean of oil price variance			
$\mathbb{E}[\sigma_t^2(\Delta p)]$	341.01	340.72	340.40
Volatility of oil price variance			
$\sigma(\sigma_t^2(\Delta p))$	667.91	669.42	670.05
Autocorrelation of oil price variance			
$\rho(\sigma_{t-1}^2(\Delta p), \sigma_t^2(\Delta p))$	0.50	0.50	0.51
Correlation between oil return and oil variance			
$\rho(\Delta p, \sigma_t^2(\Delta p))$	-0.20	0.12	0.13
Risk-free rate			
$\mathbb{E}[r_t^f]$ [%]	0.58	1.66	1.72
Volatility of risk-free rate			
$\sigma(r_t^f)$ [%]	0.86	0.71	0.87
Equity risk premium			
$\mathbb{E}[r_{ex,t+1}^{LEV}]$ [%]	6.13	3.27	2.16

The table reports the quantity and price moments produced by our model, both for the baseline and the amplified version, compared to their empirical counterparts. We simulate 100 economies of 96 quarters length and report the mean of the respective moments across these economies. The model is explicitly calibrated to match the economy's oil share, the oil inventory-production ratio, as well as the mean, volatility, and autocorrelation of oil price variance. The model is simulated at a quarterly frequency, and we report annualized moments.

Table 8: **Univariate Regressions Based on Model Simulations**

Amplified Model, $\text{corr}(\varepsilon_t^w, \varepsilon_t^A) = 0.0$

	Oil Var			Equity Var			Macro Var		
	Slope	SigRatio	Adj. R^2	Slope	SigRatio	Adj. R^2	Slope	SigRatio	Adj. R^2
Output growth	**-0.46**	**[0.95]**	0.91	**-0.48**	**[0.84]**	0.91	0.09	[0.15]	0.90
Consumption growth	**-0.29**	**[0.91]**	0.88	**-0.30**	**[0.84]**	0.88	-0.06	[0.13]	0.87
Investment growth	**-1.04**	**[0.70]**	0.81	**-1.22**	**[0.59]**	0.82	0.90	[0.47]	0.81
Employment growth	-0.31	[0.37]	0.68	-0.37	[0.39]	0.69	0.17	[0.09]	0.68
TFP growth	0.04	[0.14]	0.00	0.04	[0.20]	0.00	-0.00	[0.12]	0.00
Oil inventory growth	**0.84**	**[0.99]**	0.96	**0.82**	**[0.97]**	0.96	0.01	[0.13]	0.94
Oil consumption growth	**-0.86**	**[0.98]**	0.95	**-0.85**	**[0.99]**	0.95	-0.04	[0.09]	0.94
Aggregate market return	**-0.31**	**[0.80]**	0.84	**-0.32**	**[0.64]**	0.84	0.22	[0.47]	0.83
Non-oil equity return	**-0.32**	**[0.80]**	0.85	**-0.32**	**[0.63]**	0.85	0.22	[0.47]	0.84
Oil equity return	**3.17**	**[1.00]**	0.95	**3.19**	**[0.99]**	0.95	0.20	[0.07]	0.94

Amplified Model, $\text{corr}(\varepsilon_t^w, \varepsilon_t^A) = -0.35$

	Oil Var			Equity Var			Macro Var		
	Slope	SigRatio	Adj. R^2	Slope	SigRatio	Adj. R^2	Slope	SigRatio	Adj. R^2
Output growth	**-0.45**	**[0.95]**	0.91	**-0.46**	**[0.89]**	0.91	-0.11	[0.20]	0.90
Consumption growth	**-0.30**	**[0.91]**	0.88	**-0.30**	**[0.84]**	0.87	-0.14	[0.43]	0.87
Investment growth	**-1.05**	**[0.74]**	0.83	**-1.22**	**[0.63]**	0.83	0.27	[0.12]	0.83
Employment growth	-0.27	[0.43]	0.70	-0.30	[0.41]	0.70	-0.37	[0.42]	0.71
TFP growth	0.06	[0.18]	0.00	0.05	[0.17]	0.00	**-0.57**	**[0.66]**	0.04
Oil inventory growth	**0.84**	**[0.99]**	0.96	**0.83**	**[0.97]**	0.96	0.03	[0.13]	0.95
Oil consumption growth	**-0.86**	**[0.98]**	0.95	**-0.86**	**[0.98]**	0.95	0.00	[0.11]	0.94
Aggregate market return	**-0.32**	**[0.88]**	0.86	**-0.33**	**[0.69]**	0.86	0.05	[0.16]	0.84
Non-oil equity return	**-0.32**	**[0.88]**	0.86	**-0.33**	**[0.69]**	0.86	0.05	[0.17]	0.85
Oil equity return	**3.19**	**[1.00]**	0.96	**3.19**	**[0.99]**	0.95	0.14	[0.10]	0.94

The table reports the results for univariate regressions of macroeconomic, oil sector, and asset price variables on oil, equity, and macroeconomic variance, respectively, based on simulated data from our model. Controls include oil production growth and current values of the variable of interest, the oil return, and the considered uncertainty variable. Slope coefficients and Newey-West standard errors are estimated for 100 simulated economies of 96 quarters length. We report the median slope coefficients across these economies, the median adjusted R^2, and in square brackets the ratio of economies for which the estimated coefficient is statistically significant at the 10% level. Bold numbers indicate significance for at least 50 of the 100 sample economies (i.e., for the median simulated economy). The upper panel considers the amplified model with zero correlation between macro variance shocks and TFP level shocks, the lower panel the case of a negative correlation to account for a negative TFP effect of macro variance along the lines of Bloom et al. (2018).

Table 9: **Multivariate Regressions Based on Model Simulations**

	Amplified Model, corr($\varepsilon_t^w, \varepsilon_t^A$) = 0.0						
	Oil Var		Equity Var		Macro Var		
	Slope	SigRatio	Slope	SigRatio	Slope	SigRatio	Adj. R^2
Output growth	**-0.31**	**[0.58]**	-0.19	[0.30]	0.11	[0.16]	0.91
Consumption growth	**-0.21**	**[0.55]**	-0.11	[0.28]	-0.05	[0.15]	0.88
Investment growth	-0.52	[0.33]	-0.63	[0.29]	**0.89**	**[0.52]**	0.82
Employment growth	-0.17	[0.24]	-0.11	[0.26]	0.15	[0.11]	0.69
TFP growth	0.10	[0.15]	-0.05	[0.17]	0.02	[0.14]	0.02
Oil inventory growth	**0.63**	**[0.78]**	0.22	[0.25]	0.02	[0.12]	0.96
Oil consumption growth	**-0.57**	**[0.74]**	-0.24	[0.29]	-0.01	[0.11]	0.95
Aggregate market return	-0.19	[0.40]	-0.18	[0.35]	**0.22**	**[0.56]**	0.85
Non-oil equity return	-0.19	[0.40]	-0.18	[0.35]	**0.22**	**[0.55]**	0.85
Oil equity return	**2.43**	**[0.82]**	0.81	[0.26]	0.36	[0.13]	0.95

	Amplified Model, corr($\varepsilon_t^w, \varepsilon_t^A$) = -0.35						
	Oil Var		Equity Var		Macro Var		
	Slope	SigRatio	Slope	SigRatio	Slope	SigRatio	Adj. R^2
Output growth	**-0.32**	**[0.61]**	-0.16	[0.28]	-0.11	[0.19]	0.92
Consumption growth	**-0.21**	**[0.56]**	-0.12	[0.29]	-0.17	[0.43]	0.88
Investment growth	-0.56	[0.36]	-0.57	[0.30]	0.36	[0.15]	0.83
Employment growth	-0.20	[0.22]	-0.17	[0.24]	-0.38	[0.40]	0.71
TFP growth	0.07	[0.14]	-0.05	[0.20]	**-0.60**	**[0.62]**	0.06
Oil inventory growth	**0.63**	**[0.77]**	0.22	[0.27]	0.06	[0.17]	0.96
Oil consumption growth	**-0.60**	**[0.75]**	-0.24	[0.29]	-0.01	[0.16]	0.95
Aggregate market return	-0.17	[0.39]	-0.17	[0.35]	0.06	[0.19]	0.86
Non-oil equity return	-0.18	[0.39]	-0.18	[0.36]	0.06	[0.18]	0.87
Oil equity return	**2.46**	**[0.83]**	0.75	[0.26]	0.16	[0.14]	0.96

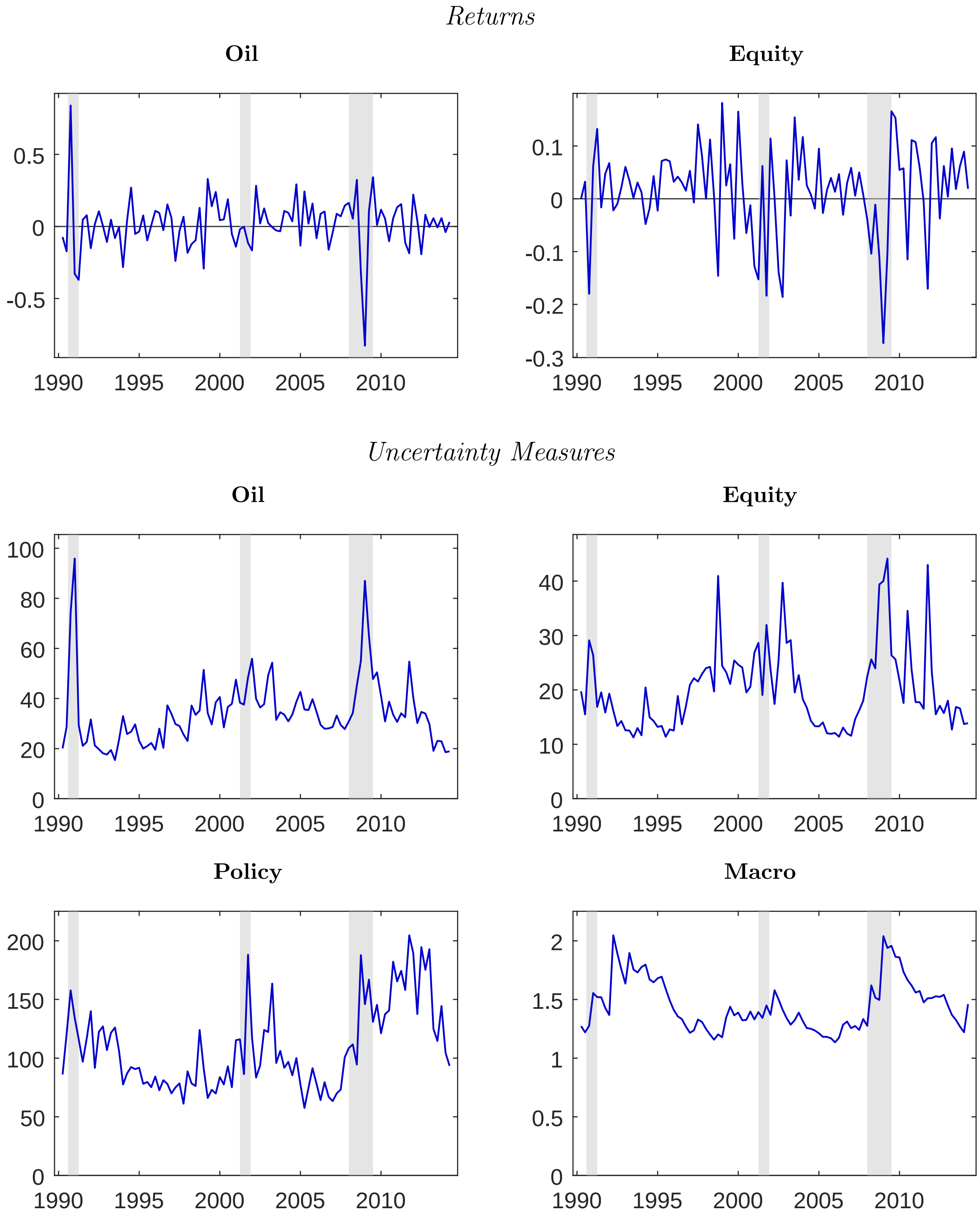
The table reports the results for multivariate regressions of macroeconomic, oil sector, and asset price variables on oil, equity, and macroeconomic variances based on simulated data from our model. Controls include production growth and current values of the variable of interest, the oil return, and the uncertainty variables. Slope coefficients and Newey-West standard errors are estimated for 100 simulated economies of 96 quarters length. We report the median slope coefficients across these economies, the median adjusted R^2, and in square brackets the ratio of economies for which the estimated coefficient is statistically significant at the 10% level. Bold numbers indicate significance for at least 50 of the 100 sample economies (i.e., for the median simulated economy). The upper panel considers the amplified model with zero correlation between macro variance shocks and TFP level shocks, the lower panel the case of a negative correlation to account for a negative TFP effect of macro variance along the lines of Bloom et al. (2018).

