Fracking, Drilling, and Asset Pricing: Estimating the Economic Benefits of the Shale Revolution*

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August 17, 2016

Abstract

We quantify the effect of a significant technological innovation, shale oil development, on asset prices. Using stock price changes on major news announcement days allows us to link aggregate stock price changes to shale technology innovations. We exploit cross-sectional variation in industry portfolio returns on days of major shale oil-related news announcements to construct a shale mimicking portfolio. This portfolio can help explain aggregate stock market fluctuations, but only during the time period of shale oil development. Based on the estimated effect of this mimicking portfolio on aggregate stock market returns, we find that $2.5 trillion of the increase in aggregate U.S. equity market capitalization since 2012 can be attributed to shale oil. We also find that 22.2% of private sector job growth since 2012 is linked with the development of shale oil technology.

*We thank Ing-Haw Cheng, John Cochrane, Thomas Covert, Stefano Giglio, Wayne Ferson, Michael Johannes, Marcin Kacperczyk, Ryan Kellogg, Christopher Knittel, Leonid Kogan, Owen Lamont, Luboš Pastor, Dimitris Papanikolaoau, Lasse Pedersen, Amit Seru, Andrei Shleifer, Amir Sufi, Pietro Veronesi, Ivo Welch, Mungo Wilson, Wei Xiong, Harold Zhang, and audiences at the AFA 2016 meeting, ESSFM Gerzensee, NBER (Asset Pricing and Commodity Markets meetings), Oklahoma Energy Finance Conference, Aalto University, Cass Business School, Chicago Booth, Copenhagen Business School, Goethe University Frankfurt, Norwegian School of Management, Oxford (Said), University of Rochester, and Vienna University for valuable comments. Funding from the Jacobs Levy Equity Management Center for Quantitative Financial Research at Wharton is gratefully acknowledged.

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1 Introduction

Technological innovations play a central role in many theoretical models of asset pricing. However, standard empirical measures of technology shocks (e.g., Solow residuals) do not appear to be large enough to explain observed movements in asset prices.[1] We provide a new approach to empirically measure innovations in technology. We apply this approach to a sequence of shocks occurring in a particular industry with profound aggregate implications: oil. Technological innovations in shale oil development from 2012 to 2014 led to a near doubling of oil production in the U.S. and a dramatic decline in global oil prices. We find that our measure of these shale oil technology shocks explains a significant component of cross-sectional and time series variation in both asset prices and employment growth during this time period. [2]

Measuring the effect of a given technological innovation is empirically challenging. Typically, such innovations are difficult to observe, making it hard to trace out their impact on stock prices or real economic outcomes. A particular technological development can have diverging (often opposite) effects on different sectors of the economy. Our empirical framework uses the entire cross section of stock returns to extract innovations to latent state variables not directly observable by the econometrician. We rely on the idea that the *arrival* of relevant public news announcements is observable.[3] Using the stock market reaction to the news allows us to estimate the exposures of various assets to the underlying unobservable shocks. We use key events related to shale oil development to undertake three empirical exercises

[1] Much of the debate in empirical asset pricing centers on the relative role of news about future cash flows in explaining variation in aggregate asset prices, as opposed to news about discount rates. See, e.g. Bansal and Yaron (2004), Campbell and Vuolteenaho (2004), Hansen, Heaton and Li (2008), Cochrane (2011), Bansal, Kiku, Shaliastovich and Yaron (2014), Greenwood and Shleifer (2014), Albuquerque, Eichenbaum and Rebelo (2015), Baker, Bloom and Davis (2015), Greenwald, Lettau and Ludvigson (2014), and Campbell, Giglio, Polk and Turley (2016), for a wide range of views on the relative roles of shocks to technology, preferences, expectations, uncertainty/volatility, etc.

[2] Our work fits into a large literature attempting to quantify the economic impact of oil shocks, e.g. Hamilton (1983), Sadorsky (1999), Hamilton (2003), Barsky and Kilian (2004), Blanchard and Gali (2007), Dvir and Rogoff (2009), Kilian (2009), Kilian and Park (2009), Hamilton (2009), Bodenstein, Guerrieri and Kilian (2012), and numerous others. Recently, Hausman and Kellogg (2015) estimated the benefits of the shale *gas* revolution by focusing on the demand elasticities of separate groups of consumers.