Table 10: **Multivariate Regressions Based on Model Simulations: Counterfactual Cases**

	Oil Var		Equity Var		Macro Var		
Amplified Model without Non-Fundamental Equity Shocks, $\sigma_d = 0$							
	Slope	SigRatio	Slope	SigRatio	Slope	SigRatio	Adj. R^2
Output growth	**1.58**	**[0.82]**	**-2.29**	**[0.92]**	0.11	[0.16]	0.92
Consumption growth	**1.27**	**[0.84]**	**-1.78**	**[0.93]**	-0.05	[0.16]	0.90
Investment growth	**5.46**	**[0.70]**	**-7.19**	**[0.82]**	0.84	[0.47]	0.84
Employment growth	0.91	[0.33]	-1.44	[0.36]	0.15	[0.12]	0.69
TFP growth	0.05	[0.17]	-0.03	[0.17]	-0.00	[0.11]	0.01
Oil inventory growth	**-1.82**	**[0.72]**	**3.08**	**[0.90]**	0.04	[0.13]	0.97
Oil consumption growth	**2.25**	**[0.83]**	**-3.43**	**[0.98]**	-0.02	[0.12]	0.96
Aggregate market return	**1.16**	**[0.69]**	**-1.71**	**[0.82]**	**0.22**	**[0.54]**	0.86
Non-oil equity return	**1.19**	**[0.72]**	**-1.80**	**[0.83]**	**0.22**	**[0.53]**	0.87
Oil equity return	**-5.36**	**[0.66]**	**9.71**	**[0.92]**	0.26	[0.14]	0.96
Amplified Model, $\text{corr}(\varepsilon_t^w, \varepsilon_t^A) = -0.7$							
	Oil Var		Equity Var		Macro Var		
	Slope	SigRatio	Slope	SigRatio	Slope	SigRatio	Adj. R^2
Output growth	**-0.31**	**[0.68]**	-0.16	[0.32]	**-0.34**	**[0.77]**	0.92
Consumption growth	**-0.21**	**[0.62]**	-0.11	[0.26]	**-0.27**	**[0.80]**	0.89
Investment growth	-0.59	[0.39]	-0.55	[0.24]	-0.26	[0.16]	0.85
Employment growth	-0.22	[0.30]	-0.15	[0.26]	**-0.88**	**[0.97]**	0.76
TFP growth	0.03	[0.17]	-0.01	[0.18]	**-1.20**	**[0.99]**	0.19
Oil inventory growth	**0.65**	**[0.76]**	0.20	[0.28]	0.10	[0.16]	0.96
Oil consumption growth	**-0.58**	**[0.74]**	-0.24	[0.26]	-0.04	[0.16]	0.96
Aggregate market return	-0.18	[0.49]	-0.18	[0.36]	-0.10	[0.25]	0.88
Non-oil equity return	-0.19	[0.49]	-0.18	[0.36]	-0.10	[0.24]	0.89
Oil equity return	**2.39**	**[0.82]**	0.76	[0.24]	0.09	[0.11]	0.96

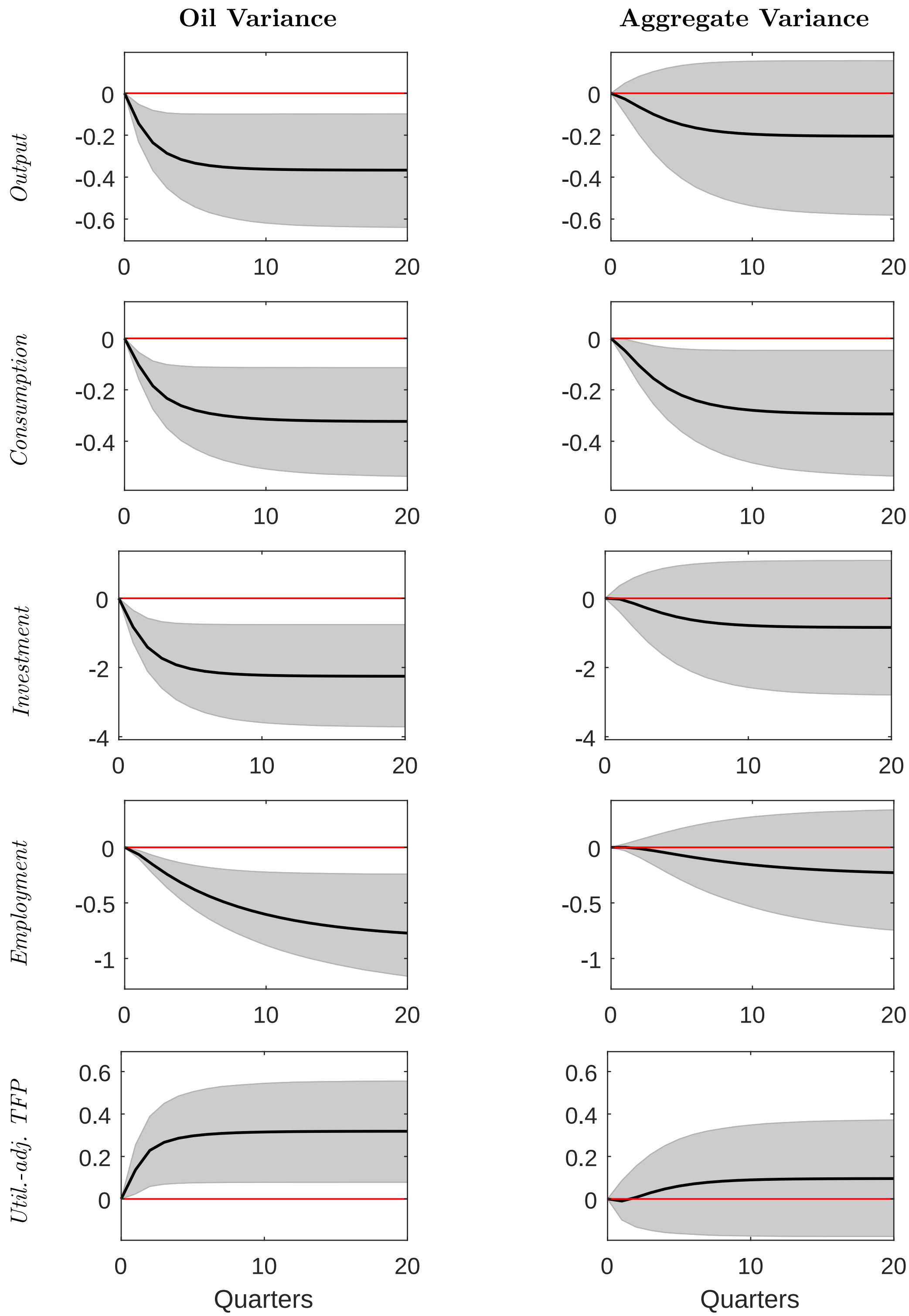
The table reports the results for multivariate regressions of macroeconomic, oil sector, and asset price variables on oil, equity, and macroeconomic variances based on simulated data from our model. Controls include production growth and current values of the variable of interest, the oil return, and the uncertainty variables. Slope coefficients and Newey-West standard errors are estimated for 100 simulated economies of 96 quarters length. We report the median slope coefficients across these economies, the median adjusted R^2, and in square brackets the ratio of economies for which the estimated coefficient is statistically significant at the 10% level. Bold numbers indicate significance for at least 50 of the 100 sample economies (i.e., for the median simulated economy). The upper panel considers the counterfactual case that equity returns are not subject to non-fundamental cash-flow shocks, the lower panel the counterfactual case of an unrealistically large negative correlation between macro variance shocks and TFP level shocks.

Figure 1: **Time Series of Excess Returns and Uncertainty Measures**



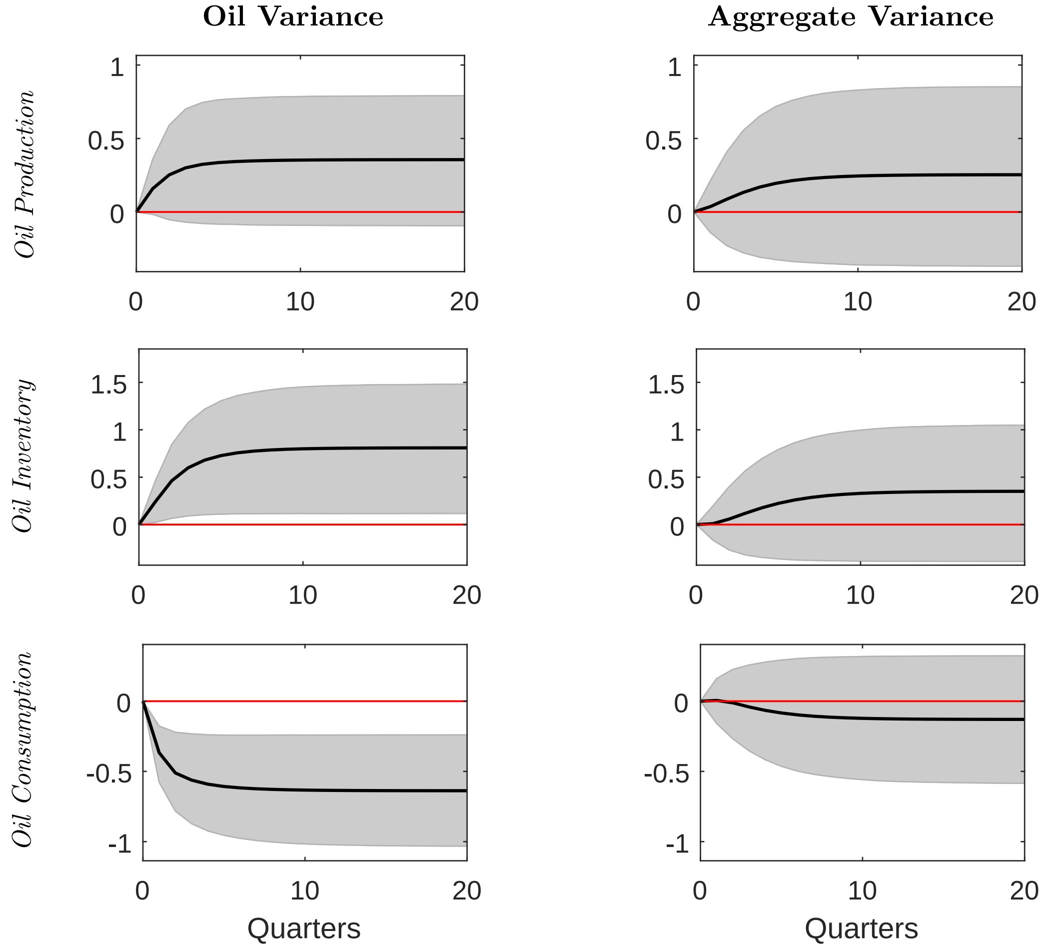
The figure shows the time series of excess returns in oil and equity markets (top panel) and of oil, equity, policy, and macroeconomic uncertainty (bottom panel). For ease of exposition, the measures for oil, equity, and macro uncertainty are expressed in annualized standard deviation units. Shaded areas indicate recessions as defined by the NBER. Data are quarterly from 1990Q1 to 2014Q1.

Figure 2: **Impulse Responses of Macroeconomic Variables to Variance Shocks**



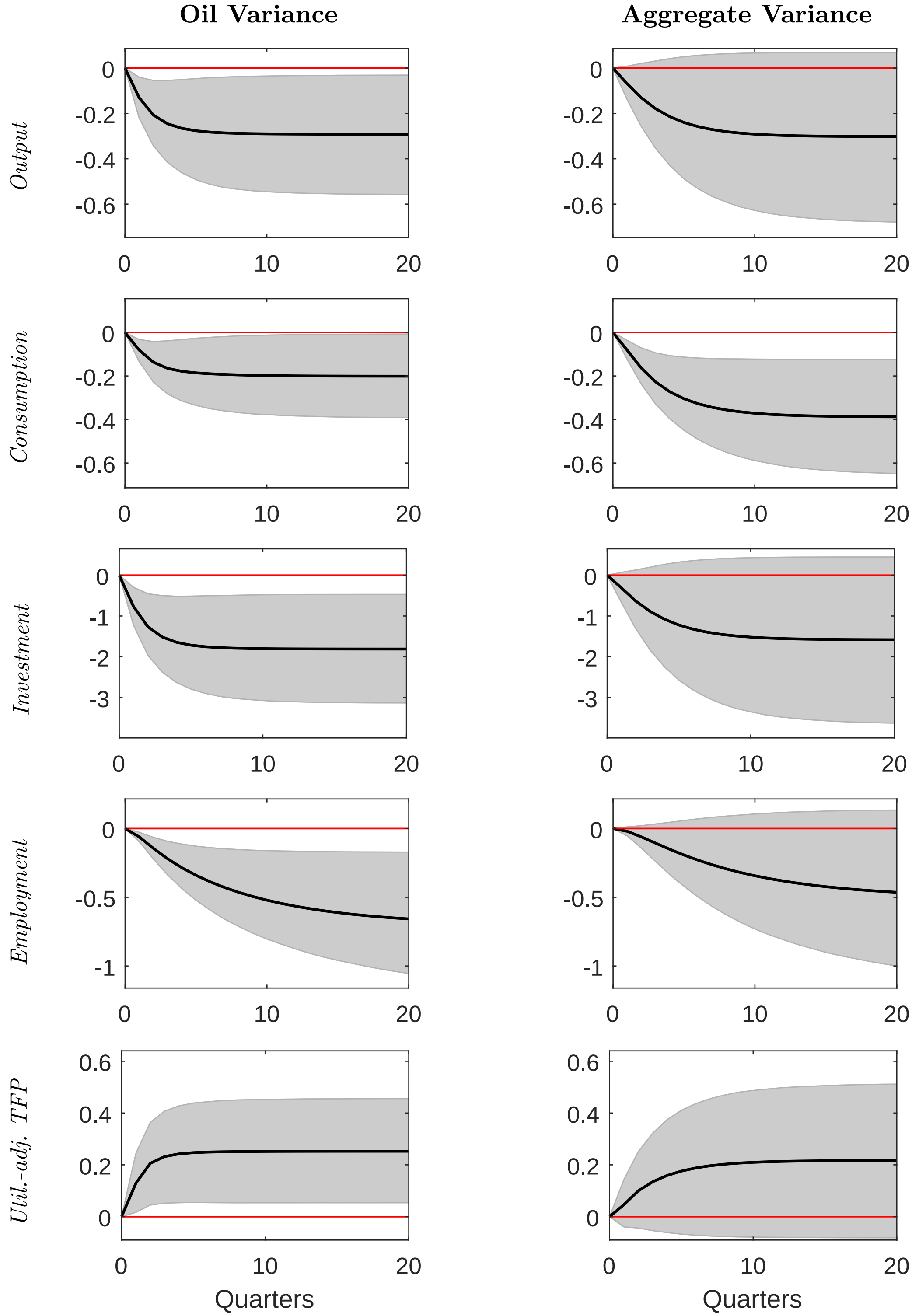
The figure shows impulse responses of macroeconomic variables to a positive one-standard-deviation shock to implied oil variance (left panel) and to aggregate variance (right panel). Aggregate variance is defined as the first principal component of implied equity variance, policy uncertainty, and macro variance. The impulse responses are based on a lower-triangular Cholesky decomposition of a VAR(1) fitted to the corresponding series, oil return, implied oil variance, and aggregate variance (in this order). Gray regions indicate 90% confidence intervals computed by block bootstrap. Data are quarterly from 1990Q1 to 2014Q1. Changes are in percent.

Figure 3: **Impulse Responses of Oil Sector Variables to Variance Shocks**



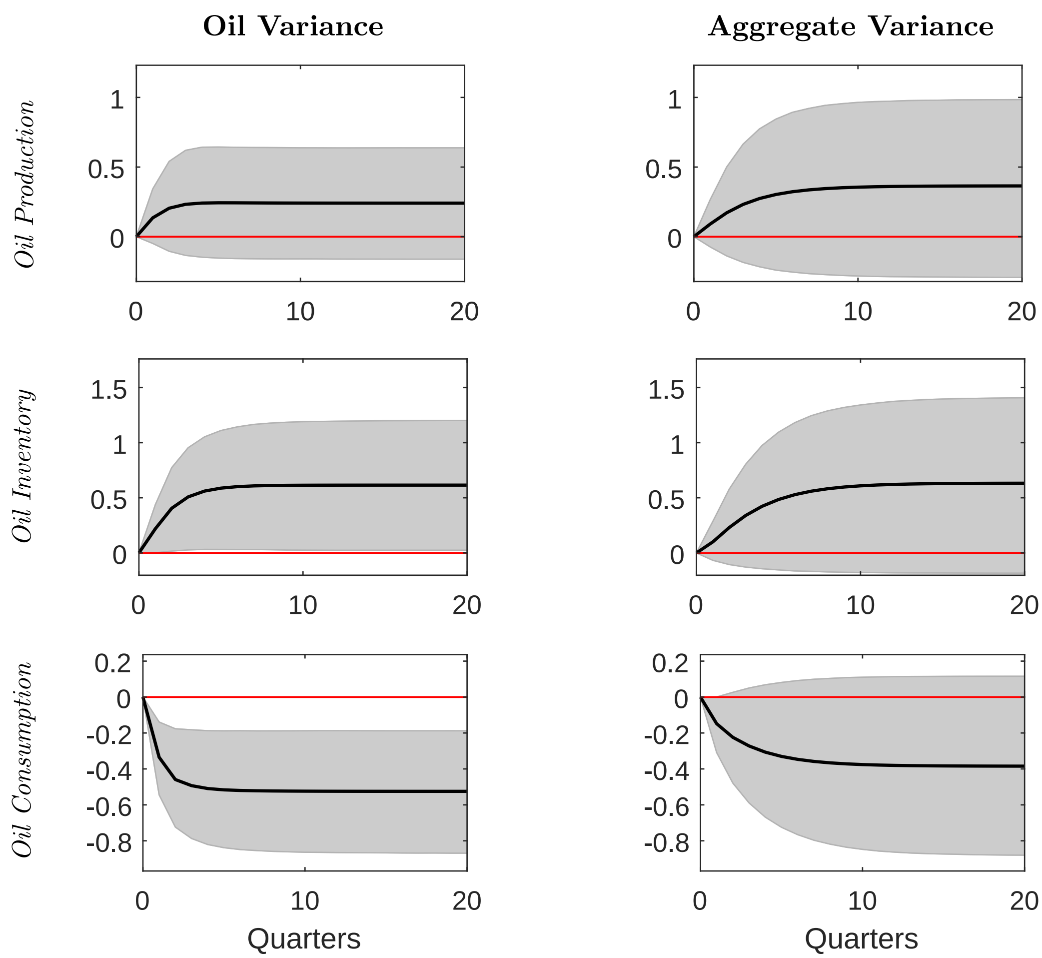
The figure shows impulse responses of oil sector variables to a positive one-standard-deviation shock to implied oil variance (left panel) and to aggregate variance (right panel). Aggregate variance is defined as the first principal component of implied equity variance, policy uncertainty, and macro variance. The impulse responses are based on a lower-triangular Cholesky decomposition of a VAR(1) fitted to the corresponding series, oil return, implied oil variance, and aggregate variance (in this order). Gray regions indicate 90% confidence intervals computed by block bootstrap. Data are quarterly from 1990Q1 to 2014Q1. Changes are in percent.

Figure 4: **Impulse Responses of Macro Variables: Alternative Specification**



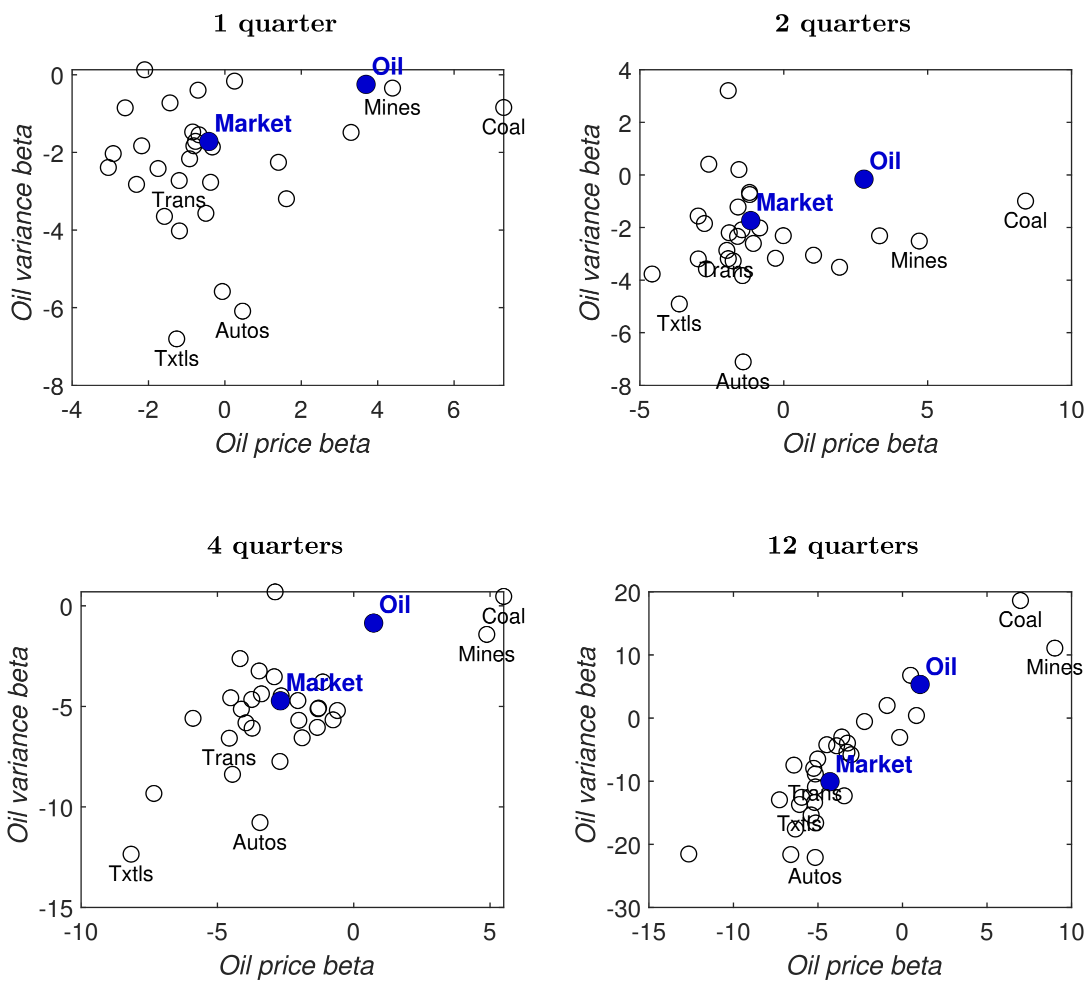
The figure shows impulse responses of macroeconomic variables to a positive one-standard-deviation shock to implied oil variance (left panel) and to aggregate variance (right panel). Aggregate variance is defined as the first principal component of implied equity variance, policy uncertainty, and macro variance. The impulse responses are based on a lower-triangular Cholesky decomposition of a VAR(1) fitted to the corresponding series, oil return, aggregate variance, and implied oil variance (in this order). Gray regions indicate 90% confidence intervals computed by block bootstrap. Data are quarterly from 1990Q1 to 2014Q1. Changes are in percent.

Figure 5: **Impulse Responses of Oil Sector Variables: Alternative Specification**



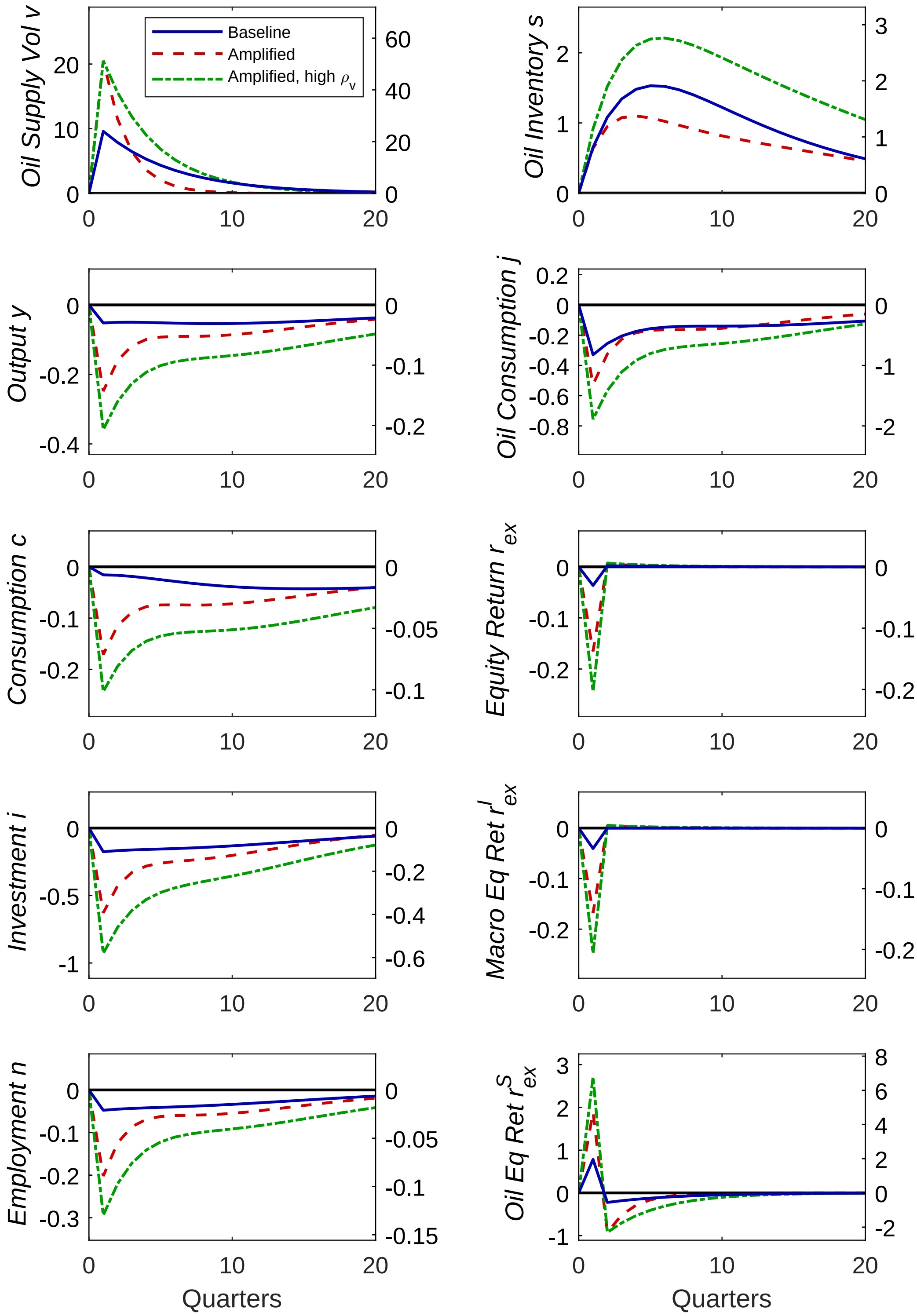
The figure shows impulse responses of oil sector variables to a positive one-standard-deviation shock to oil variance (left panel) and to aggregate variance (right panel). Aggregate variance is defined as the first principal component of implied equity variance, policy uncertainty, and macro variance. The impulse responses are based on a lower-triangular Cholesky decomposition of a VAR(1) fitted to the corresponding series, oil return, aggregate variance, and implied oil variance (in this order). Gray regions indicate 90% confidence intervals computed by block bootstrap. Data are quarterly from 1990Q1 to 2014Q1. Changes are in percent.