[3] Our approach to empirically identifying the economic effect of technological innovations is closely related - and complementary - to recent work by Kogan, Papanikolaou, Seru and Stoffman (2012) linking news on patented technologies to equity returns.

designed to measure the effect of shale oil technological innovations on the economy.[4]

We first test whether an industry's exposure to shale technology development is linked with its stock price performance. To identify an industry's exposure to shale oil we measure how stock prices change in response to the disclosure of a major new shale oil discovery in the summer of 2013. This discovery is the largest shale oil discovery announced to date, representing a 35% increase in expected recoverable oil reserves from the second largest oil field in the world. We trace out how different industries are affected by examining the cross-section of industry returns on this day. We find that there is significant dispersion, and that an industry's announcement return is linked with its stock performance during the shale oil time period. Specifically, a one standard deviation increase in an industry's shale discovery announcement return leads to a 3.6% higher average annual return relative to the average industry. This relationship only exists during the time period of shale oil development (from January 2012 to March 2015), and not during earlier time periods.

In our second empirical exercise we estimate the total contribution of shale oil technology to the aggregate U.S. stock market over time, by constructing a shale mimicking portfolio based on the exposures of different industries to the shale discovery shock. The shale discovery announcement exposures can then be used to construct a factor-mimicking portfolio that tracks the unobservable innovations in shale technology over time - an intuition that goes back to Fama (1976).[5] We use this shale-mimicking portfolio to identify the component of aggregate market fluctuations that can be attributed to shale technology shocks. Firms with high announcement returns receive a greater weight in this portfolio; firms with lower returns receive less weight. The intuition behind this empirical design is that there is no single asset we can use to cleanly measure innovations in shale development. However, the mimicking portfolio weights that are constructed using the slopes of the cross-sectional regressions allow us to synthetically create such an asset, building on the classic approach of

[4]Our approach is related to several strands of asset pricing literature that focus on dates with significant public announcements. Lamont and Frazzini (2007) and Savor and Wilson (2015) focus on corporate earnings; others, such as Jones, Lamont and Lumsdaine (1998), Gürkaynak, Sack and Swanson (2005), and Savor and Wilson (2013) focus on releases of macroeconomic news; a large literature studies Federal Reserve monetary policy announcement days, e.g. Bernanke and Kuttner (2005), Savor and Wilson (2014), and Lucca and Moench (2015).

[5]The approach of using asset price fluctuations to track the empirical dynamics of a hard-to-measure underlying economic variable is related to the economic tracking portfolios of Lamont (2001).

Fama and MacBeth (1973). These weights are based on responses of industries' stock returns to an exogenous unexpected positive innovation in shale oil technology. We use this portfolio as an asset-price proxy for the value of shale oil development, and assess the explanatory power of this portfolio for market returns over different time periods.

We find that exposure to the shale mimicking portfolio has strong explanatory power for aggregate stock market returns from 2012 to Q1 2015 period. In total, shale oil development is responsible for $2.5 trillion of the increase in stock market value during this time period. Our shale exposure proxy has no explanatory power in earlier time periods when shale oil production was virtually nonexistent. In addition, it captures the bulk of the variation in returns on an index of firms most directly involved in shale oil extraction, which helps to validate our approach.

Finally, we assess whether the economic impact from shale oil that we measure from asset prices translates into meaningful effects on the real economy. To do this, we estimate whether the cross-section of shale discovery announcement day returns contains information about changes in industry employment. We show that the shale discovery announcement returns have significant explanatory power for the cross-section of employment growth rates of U.S. industries, indicating that the effect we identify operates through real economic channels. In aggregate, we estimate that during the shale oil period 22.2% of the private sector job growth in the industries in our study is due to the development of shale oil technology.