Figure 6: **Portfolio Exposures to Oil Variance and Oil Price Risk**



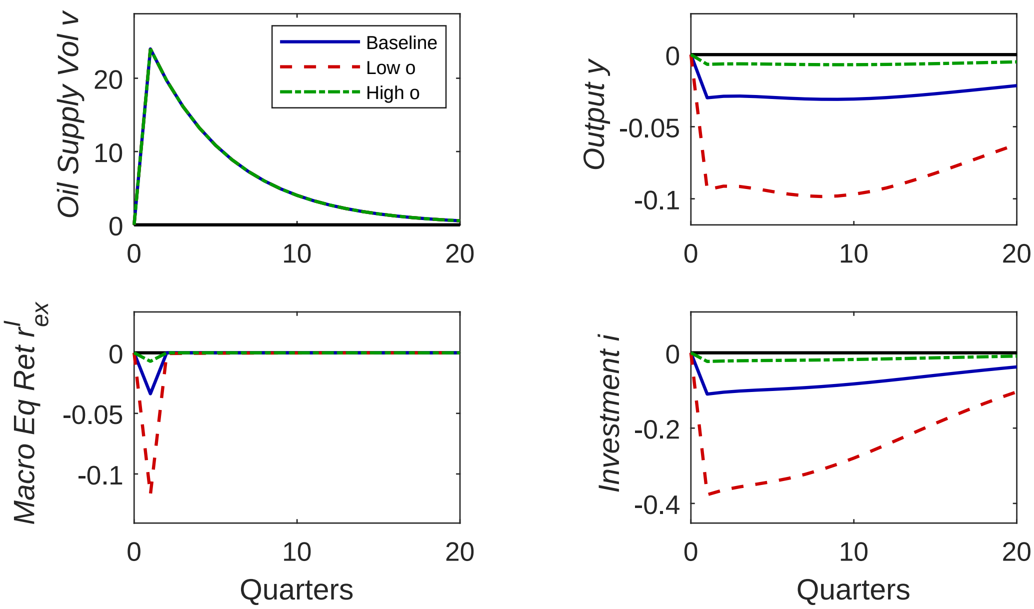
The figure shows the equity return exposures of the aggregate market and of the 30 Fama-French industry portfolios to oil variance and to oil price risk at 1, 2, 4, and 12 quarter frequencies. Exposures are estimated by a multivariate regression of the return of interest on the four uncertainty measures (implied oil variance, implied equity variance, policy uncertainty, macro variance), the oil return, and control variables. Data are quarterly from 1990Q1 to 2014Q1.

Figure 7: **Model-Based Impulse Responses to Oil Uncertainty Shocks**



The figure shows model-based impulse response functions for a positive one-standard-deviation shock to oil production volatility v_t. The blue solid lines and the right axis stand for the baseline model, the left axis and red dashed lines for the amplified model, and green dot-dashed lines for the amplified model with increased persistence of oil production volatility ($\rho_v = 0.76$). Changes are in percent.

Figure 8: **Model-Based Impulse Responses to Oil Uncertainty Shocks: Different Oil Input Sensitivities**



The figure shows model-based impulse response functions for a positive one-standard-deviation shock to oil production volatility v_t. The impulse responses are calculated for the baseline model calibration, but for different levels of the oil elasticity o. The blue solid lines stand for the baseline calibration with $o = 0.4$, the red dashed lines for $o = 0.35$, and the green dot-dashed lines for $o = 0.45$. Changes are in percent.

A Appendix

A.1 Oil Volatility Measure

For computing implied oil variance in a model-free way, we obtain daily data on futures and option prices on West Texas Intermediate (WTI) light sweet crude oil from the Commodity Research Bureau (CRB). The WTI crude oil contracts have the longest history of option and futures prices available compared to other oil contracts, such as Brent, and are widely used in the literature (see, e.g., Christoffersen and Pan 2018). Oil options are American-style and are written on the oil futures contracts. Both oil options and futures are traded on the Chicago Mercantile Exchange (CME). We convert American option prices to European options following Barone-Adesi and Whaley (1987).[27] Options violating standard no-arbitrage conditions and those with a price below five times the minimum tick value are excluded from our sample. We compute the 30-day model-free option implied variance following Bakshi, Kapadia, and Madan (2003), truncating upper and lower strike prices at $K_t = F_{t,T} \cdot \exp\{\pm 6\sigma(T-t)\}$.[28]

Our crude oil volatility measure tracks very closely the crude oil volatility index (OVX) traded on the CME exchange. The OVX index is based on options on the United States Oil Fund, and is available from 2007. For the overlapping period, the correlation between the square-root of our oil variance measure and the OVX is 99.1%.

[27] This is similar to Trolle and Schwartz (2009) or Christoffersen and Pan (2018).

[28] Jiang and Tian (2005) find that the truncation error can be ignored if the truncation points are more than two standard deviations away from the forward price. We also try using alternative truncation points at 10σ, and the difference is negligible.

A.2 Firms' First Order Conditions

Final goods producer Without loss of generality, consider (3.4) at time 0 and add the Lagrange multiplier Q_t^I for the capital law of motion (3.2):

$$\max_{I_t,K_{t+1},N_t,J_t} \mathbb{E}_0 \sum_{t=0}^{\infty} M_t(Y_t - I_t - P_t J_t - W_t^N N_t - Q_t^I(K_{t+1} - (1-\delta)K_t - I_t + G_t K_t)) \quad \text{(A.1)}$$

Setting the derivative with respect to I_t to zero yields

$$Q_t^I = \frac{1}{1 - G_t'}. \quad \text{(A.2)}$$

Setting the derivative with respect to K_{t+1} to zero, we obtain

$$\mathbb{E}_t \left[M_{t+1} \frac{\alpha(1-\tilde{\iota})\frac{Y_{t+1}}{K_{t+1}^{\frac{1}{o}}[(1-\tilde{\iota})K_{t+1}^{1-\frac{1}{o}} + \tilde{\iota} J_{t+1}^{1-\frac{1}{o}}]} + ((1-\delta) + G_{t+1}{}' \frac{I_{t+1}}{K_{t+1}} - G_{t+1})Q_{t+1}^I}{Q_t^I} \right] = 1, \quad \text{(A.3)}$$

the Euler equation for the macro sector return R_{t+1}^I as given by (3.20).

Setting the derivative with respect to N_t to zero, we have

$$W_t^N = \frac{\partial Y_t}{\partial N_t} = (1-\alpha)\frac{Y_t}{N_t}. \quad \text{(A.4)}$$

Finally, we set the derivative with respect to J_t to zero and get

$$P_t = \frac{\partial Y_t}{\partial J_t} = \alpha\tilde{\iota} \frac{Y_t}{J_t^{\frac{1}{o}}[(1-\tilde{\iota})K_t^{1-\frac{1}{o}} + \tilde{\iota} J_t^{1-\frac{1}{o}}]}. \quad \text{(A.5)}$$

Oil inventory holder In a similar way, consider (3.9) at time 0 and add the Lagrange multiplier Q_t^S for the resource constraint (3.5)

$$\max_{D_t,S_t} \mathbb{E}_0 \sum_{t=0}^{\infty} M_t(P_t D_t - Q_t^S(S_t - (1-\omega)S_{t-1} - E_t + D_t + \Pi_{t-1}A_{t-1})). \quad \text{(A.6)}$$

Setting the derivative with respect to D_t to zero, we get

$$P_t = Q_t^S. \tag{A.7}$$

Setting the derivative with respect to S_t to zero yields

$$\mathbb{E}_t\left[M_{t+1}\frac{(1-\omega-\Pi_t')Q_{t+1}^S}{Q_t^S}\right] = 1, \tag{A.8}$$

the Euler equation for the oil sector return R_{t+1}^S as given by (3.21).

A.3 Amplified Model

As described in Section 3.5, we consider a version of our model in which the effect of oil uncertainty shocks on the macroeconomy is amplified through time-varying markups and an intermediate goods multiplier. Technically, we specify markups $\theta_t = \mu_\theta J_t^{\varepsilon_\theta}$ to be driven by the oil input J_t to the productive sector. For negative elasticity ε_θ, we thus obtain countercyclical markups in line with Rotemberg and Woodford (1996) due to the positive relation of effective oil supply and macroeconomic output. The interlinked intermediate goods sector with share ν amplifies markups to a factor of $\Theta_t = \theta^{\frac{1}{1-\nu}}$ in line with Jones (2011).

Altogether, these amplifiers alter equations (3.1), (3.17), and (3.20) of our model as follows:

$$Y_t = \Theta_t \cdot \lambda J_t^\zeta \cdot (A_t N_t)^{1-\alpha}[(1-\tilde{\iota})K_t^{1-\frac{1}{o}} + \tilde{\iota} J_t^{1-\frac{1}{o}}]^{\frac{\alpha}{1-\frac{1}{o}}} \tag{3.1'}$$

$$\begin{aligned} P_t &= \frac{\alpha\tilde{\iota}}{\Theta_t}\frac{Y_t}{J_t^{\frac{1}{o}}[(1-\tilde{\iota})K_t^{1-\frac{1}{o}} + \tilde{\iota} J_t^{1-\frac{1}{o}}]} \\ W_t^N &= \frac{1-\alpha}{\Theta_t}\frac{Y_t}{N_t} = \frac{\partial \tilde{C}}{\partial L_t}\Big/\frac{\partial \tilde{C}}{\partial C_t} \end{aligned} \tag{3.17'}$$

$$R_{t+1}^I = \frac{\frac{\alpha(1-\tilde{\iota})}{\Theta_t}\frac{Y_{t+1}}{K_{t+1}^{\frac{1}{o}}[(1-\tilde{\iota})K_t^{1-\frac{1}{o}} + \tilde{\iota} J_t^{1-\frac{1}{o}}]} + ((1-\delta) + G_{t+1}'\frac{I_{t+1}}{K_{t+1}} - G_{t+1})Q_{t+1}^I}{Q_t^I} \tag{3.20'}$$

with a scaling factor λJ_t^ζ resulting from the Jones (2011) multiplier.

We calibrate the model as reported by Table 6. Most values are the same as in the baseline calibration, except the parameters ι, π, σ_κ, ρ_v, and σ_v, which are chosen to match the five moments as for the baseline model, as well as the adjustment costs ξ and the oil elasticity o, which we set to 0.225 in line with Ready (2018a). For the introduced amplifiers, we set the elasticity ε_θ of markups to -0.1, and the share ν of the intermediate goods sector is set to 0.5 in line with Jones (2011). The scaling parameters μ_θ, λ, and ζ are fixed at 0.8, 0.2, and 0.4, respectively.

Table A.1: **Summary Statistics Excluding Great Recession**

				Quarterly Correlations with				Annual Correlations with			
	Mean	Std Dev	AR(1)	Oil Var	Eq Var	Pol Unc	Macro Var	Oil Var	Eq Var	Pol Unc	Macro Var
GDP growth	1.73	1.01	0.21	-0.35	-0.09	-0.32	-0.09	-0.51	-0.27	-0.43	-0.23
Consumption growth	1.59	0.67	0.33	-0.36	-0.08	-0.45	-0.14	-0.33	-0.14	-0.58	-0.38
Investment growth	3.86	5.18	0.14	-0.31	-0.07	-0.05	0.09	-0.54	-0.18	0.01	0.00
Employment growth	1.38	0.83	0.86	-0.40	-0.24	-0.29	-0.14	-0.33	-0.16	-0.36	-0.09
Util.-adj. TFP growth	0.89	1.41	-0.02	0.05	0.11	-0.15	-0.12	0.00	-0.13	-0.24	-0.55
Oil production growth	0.17	2.83	0.26	-0.27	-0.12	-0.02	0.11	-0.51	-0.15	-0.02	-0.05
Oil inventory growth	0.44	3.18	0.33	-0.17	-0.17	-0.10	-0.18	0.14	-0.34	-0.22	-0.28
Oil consumption growth	0.19	2.58	-0.07	-0.33	0.15	0.08	0.10	-0.60	-0.05	0.22	0.09
Excess oil return	7.53	32.62	-0.21	-0.00	-0.00	-0.03	-0.04	0.13	0.02	-0.03	0.05
Excess equity return	8.72	15.76	-0.10	-0.14	-0.51	-0.17	-0.00	-0.44	-0.34	-0.08	-0.02
Risk-free rate	0.70	0.85	0.94	0.09	-0.08	-0.55	-0.21	0.20	-0.23	-0.59	-0.21
Oil variance	308.49	577.85	0.42	1.00	0.43	0.28	-0.10	1.00	0.43	0.25	0.11
Equity variance	103.21	163.04	0.34	0.43	1.00	0.37	-0.09	0.43	1.00	0.60	0.06
Policy uncertainty	106.94	71.87	0.70	0.28	0.37	1.00	0.30	0.25	0.60	1.00	0.38
Macro variance	0.52	0.31	0.79	-0.10	-0.09	0.30	1.00	0.11	0.06	0.38	1.00

The table reports summary statistics for the macroeconomic, oil sector, asset price, and uncertainty variables. Means and standard deviations are annualized. Data are quarterly from 1990Q1 to 2014Q1, excluding 2008Q1–2009Q2.