What are the channels through which shale oil technology could affect the U.S. economy? Industries' sensitivity to shale news can arise through several types of "spillovers." To the extent that an increase in fracking/drilling activity increases demand for output of (imperfectly competitive) industries that provide labor or materials for shale oil extraction, the positive news about shale sector productivity is good news for these industries - we refer to this as the "supply-chain effect."[6] To the extent that increasing income of households involved in the shale oil production, directly or indirectly, improves the health of the local economies, it might benefit consumer-oriented industries that experience increasing demand for their

[6]To the extent that shale oil development puts upward pressure on the prices of relatively less traded factors, such as labor, there might be a countervailing negative spillover effect on local firms akin to the "Dutch disease." This effect is less apparent at the country-wide industry level. Using detailed data on manufacturing establishments in the U.S., Allcott and Keniston (2014) also find that the positive supply chain and income effects dominate.

goods - we can refer to this as the "income effect."[7] Finally, to the extent that good news about shale oil supply can depress oil prices, it may benefit a variety of industries whose output consists of goods that are complements with oil (e.g. cars) or whose expenditure shares increase through the effect on the consumers' budget constraints - this can be called the "price effect." Additionally, a positive shock to shale oil technology that lowers oil prices can have an adverse effect on industries that supply substitute energy sources, such as coal.[8]

We find empirical support for each of the channels described above, based on the different weights industries receive in the mimicking portfolio that we construct. For example, Oil and Gas Drilling, Business Services, Engineering Services, and Railroads receive among the highest weights in the mimicking portfolio. All of these industries are important components in the supply chain of shale oil development. Clothes also receives a high weight, which is consistent with both an "income effect" and a "price effect." We observe that Coal Mining has the greatest negative weight in the portfolio, which is consistent with a product market rival effect driven by being a potential substitute energy source. Lastly, the impact of shale oil technology on job growth is consistent with both the "supply-chain" and "income" channels, as the employment effect we identify is concentrated in the "shale oil states" (Texas, North Dakota, Oklahoma, Colorado, and New Mexico). The advantage of our methodology that uses the entire cross section of (publicly traded) firms is that we are able to estimate the net effect of the several, often countervailing, spillover effects of a technological innovation - a major challenge in the literature (e.g., see Bloom, Schankerman and Van Reenen (2013)).

Importantly, the different channels discussed above suggest that the drop in oil prices since mid 2014 does not necessarily result in a meaningful change in the overall economic magnitudes that we estimate. Instead, it likely means that the relative importance of different channels may change. For example, while "supply chain" and "income" effects may be reduced, the "price" effect may increase. Consistent with the effect of these channels offsetting each other, while oil prices dropped 54.8% from their high in mid-2014 to the end of the first

[7]Acemoglu, Finkelstein and Notowidigdo (2013) use oil reserves in the pre-shale oil period to capture shocks to local incomes. Gilje (2011) documents the impact of windfall shale oil revenues on the local economies, while Cascio and Narayan (2015) focus on the increase in wages of low skilled workers and its consequences for educational attainment.

[8]The "price effect" is quite distinct from the others in that its magnitude can be affected by non-shale oil supply shocks. We control for such shocks in our regressions using a second mimicking portfolio based on an OPEC-driven oil supply shock.

quarter of 2015, the level of the shale mimicking portfolio we construct remained high (despite the decline in the equity market capitalizations of the shale oil firms).[9]

A potential concern with our methodology is that while the discovery announcement we use to derive our portfolio weights can be considered exogenous, there may have been other reasons why stock prices changed on the key shale discovery announcement date we use in our empirical design. For example, if the overall market increased for other, non-shale-oil-related, reasons, we may just be picking up the effect of high market beta as opposed to high shale exposure. We control directly for the effect of aggregate stock market beta in our main regression. However, since betas are measured with error, such controls might be imperfect. Therefore, we conduct several additional tests that demonstrate the robustness of our approach. First, we ask how likely is it that a randomly picked day would yield a cross-section of industry returns that can be successfully used to construct a factor that explains the time-series variation in both the aggregate market return (especially over the shale oil period) and the returns on shale oil firms. We find that the shale discovery announcement day is in the 99.8 percentile of such days in our sample. Second, we conduct a falsification test that uses European stock market index returns instead of the U.S.. We show that the shale mimicking portfolio has no explanatory power for the European stock market, despite its substantial covariation with the U.S. equity returns. Third, instead of using the shale discovery announcement day to construct the shale mimicking portfolio, we focus on industries that are known to be part of the shale oil production chain. While this rules out some of the channels through which shale might impact various sectors of the economy, this narrower exercise still allows us to recover the underlying shale shocks and provide similar estimates of the magnitude of their contribution to the total stock market value. Taken together, this evidence sets a high bar for alternative explanations of our results.