Table A.2: **Multivariate Predictability Evidence Without Controlling for Oil Price Changes**

	Oil Var		Equity Var		Pol Unc		Macro Var		
	Slope	SE	Slope	SE	Slope	SE	Slope	SE	Adj. R^2
GDP Growth:									
1q ahead	**-0.20**	**(0.06)**	0.05	(0.09)	**-0.10**	**(0.05)**	0.01	(0.05)	0.21
2q ahead	**-0.15**	**(0.08)**	0.01	(0.14)	-0.15	(0.10)	0.05	(0.10)	0.19
4q ahead	-0.12	(0.20)	0.07	(0.22)	-0.16	(0.17)	0.11	(0.20)	0.10
12q ahead	-0.11	(0.46)	0.37	(0.48)	0.09	(0.87)	0.87	(0.58)	0.06
Consumption Growth:									
1q ahead	**-0.11**	**(0.04)**	-0.01	(0.04)	-0.05	(0.04)	-0.04	(0.03)	0.34
2q ahead	-0.12	(0.09)	-0.01	(0.08)	-0.09	(0.08)	-0.05	(0.05)	0.33
4q ahead	-0.10	(0.13)	0.03	(0.14)	-0.16	(0.17)	-0.03	(0.13)	0.29
12q ahead	-0.09	(0.34)	0.46	(0.48)	-0.17	(0.77)	0.16	(0.43)	0.08
Investment Growth:									
1q ahead	**-1.02**	**(0.42)**	0.02	(0.48)	-0.25	(0.28)	0.27	(0.34)	0.22
2q ahead	**-1.32**	**(0.62)**	-0.41	(0.81)	-0.14	(0.49)	0.66	(0.60)	0.20
4q ahead	-0.66	(0.94)	-0.70	(1.18)	0.22	(0.82)	**1.96**	**(0.94)**	0.08
12q ahead	-0.86	(1.39)	0.88	(2.25)	3.58	(2.88)	**7.30**	**(2.10)**	0.23
Employment Growth:									
1q ahead	**-0.08**	**(0.04)**	-0.04	(0.04)	-0.00	(0.02)	0.04	(0.03)	0.84
2q ahead	**-0.17**	**(0.07)**	-0.09	(0.09)	-0.00	(0.04)	**0.13**	**(0.06)**	0.76
4q ahead	-0.17	(0.14)	-0.24	(0.19)	0.06	(0.11)	**0.44**	**(0.16)**	0.57
12q ahead	-0.31	(0.28)	-0.51	(0.56)	**1.27**	**(0.69)**	**2.00**	**(0.55)**	0.29
Utilization-adjusted TFP Growth:									
1q ahead	0.14	(0.10)	0.15	(0.11)	-0.03	(0.07)	-0.10	(0.07)	0.07
2q ahead	0.22	(0.15)	**0.35**	**(0.13)**	-0.08	(0.11)	**-0.20**	**(0.12)**	0.19
4q ahead	0.10	(0.22)	**0.69**	**(0.21)**	-0.21	(0.18)	**-0.47**	**(0.25)**	0.23
12q ahead	-0.42	(0.28)	**1.75**	**(0.56)**	**-1.54**	**(0.67)**	-0.46	(0.45)	0.25
Oil Production Growth:									
1q ahead	0.14	(0.28)	0.05	(0.16)	-0.05	(0.12)	**0.30**	**(0.09)**	0.04
2q ahead	-0.10	(0.28)	0.25	(0.26)	-0.01	(0.22)	0.13	(0.17)	-0.03
4q ahead	-0.21	(0.23)	0.16	(0.45)	0.22	(0.36)	0.34	(0.23)	-0.01
12q ahead	**-1.16**	**(0.58)**	0.76	(1.14)	**2.08**	**(0.84)**	-0.32	(0.33)	0.13
Oil Inventory Growth:									
1q ahead	**0.32**	**(0.11)**	-0.00	(0.18)	0.09	(0.18)	-0.06	(0.13)	0.14
2q ahead	**0.43**	**(0.21)**	0.06	(0.32)	0.16	(0.37)	-0.23	(0.25)	0.03
4q ahead	0.12	(0.28)	0.27	(0.54)	0.09	(0.65)	-0.39	(0.44)	-0.02
12q ahead	-0.07	(0.52)	-0.34	(0.99)	0.16	(1.10)	-1.08	(0.68)	0.11
Oil Consumption Growth:									
1q ahead	-0.37	(0.24)	-0.11	(0.16)	0.00	(0.12)	0.16	(0.12)	0.05
2q ahead	-0.41	(0.26)	-0.18	(0.30)	0.11	(0.18)	0.34	(0.23)	0.07
4q ahead	0.09	(0.23)	**-0.66**	**(0.33)**	**0.53**	**(0.19)**	**0.70**	**(0.37)**	0.13
12q ahead	-0.22	(0.17)	0.45	(0.40)	**1.62**	**(0.41)**	**1.75**	**(0.35)**	0.52

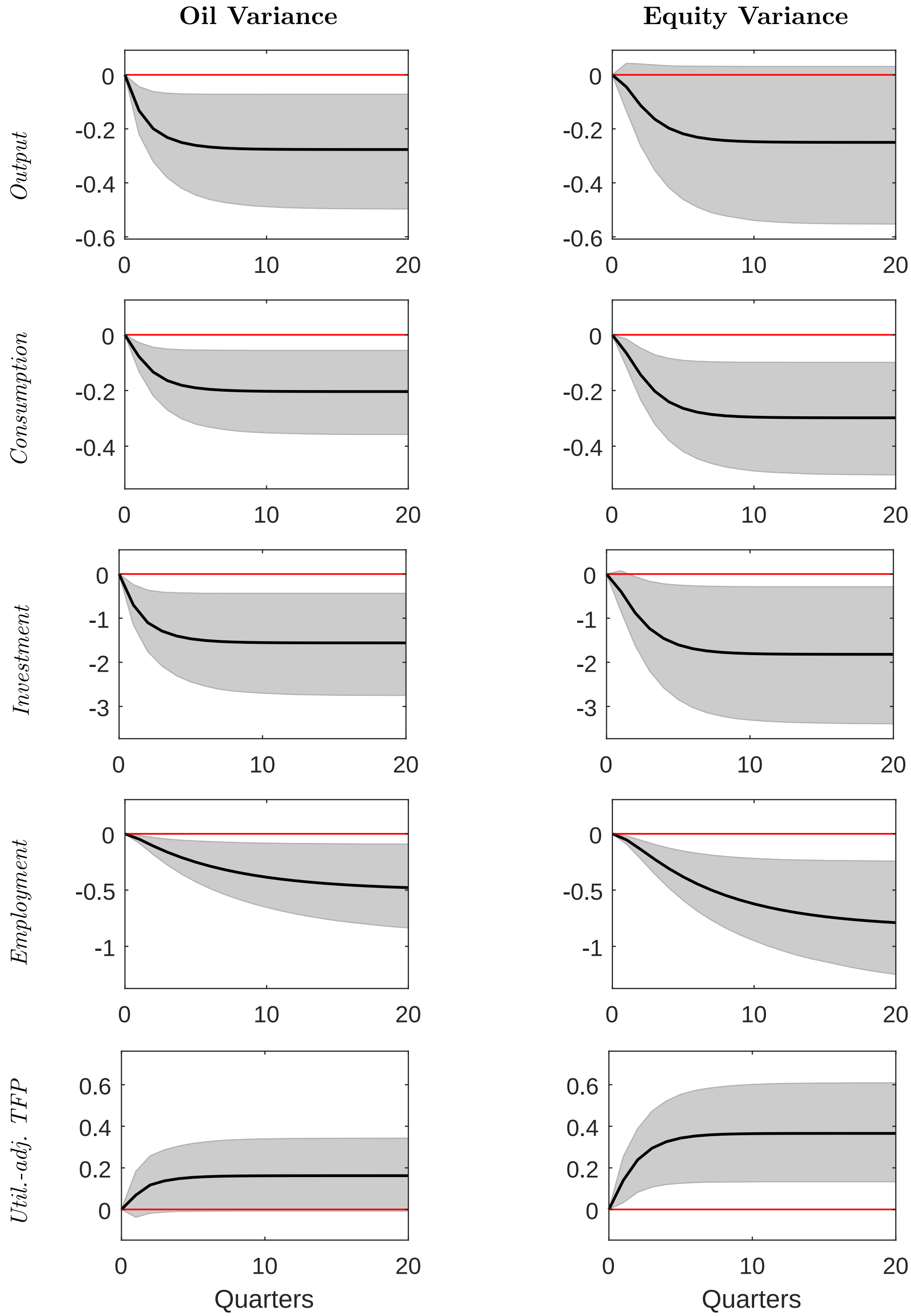
The table reports the results for the multivariate predictability of future macroeconomic and oil sector variables by implied oil and equity variances, policy uncertainty, and macroeconomic variance, controlling for the current value of the predicted variable. Newey-West standard errors are in parentheses. Bold numbers indicate statistical significance at the 10% level. Data are quarterly from 1990Q1 to 2014Q1.

Table A.3: **Bivariate Predictability Evidence: Oil Variance and Aggregate Variance**

	Full Sample					Excluding Great Recession				
	Oil Var		Aggr Var			Oil Var		Aggr Var		
	Slope	SE	Slope	SE	Adj. R^2	Slope	SE	Slope	SE	Adj. R^2
GDP Growth:										
1q ahead	**-0.18**	**(0.05)**	-0.05	(0.08)	0.21	**-0.15**	**(0.06)**	0.01	(0.05)	0.09
2q ahead	**-0.16**	**(0.07)**	-0.10	(0.12)	0.21	-0.12	(0.07)	-0.04	(0.09)	0.12
4q ahead	-0.13	(0.15)	-0.02	(0.17)	0.12	**-0.21**	**(0.11)**	-0.06	(0.16)	0.05
12q ahead	-0.31	(0.46)	1.06	(1.07)	0.08	**-0.50**	**(0.28)**	-0.04	(0.58)	0.03
Consumption Growth:										
1q ahead	**-0.11**	**(0.03)**	**-0.08**	**(0.03)**	0.38	**-0.10**	**(0.03)**	**-0.06**	**(0.03)**	0.21
2q ahead	-0.11	(0.07)	**-0.12**	**(0.07)**	0.35	-0.07	(0.06)	-0.08	(0.06)	0.17
4q ahead	-0.09	(0.11)	-0.14	(0.15)	0.31	-0.08	(0.10)	-0.15	(0.15)	0.16
12q ahead	-0.07	(0.27)	0.31	(0.91)	0.10	-0.08	(0.22)	-0.16	(0.61)	0.03
Investment Growth:										
1q ahead	**-1.07**	**(0.37)**	-0.03	(0.42)	0.22	**-0.78**	**(0.25)**	0.47	(0.39)	0.07
2q ahead	**-1.56**	**(0.56)**	0.10	(0.77)	0.19	**-1.14**	**(0.27)**	0.78	(0.54)	0.07
4q ahead	-1.37	(1.00)	1.14	(1.05)	0.05	**-1.41**	**(0.51)**	**1.38**	**(0.76)**	0.03
12q ahead	-2.75	(1.94)	**9.46**	**(4.09)**	0.18	**-3.35**	**(1.37)**	**2.70**	**(1.37)**	0.07
Employment Growth:										
1q ahead	**-0.09**	**(0.03)**	0.00	(0.03)	0.84	**-0.06**	**(0.02)**	0.03	(0.02)	0.74
2q ahead	**-0.21**	**(0.06)**	0.03	(0.07)	0.75	**-0.15**	**(0.03)**	**0.11**	**(0.06)**	0.68
4q ahead	**-0.35**	**(0.15)**	0.20	(0.15)	0.53	**-0.31**	**(0.10)**	**0.32**	**(0.17)**	0.52
12q ahead	**-1.02**	**(0.48)**	**2.29**	**(0.97)**	0.18	**-1.15**	**(0.51)**	**1.57**	**(0.55)**	0.23
Utilization-adjusted TFP Growth:										
1q ahead	**0.17**	**(0.10)**	-0.02	(0.09)	0.06	0.17	(0.11)	-0.07	(0.07)	0.04
2q ahead	**0.33**	**(0.16)**	-0.02	(0.13)	0.12	**0.26**	**(0.14)**	-0.11	(0.15)	0.01
4q ahead	0.35	(0.31)	-0.12	(0.29)	0.04	0.26	(0.29)	-0.20	(0.32)	0.00
12q ahead	0.01	(0.41)	-0.47	(0.76)	-0.01	0.01	(0.39)	0.16	(1.07)	-0.02
Oil Production Growth:										
1q ahead	0.20	(0.24)	0.06	(0.14)	0.08	0.30	(0.22)	0.10	(0.13)	0.08
2q ahead	0.04	(0.25)	**0.36**	**(0.21)**	0.06	0.09	(0.25)	**0.46**	**(0.24)**	0.05
4q ahead	-0.23	(0.26)	**0.71**	**(0.34)**	0.06	-0.27	(0.31)	**0.76**	**(0.40)**	0.07
12q ahead	**-1.67**	**(0.58)**	**3.40**	**(0.82)**	0.32	**-1.65**	**(0.49)**	**3.44**	**(0.92)**	0.28
Oil Inventory Growth:										
1q ahead	**0.30**	**(0.09)**	0.02	(0.16)	0.15	**0.29**	**(0.10)**	0.07	(0.16)	0.12
2q ahead	**0.45**	**(0.20)**	-0.00	(0.30)	0.03	**0.46**	**(0.20)**	0.03	(0.33)	0.02
4q ahead	0.24	(0.34)	-0.06	(0.56)	-0.02	0.23	(0.34)	-0.21	(0.64)	-0.02
12q ahead	0.09	(0.46)	-1.02	(0.69)	0.09	0.18	(0.71)	-0.04	(1.11)	0.00
Oil Consumption Growth:										
1q ahead	**-0.47**	**(0.17)**	0.01	(0.14)	0.14	**-0.39**	**(0.17)**	0.09	(0.15)	0.14
2q ahead	**-0.57**	**(0.23)**	0.20	(0.25)	0.06	**-0.53**	**(0.18)**	**0.55**	**(0.24)**	0.17
4q ahead	-0.36	(0.25)	**0.58**	**(0.35)**	0.01	**-0.31**	**(0.16)**	**0.80**	**(0.34)**	0.08
12q ahead	**-0.62**	**(0.23)**	**3.01**	**(0.59)**	0.47	**-0.38**	**(0.20)**	**1.09**	**(0.55)**	0.05