Nevertheless, we control for another candidate driver of aggregate stock market returns over this period, namely monetary policy. We adopt our methodology of constructing a portfolio that tracks underlying unobserved shocks by analyzing the cross-section of stock returns on the days of key announcements by the U.S. Federal Reserve (e.g., as in Savor

[9] Consistent with the economic effect we identify, shale oil investment has continued, and production has dropped by only 8.2% from its peak.

and Wilson (2014)). We focus either on all scheduled FOMC meeting or on unconventional monetary policy announcements. We show that such portfolios track very closely the returns on a portfolio constructed using market betas. However, while monetary policy helps explain the stock market run-up following the global financial crisis in 2009, such monetary policy mimicking portfolios do not help explain its average returns over the recent time period, and thus do not take any explanatory power away from the shale mimicking portfolio. This exercise highlights the general applicability of our empirical methodology, as well as the robustness of our conclusions.

This paper proceeds as follows. We describe the data, the general economic setting, and our empirical approach in Section 2.Section 3 details our econometric approach and presents the results of our empirical analysis. Section 4 presents the set of robustness tests. Section 5 concludes.

2 The Setting

2.1 The Shale Revolution: a Primer

Over the five years following the Great Recession (2009 through 2014) the U.S. equity market capitalization roughly doubled, despite fairly anemic rates of growth in the real economy. Over the same time period U.S. oil production increased dramatically, from 5.4 Mb/d (million barrels of oil per day) at year end 2009 to 9.4 Mb/d at year end 2014. This increase accounted for 52.2% of overall global oil production growth. Almost all of this increase can be attributed to a breakthrough technological innovation that allows oil to be extracted from shale rock formations that were previously too costly to access. This innovation, which involves a combination of two previously known technologies, hydraulic fracturing ("fracking") and horizontal drilling, in the matter of a few years has fundamentally changed the global energy supply-demand balance. Its success was also largely unexpected, as evidenced by the published forecasts of the Energy Information agency (EIA).

Shale oil and natural gas reserves were long thought to be uneconomic to develop. For example, as recently as the late 1990s only 1% of U.S. natural gas production came from shale. Then in the early 2000s Mitchell Energy began experimenting with new techniques for drilling shale, and found that by combining horizontal drilling with hydraulic fracturing, natural gas from shale could be economically produced. The unlocking of shale has led to a dramatic increase in production of natural gas, which ultimately led to lower prices of natural gas in the U.S. and, consequently, electricity. With low natural gas prices and high oil prices in 2009, firms began to experiment with using shale technology to extract oil, as oil and gas are often trapped in similar geologic formations. Figure 1 displays the recent trends in oil production. Several firms were successful in adopting shale technology in oil basins, including the Permian, the Bakken, and the Eagle Ford shale. As Panel A shows, with the adoption of shale technology production in these basins has increased significantly.

There are three features of the shale oil boom that make it especially interesting from an asset pricing perspective. The first is that the rise in production was unexpected, and can therefore be interpreted as a true "Technology Shock". Panel B of Figure 1 shows U.S. crude oil production from 2005 to 2014, along with monthly forecasts of future oil production from the EIA's monthly publication of Short Term Energy Outlook. Consistent with Panel A, starting in 2012 U.S. Crude Production rises dramatically. This rise in production was unanticipated by forecasts, which consistently undershoot production for the first year of the Shale Boom, before adjusting towards the end of the period.

The second important feature of the boom is its magnitude. While clearly increased productivity is a benefit for shale oil producers, its importance for the rest of the economy hinges on the fact that this production increase is significant relative to total world supply. Panel C of Figure 1 illustrates that the increase in U.S. oil production driven by shale deposits amounts to roughly 5% of total world oil production, and 52.2% of the increase in production since 2009. While this may not seem large, given the highly inelastic nature of oil demand it has a potential to have a large long-run impact on price levels. Typical estimates of long-run demand elasticity (see for instance Kilian and Murphy (2014)) are near -0.25, suggesting that a 5% increase in world supply may yield up to a 20% drop in price. Prices begin to drop towards the end of our sample period. Without U.S. oil production increases, it is very likely that the recent reductions in Middle East supply would have translated into significantly higher prices than those observed.