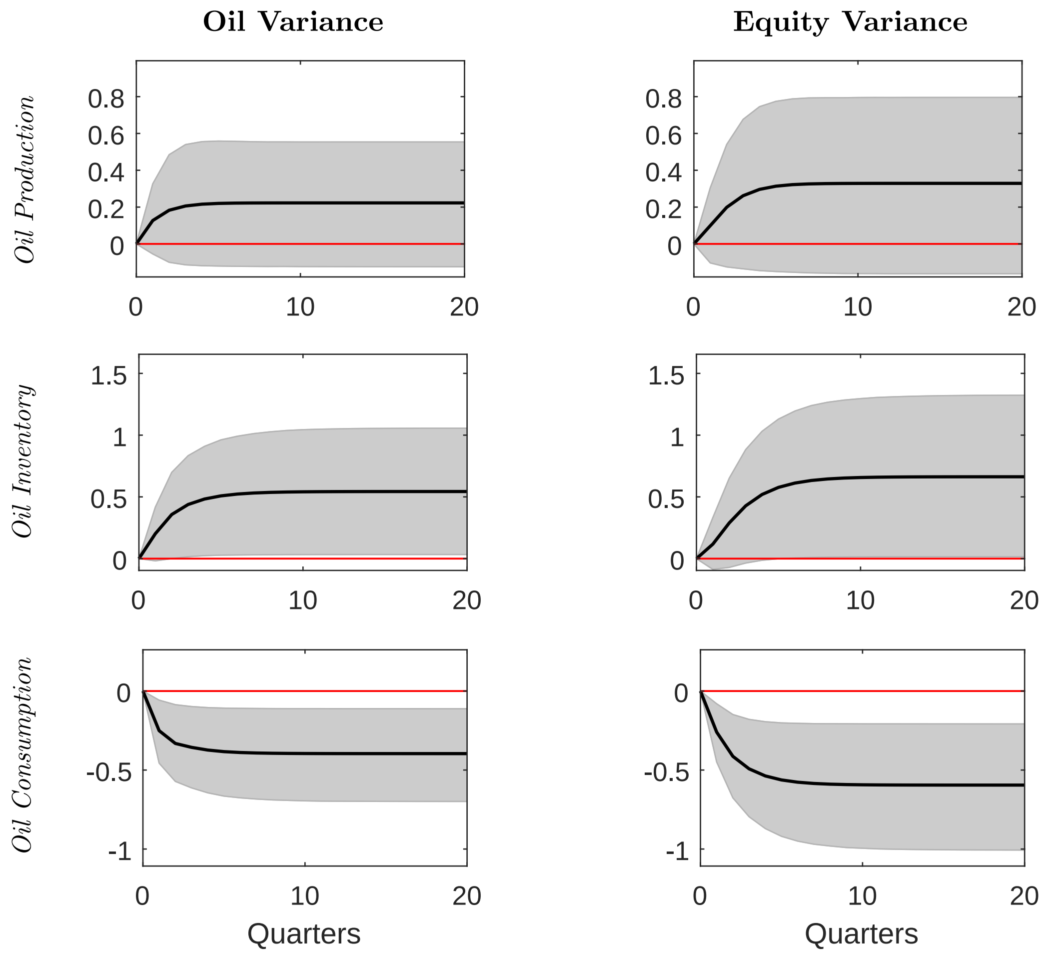
The table reports the results for the predictability of future macroeconomic and oil sector variables by implied oil variance and by aggregate variance, controlling for the current value of the predicted variable and the oil return. Aggregate variance is defined as the first principal component of implied equity variance, policy uncertainty, and macroeconomic variance. Newey-West standard errors are in parentheses. Bold numbers indicate statistical significance at the 10% level. Data are quarterly from 1990Q1 to 2014Q1 (left panel) and excluding 2008Q1–2009Q2 (right panel).

Figure A.1: **Impulse Responses of Macro Variables: VAR with Oil Variance and Equity Variance**



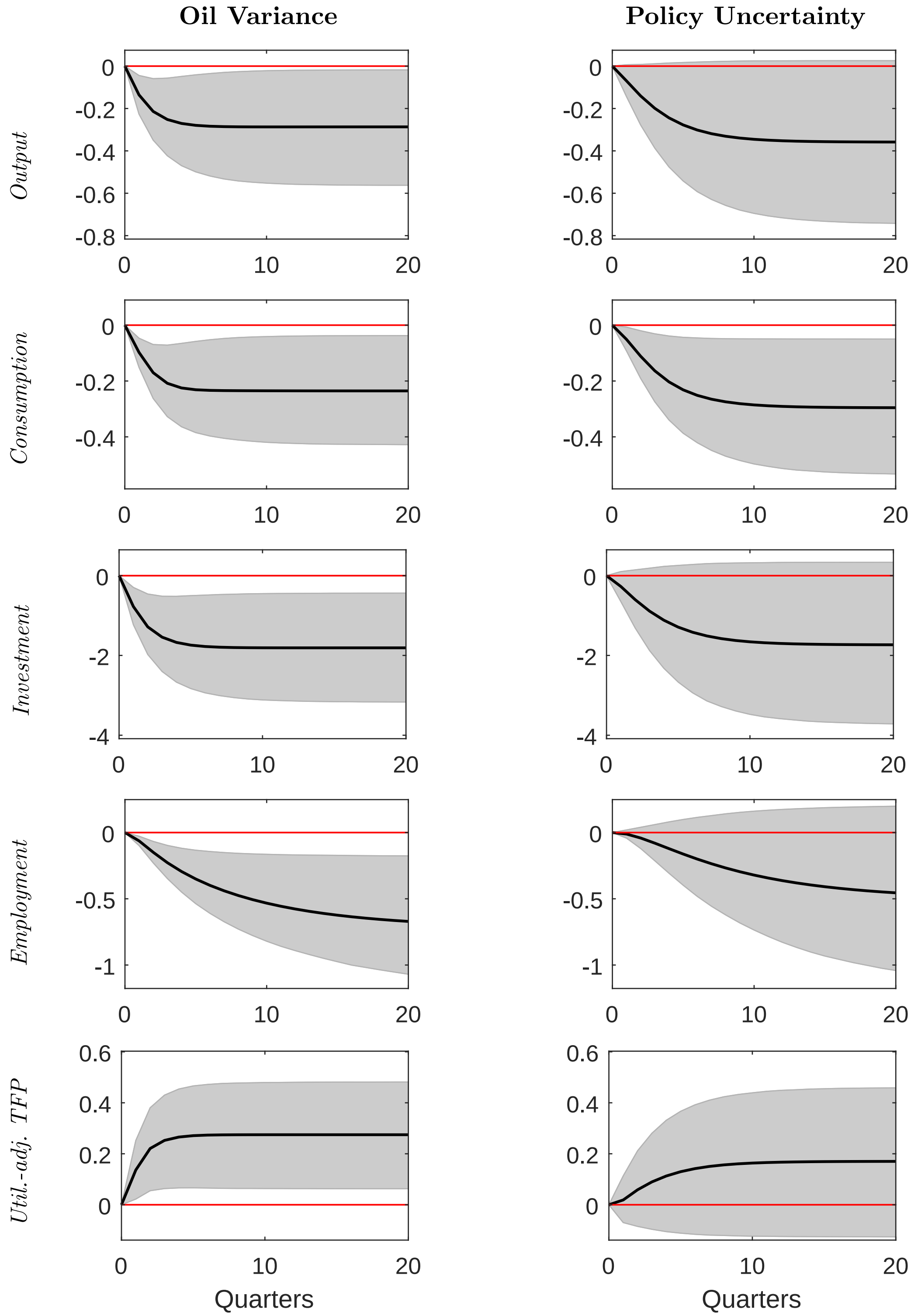
The figure shows impulse responses of macroeconomic variables to a positive one-standard-deviation shock to implied oil variance (left panel) and to implied equity variance (right panel). The impulse responses are based on a lower-triangular Cholesky decomposition of a VAR(1) fitted to the corresponding series, oil return, implied equity variance, and implied oil variance (in this order). Gray regions indicate 90% confidence intervals computed by block bootstrap. Data are quarterly from 1990Q1 to 2014Q1. Changes are in percent.

Figure A.2: **Impulse Responses of Oil Sector Variables: VAR with Oil Variance and Equity Variance**



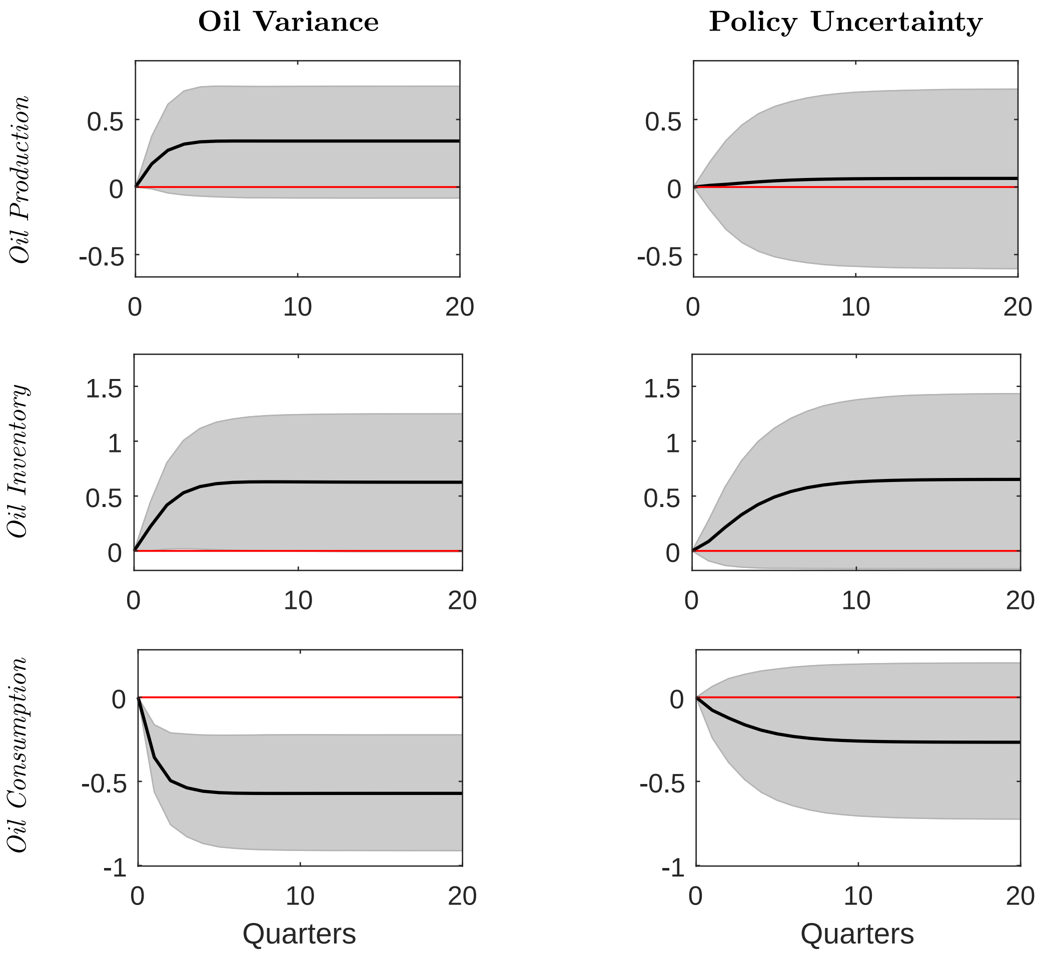
The figure shows impulse responses of oil sector variables to a positive one-standard-deviation shock to implied oil variance (left panel) and to implied equity variance (right panel). The impulse responses are based on a lower-triangular Cholesky decomposition of a VAR(1) fitted to the corresponding series, oil return, implied equity variance, and implied oil variance (in this order). Gray regions indicate 90% confidence intervals computed by block bootstrap. Data are quarterly from 1990Q1 to 2014Q1. Changes are in percent.

Figure A.3: **Impulse Responses of Macro Variables: VAR with Oil Variance and Policy Uncertainty**



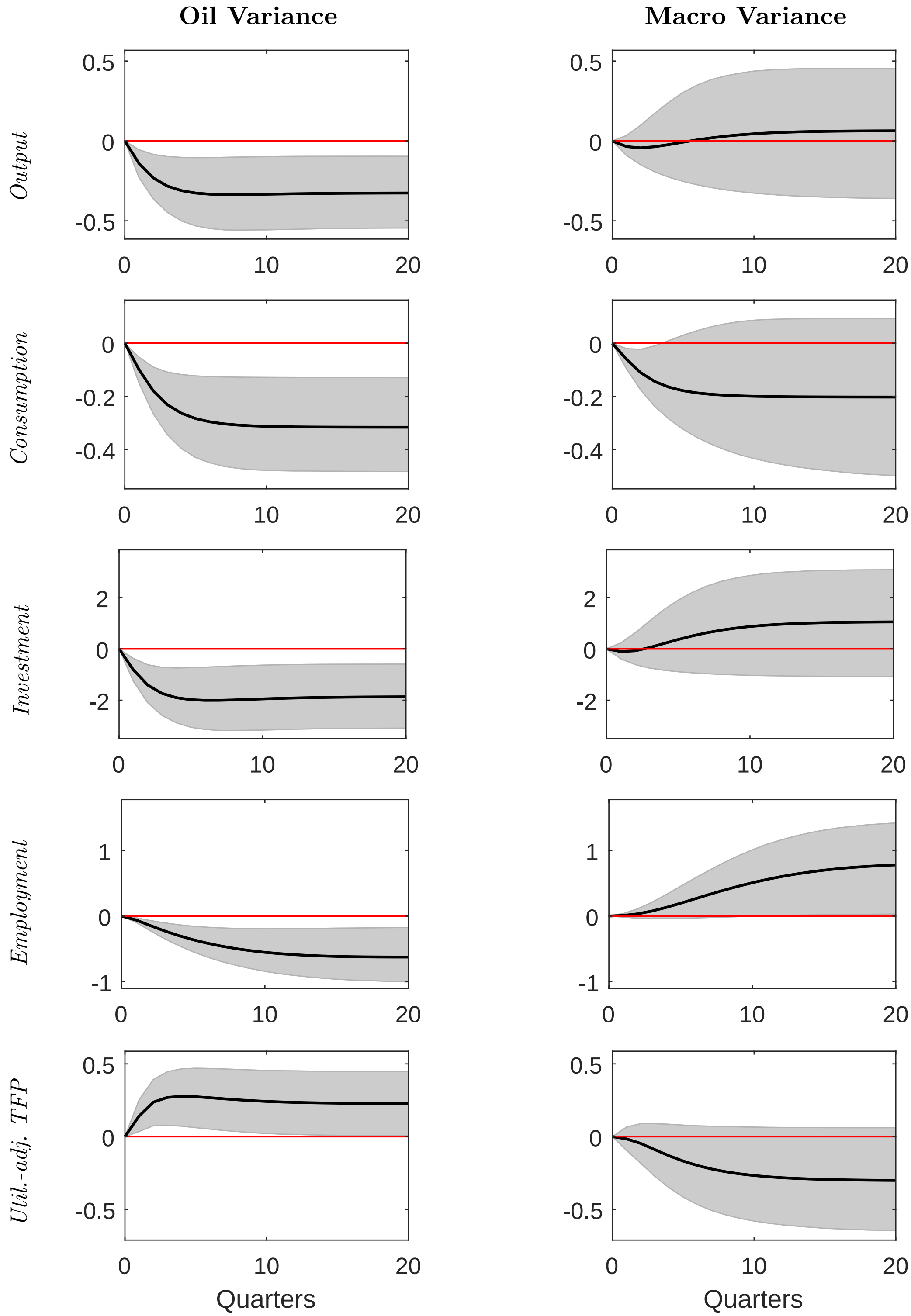
The figure shows impulse responses of macroeconomic variables to a positive one-standard-deviation shock to implied oil variance (left panel) and to policy uncertainty (right panel). The impulse responses are based on a lower-triangular Cholesky decomposition of a VAR(1) fitted to the corresponding series, oil return, policy uncertainty, and implied oil variance (in this order). Gray regions indicate 90% confidence intervals computed by block bootstrap. Data are quarterly from 1990Q1 to 2014Q1. Changes are in percent.