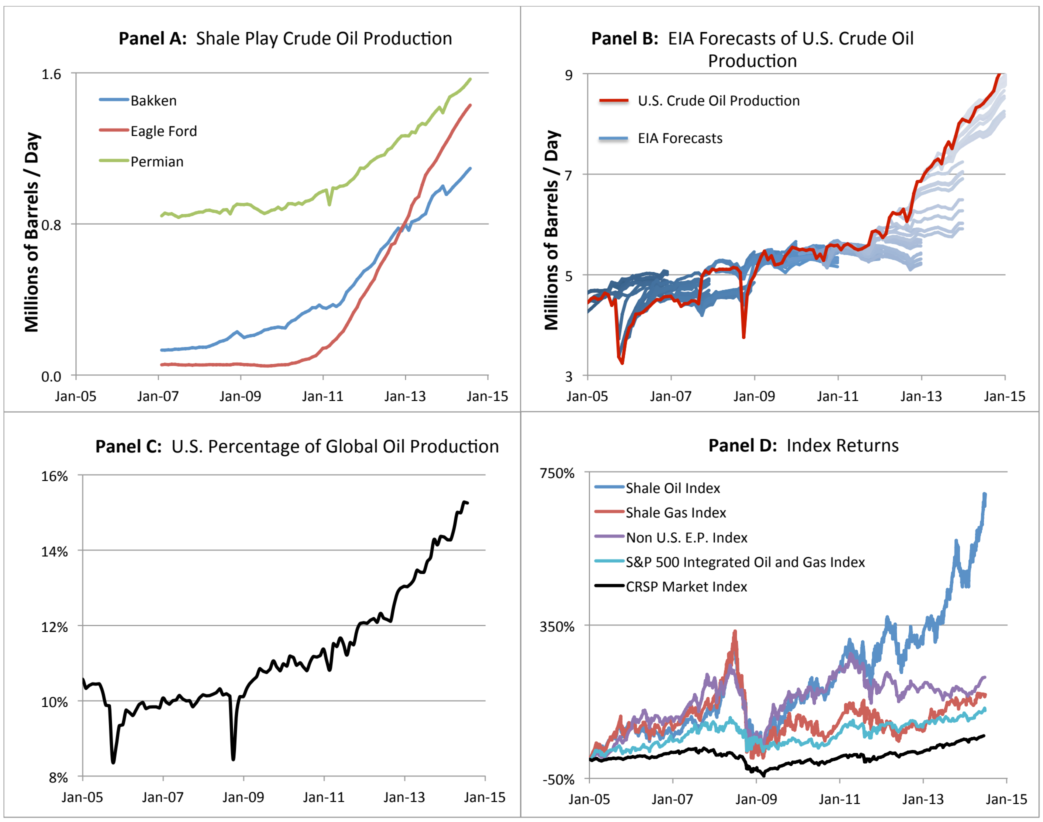
The final feature that makes this shock somewhat unique is that it originated in a small number of easily identifiable firms which we designate as the "Shale Oil Index." These are firms with a significant amount of production derived from shale oil. Panel D illustrates the cumulative returns of this "Shale Oil Index" to several stock price indices. The returns to the Shale Oil Index are plotted with several other energy producer stock indices. The first is the"Shale Gas Index", described in Section 2.2, the second is a "Non U.S. E&P Index", which consists of E&P firms outside of the United States. The third is an index of the four large integrated oil and gas producers on the S&P 500. The cumulative returns to the aggregate CRSP market index are also included for comparison. As Panel D shows, the shale oil firms exhibit no abnormal returns relative to other industry producers prior to the sharp rise in production. However, following that rise, they experience a period of extraordinary growth, rising roughly 200% in a two year time. These stock returns are useful for understanding when asset prices began reflecting shale oil expectations. However, using a "Shale Oil Index" to precisely measure aggregate stock market effects is problematic, as discount rate shocks, as well as aggregate productivity, demand, and other shocks likely affect both the Shale Oil Index and aggregate stock prices. For this reason, we focus our identification using asset price changes around important news announcements relevant to shale.

2.2 Data

Data for this project come from several sources. All data for oil production and forecasts are from the Energy Information Assocation (EIA). WTI futures returns are constructed using data from Bloomberg. Stock market data is from CRSP and Datastream (details of industry portfolio construction are in the appendix). We use NAICS code descriptions to construct industry portfolios of all CRSP stocks.[10] We treat stocks of oil and gas producing companies differently, using the S&P Integrated Oil and Gas Index as our non-shale oil industry portfolio, the Shale Oil Index and the Shale Gas Index described in Appendix 4, while all the other oil producers not included in these indices populate the "Other Oil" portfolio.

[10]Alternatively, one could use the standard Fama-French industries available from Ken French's website. We construct our own industries in order to generate greater variation in exposure to oil.

Figure 1: U.S. Oil Production and Stock Returns



2.3 Identification Approach: Shale News and Stock Returns

A simple toy model of oil production and demand presented in Appendix 1 shows that asset prices contain information about the technological shocks affecting oil production (as well as demand). It is challenging control for oil price innovations and, more generally for other shocks that simultaneously drive returns to both shale oil firms and other firms in the economy, such as changing discount rates (e.g. through time varying aggregate uncertainty or preference shocks).

Our approach to overcoming this challenge involves using stock returns around news announcements pertaining to oil supply, specifically shale-oil and non-shale oil. The idea behind this identification strategy is that news announcements that are specific to shale, and oil more broadly, are plausibly exogenous to other aspects of the macroeconomy, and in particular to discount rates. Analysis presented in Appendix 5 shows that even for a small number of days that contain earnings announcements for the two main firms in our Shale Oil Index, unexpected positive earnings news for shale producers leads to significant abnormal stock returns for shale firms, which in turn have a significant positive effect on aggregate market returns. Specifically, for a 1% increase in the stock price of an index of shale firms, there is a 0.19% increase in the aggregate market on these days, after instrumenting for the shale returns with revenue surprises of the main shale oil firms.

The time series of revenue surprises and market returns suggest a link between shale discoveries and the stock market. However, the number of announcements is too small to construct a reliable measure of the time-series of innovation. Instead we exploit heterogeneity in industry exposures to shale innovations to quantify the impact of shale production on the stock market. We consider the cross-section of industry returns around a major shale announcement and a significant OPEC announcement and examine the performance of this cross-section over various time periods related to shale production.

2.4 Shale and OPEC Announcements

Hydraulic fracturing and horizontal drilling provide the basic building blocks for shale development. However, companies need to apply this technology and then calibrate these techniques to particular oil and gas reservoirs (e.g., see Covert (2014)). Often it is the case that the economics of shale in a given reservoir are unknown. Therefore when successful shale efforts are announced, significant asset revaluations occur. In many cases, a single positive well result for a reservoir can indicate the potential for hundreds of follow-on wells, which can have billions of dollars of NPV for a given company. The announcements of these positive well results represent a unique opportunity to assess how other-non-shale industries respond to unexpected announcements of significant improvements in shale supply.

The largest of these announcements in the sample is the announcement of Pioneer Natural Resources DL Hutt C #1H well in the Wolfcamp A reservoir. On July 31, 2013 after market close, Pioneer Natural Resources announced the successful test of the DL Hutt C #1H, which began production at 1,712 Barrels of Oil Equivalent per Day (BOEPD) of natural gas and crude oil, with 72% crude oil content. This was the first successful well test of the Wolfcamp A, and represented a significant improvement of shale potential across the entire Spaberry/Wolfcamp field, the world's second largest behind only the Ghawar Field in Saudi Arabia. Pioneer's stock price increased 12.2% on this announcement, adding $2.7 Billion to the firm's enterprise value. We use the industry portfolio return on this single announcement day as a proxy for industry's exposure to increases in shale productivity.

One concern regarding our methodology is that the "price effect" channel we identify is quite distinct from the others in that its magnitude can be affected by non-shale oil supply shocks, in the direction that is opposite of the supply-chain and income effects.