Figure A.4: **Impulse Responses of Oil Sector Variables: VAR with Oil Variance and Policy Uncertainty**



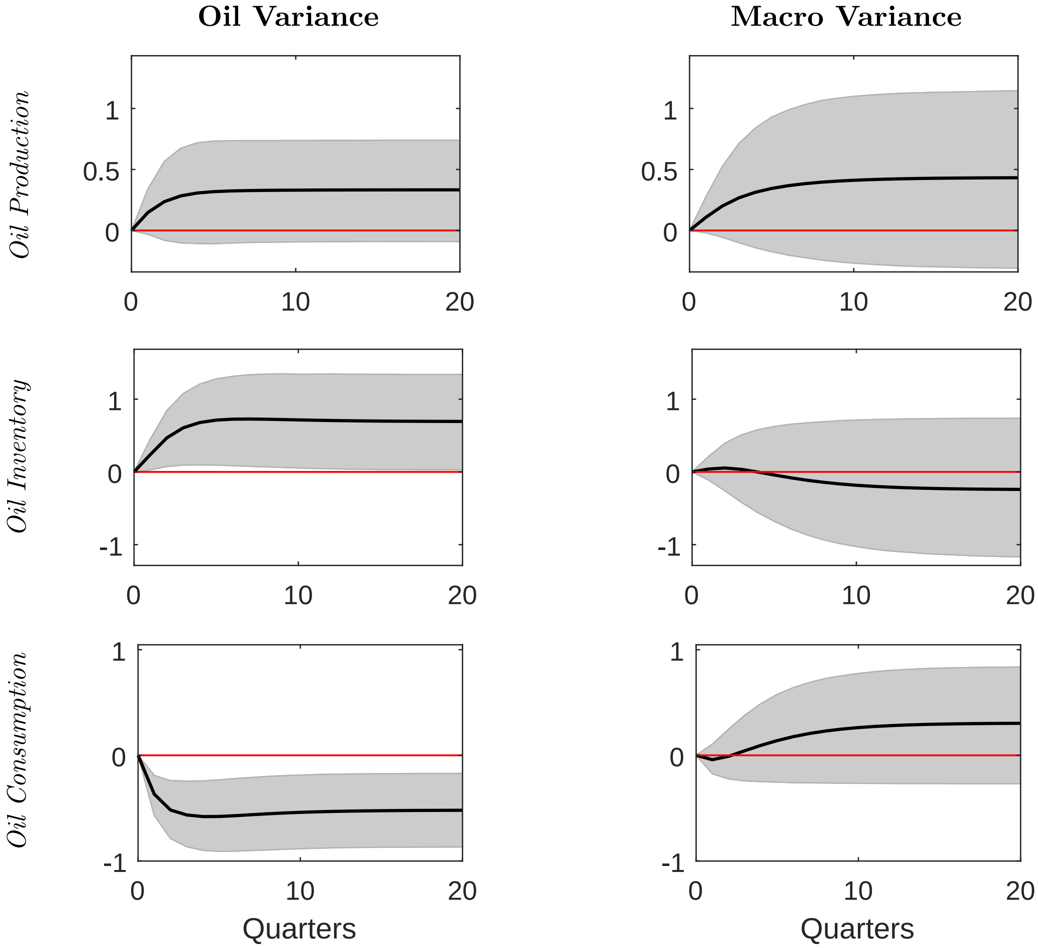
The figure shows impulse responses of oil sector variables to a positive one-standard-deviation shock to implied oil variance (left panel) and to policy uncertainty (right panel). The impulse responses are based on a lower-triangular Cholesky decomposition of a VAR(1) fitted to the corresponding series, oil return, policy uncertainty, and implied oil variance (in this order). Gray regions indicate 90% confidence intervals computed by block bootstrap. Data are quarterly from 1990Q1 to 2014Q1. Changes are in percent.

Figure A.5: **Impulse Responses of Macro Variables: VAR with Oil Variance and Macro Variance**



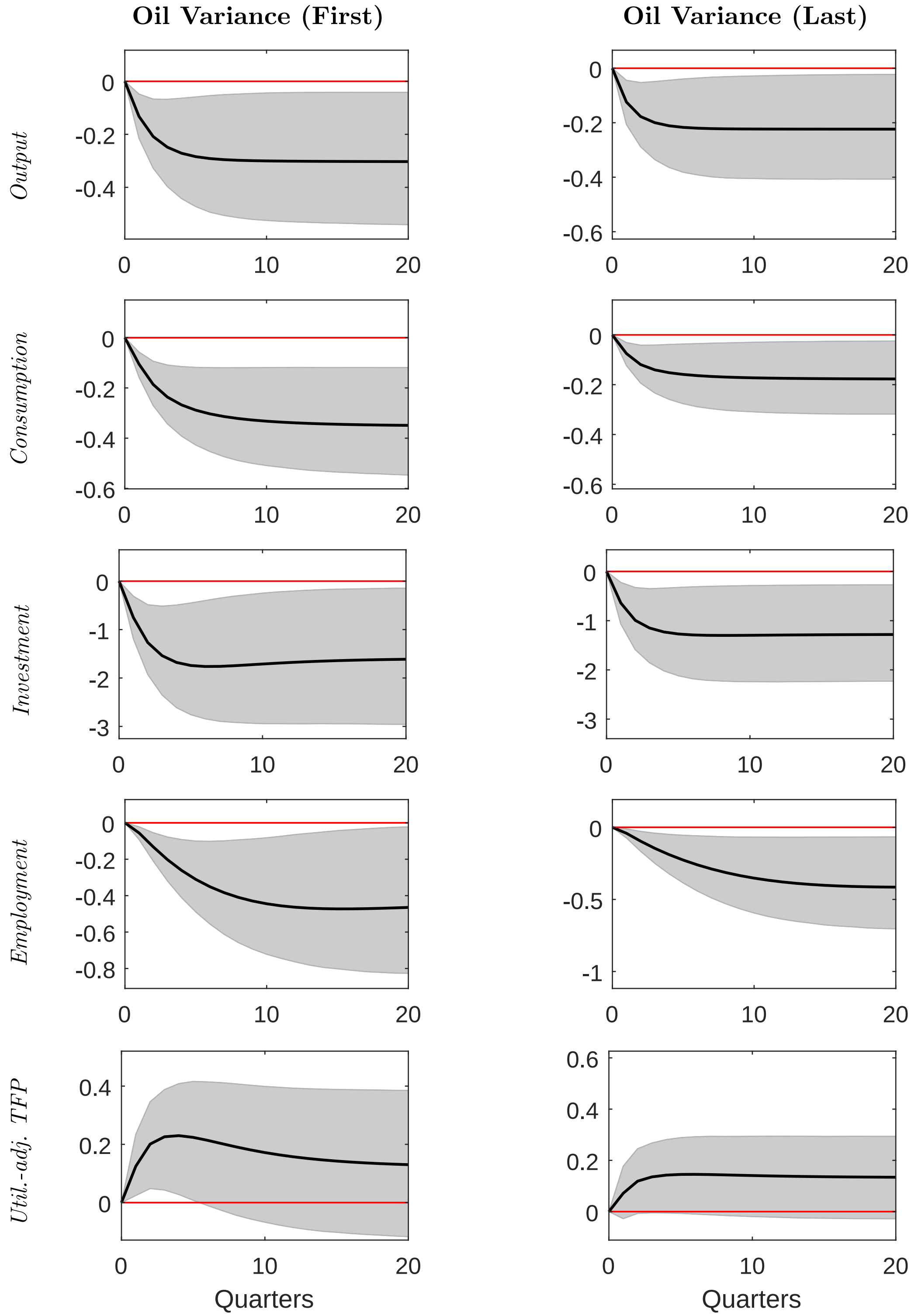
The figure shows impulse responses of macroeconomic variables to a positive one-standard-deviation shock to implied oil variance (left panel) and to macro variance (right panel). The impulse responses are based on a lower-triangular Cholesky decomposition of a VAR(1) fitted to the corresponding series, oil return, macro variance, and implied oil variance (in this order). Gray regions indicate 90% confidence intervals computed by block bootstrap. Data are quarterly from 1990Q1 to 2014Q1. Changes are in percent.

Figure A.6: **Impulse Responses of Oil Sector Variables: VAR with Oil Variance and Macro Variance**



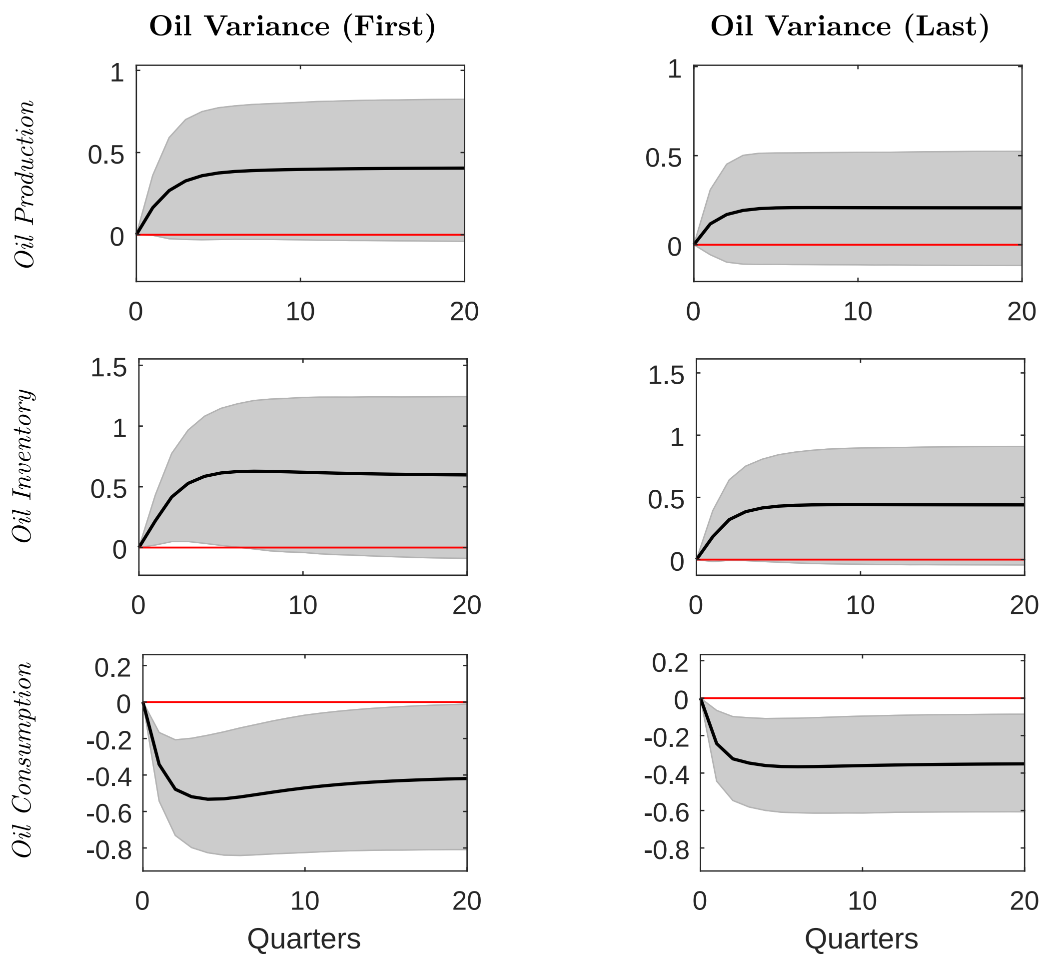
The figure shows impulse responses of oil sector variables to a positive one-standard-deviation shock to implied oil variance (left panel) and to macro variance (right panel). The impulse responses are based on a lower-triangular Cholesky decomposition of a VAR(1) fitted to the corresponding series, oil return, macro variance, and implied oil variance (in this order). Gray regions indicate 90% confidence intervals computed by block bootstrap. Data are quarterly from 1990Q1 to 2014Q1. Changes are in percent.

Figure A.7: **Imp. Resp. of Macro Variables: VAR with All Uncertainty Measures**



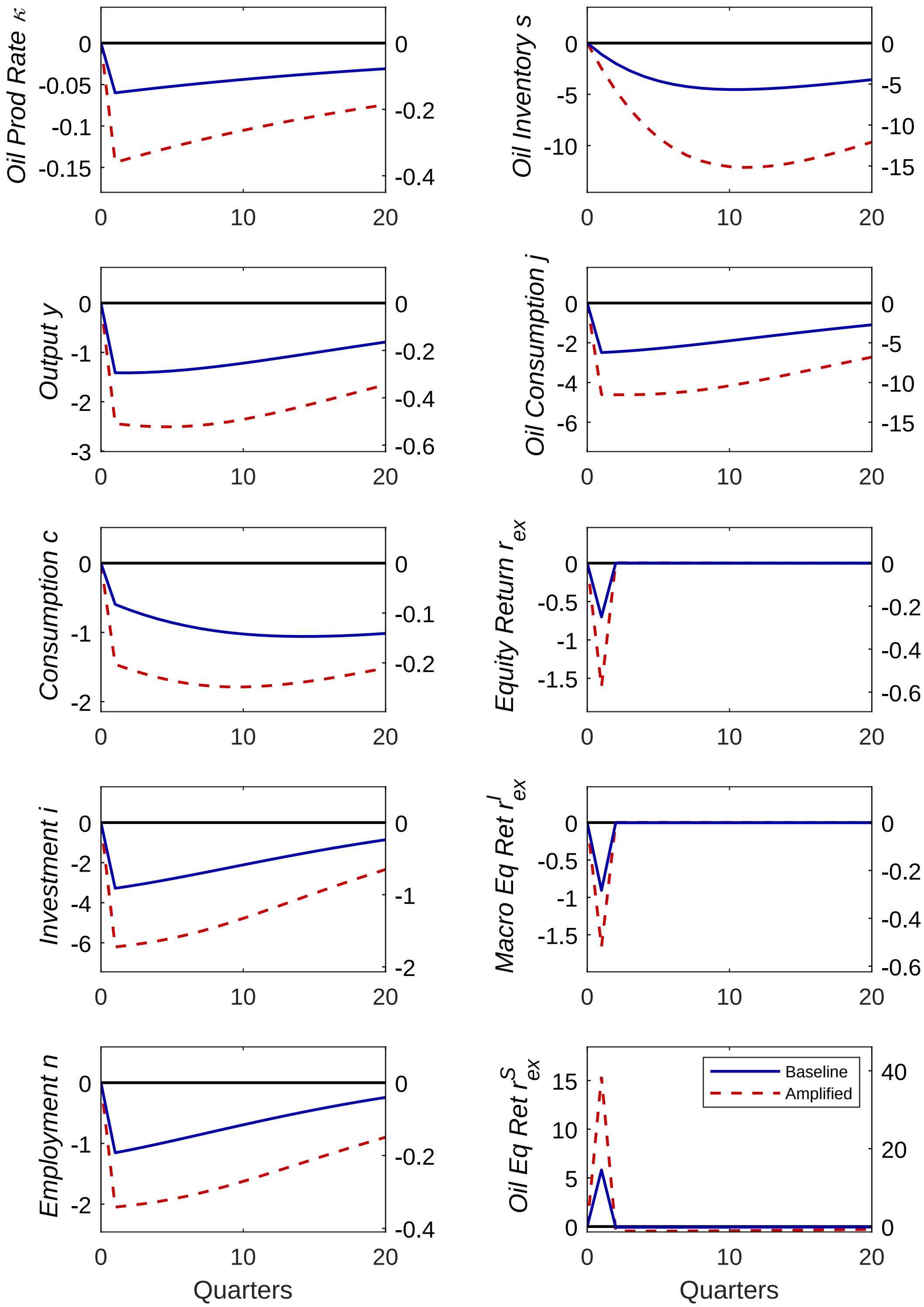
The figure shows impulse responses of macroeconomic variables to a positive one-standard-deviation shock to implied oil variance. The impulse responses are based on a lower-triangular Cholesky decomposition of a VAR(1) fitted to the corresponding series, oil return, and the four uncertainty measures (implied oil variance, implied equity variance, policy uncertainty, macro variance). In the left panel, oil variance is ordered first among the uncertainty measures but after the other variables, and it is ordered last in the right panel. Gray regions indicate 90% confidence intervals computed by block bootstrap. Data are quarterly from 1990Q1 to 2014Q1. Changes are in percent.

Figure A.8: **Impulse Responses of Oil Sector Variables: VAR with All Uncertainty Measures**



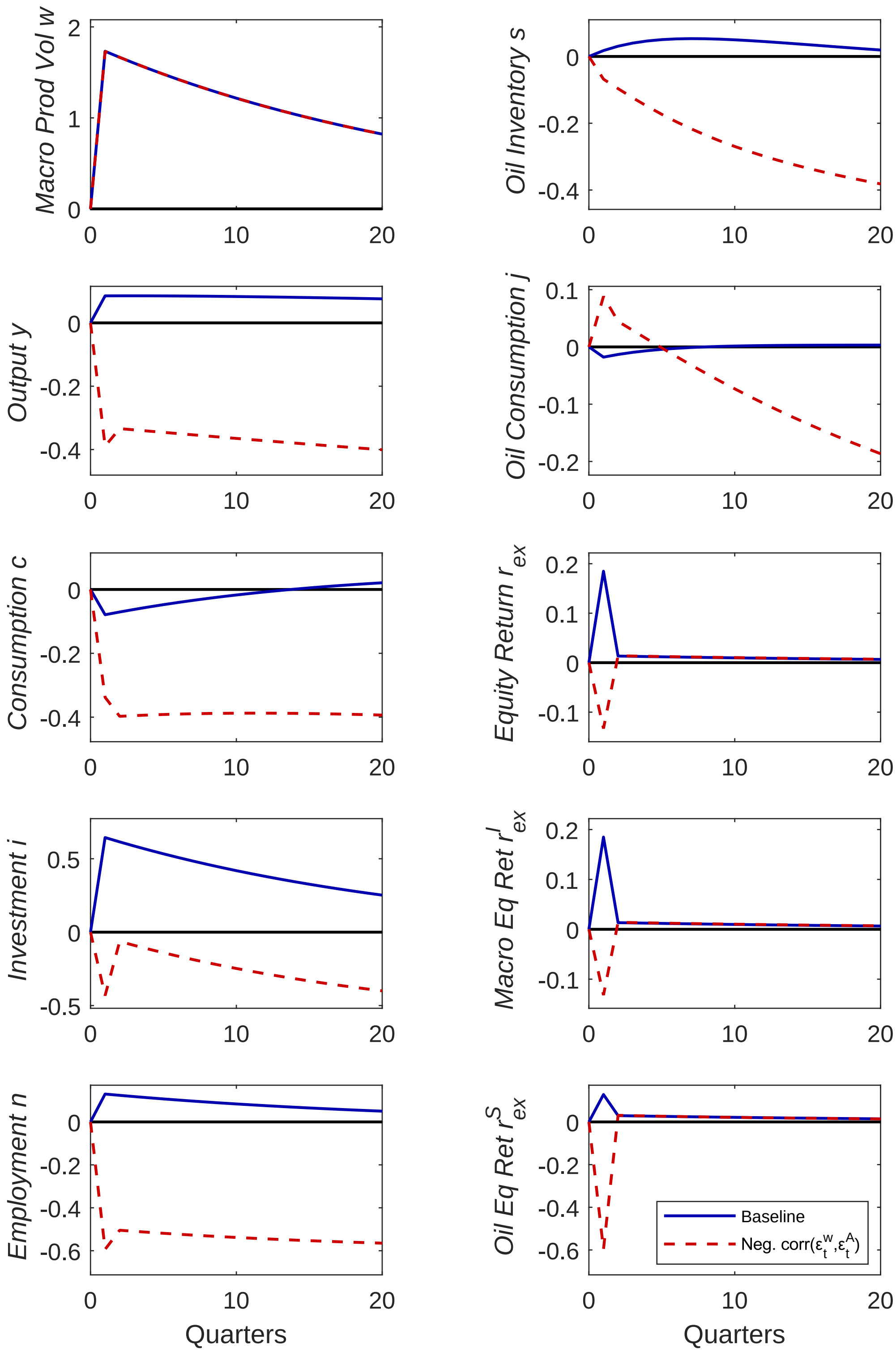
The figure shows impulse responses of oil sector variables to a positive one-standard-deviation shock to implied oil variance. The impulse responses are based on a lower-triangular Cholesky decomposition of a VAR(1) fitted to the corresponding series, oil return, and the four uncertainty measures (implied oil variance, implied equity variance, policy uncertainty, macro variance). In the left panel, oil variance is ordered first among the uncertainty measures but after the other variables, and it is ordered last in the right panel. Gray regions indicate 90% confidence intervals computed by block bootstrap. Data are quarterly from 1990Q1 to 2014Q1. Changes are in percent.

Figure A.9: **Model-Based Impulse Responses to Oil Supply Shocks**



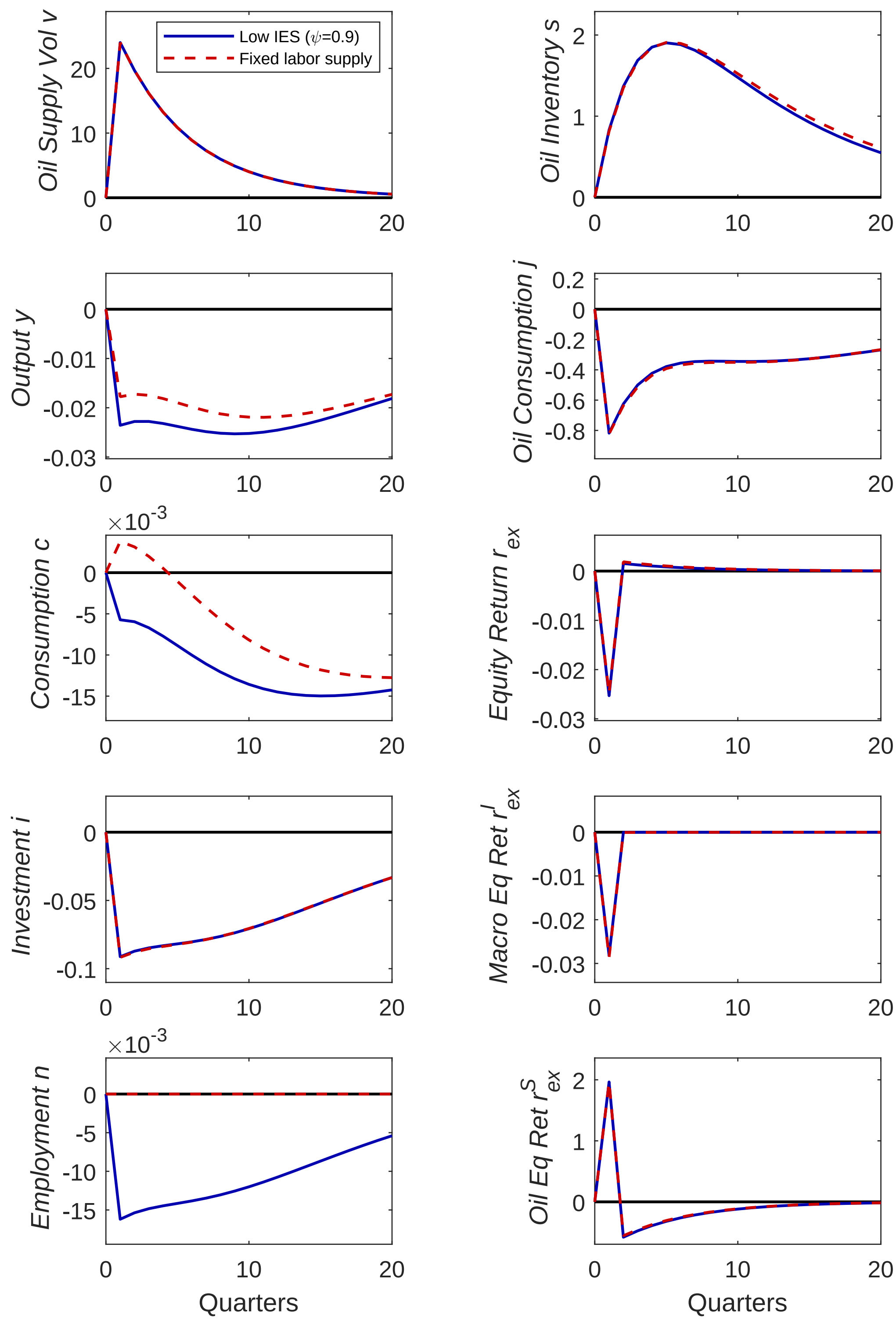
The figure shows model-based impulse response functions for a negative one-standard-deviation shock to the oil production rate κ_t. The blue solid lines and the right axis stand for the baseline model, the red dashed lines and the left axis for the amplified model. Changes are in percent.

Figure A.10: **Model-Based Impulse Responses to Macro Uncertainty Shocks**



The figure shows model-based impulse response functions for a positive one-standard-deviation shock to macroeconomic volatility w_t in the baseline model. The red dashed lines stand for the case of a negative correlation between macro uncertainty shocks and TFP shocks, $\text{corr}(\varepsilon^w_t, \varepsilon^A_t) = -0.35$, the blue solid lines for the case of zero correlation. Changes are in percent.

Figure A.11: **Model-Based Impulse Responses to Oil Uncertainty Shocks: Robustness**



The figure shows model-based impulse response functions for a positive one-standard-deviation shock to oil production volatility v_t for two alternative calibrations. The blue solid lines stand for a calibration with an IES ψ of 0.9, the red dashed lines stand for a model variant with fixed labor supply, $n_t = \bar{n}$. Changes are in percent.

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