It is therefore important to ensure that our measure does not pick up industries' sensitivities to such price effects that are coming from other sources of oil supply. In fact, the data provides the perfect event for identifying the impact of non-shale supply shocks on oil prices. On November 28, 2014, the OPEC released the outcome of 166th Meeting of the OPEC Conference in Vienna that occurred on the preceding day. The key result of the meeting was the decision that member countries would not cut their oil supply in response to increased supply from non-OPEC sources and falling prices. On the announcement day oil prices dropped by over 10%, and the shale index fell by roughly 8%, while the aggregate U.S. market return was essentially zero. Abnormal return on this announcement gives us a measure of exposure to an exogenous supply shock to oil prices, unrelated to technological innovation in the shale sector. Indeed, just like for the shale announcement, these returns vary dramatically across industries.

3 Empirical evidence

3.1 Evidence from the Cross-section of Realized Stock Returns

In order to estimate the impact of shale (and oil) news on the cross section of industries we run standard Fama-MacBeth regressions of weekly excess returns of the industry portfolios on characteristics, where the latter include the shale announcement return and the OPEC announcement return of each industry. The announcement returns are standardized to have the standard deviation equal to one. We also control for the lagged market betas of each of the industries estimated before and during the financial crisis, when we would expect shale to have a minimal impact on market returns. We do not control for contemporaneous betas as those may be endogenous to the shale shock, as industries' relative importance in the market portfolio changes.

Table 1 presents the results of these regressions across four subperiods: Pre-Crisis (01/2003 - 07/2008), Crisis (07/2008 - 06/2009), Post-Crisis (06/2009 - 12/2011), and the Shale Oil Period (01/2012 - 03/2015). Panel A presents the results using the full cross-section of industries, where as in Panel B the three key industries related to oil and gas (Shale Oil, Shale Gas, S&P Integrated producers) are excluded. Thus, all of the cross-sectional slope coefficients are averaged over subperiods in order to understand the role of oil shock sensitivities on industry returns during the period when shale oil was – and was not – a major source of innovation.

The first result is that oil shocks are an important driver of stock returns. The effect identified through the OPEC announcement return is strongly statistically significantly negative during the pre-crisis period of rising oil prices. The average Fama-MacBeth slope coefficient of -0.155 suggests that a one standard deviation increase in an industry's sensitivity to the OPEC shock translates into a 15.5 basis point per week (or, about 8 percent per year) lower return on average over this period than an average industry. During both the crisis and the post-crisis periods the coefficient is not statistically significant, as both oil prices and stock returns fall dramatically during the crisis and then recover. Finally, during the shale period the OPEC announcement coefficient is strongly and significantly positive at 0.131 (or 0.148 if oil firms are excluded). This is a clear manifestation of the fact that the falling oil prices during this period (both due to shale and the OPEC announcement, as well as other supply shocks and possible non-U.S. demand shocks) have lifted stock prices of firms that most benefit from low oil prices - the same firms whose valuations suffered during the period of rising oil costs before the crisis.

What is the role of shale? Unlike the OPEC announcement, the shale announcement sensitivity is a significant (and positive) driver of returns only during the last period, when shale production became a significant economic force. When the shale announcement return is the only characteristic its effect is marginally significant, with a coefficient of 0.048, in the full sample, but strongly significant, with a coefficient of 0.098, when the shale oil, shale gas, and integrated oil and gas sectors are excluded. This suggests that the decline in oil prices driven by forces outside of the U.S. (e.g., global demand or OPEC supply) depressed valuations of U.S. shale and non-shale oil firms to a substantial degree. Indeed, when we control for the OPEC announcement return the shale coefficient becomes strongly significant in both sample, with the similar magnitudes (0.71 and 0.08). Controlling for the OPEC sensitivity raises the shale slope because it allows us to disentangle two opposing effects oil prices have on U.S. firms, in their relation to the shale industry. While the "supply chain," "income," and "price" effects may all be positive for shale, only the direct "price effect" is positive for the OPEC shock, since it lowers oil prices without helping U.S. production. In fact the effect is negative for the firms that benefit from shale for non-price reasons, since it hurts U.S. shale oil production and therefore limits the extent of positive spillovers.

Overall, the effect of a one standard deviation increase in its sensitivity to the shale oil discovery announcement increases an industry stock return over the shale period by about 3 to 4 percent per annum, but has no statistically discernible effect on stock returns in any other time period. Controlling for the pre-crisis and crisis period stock market betas does not have any effect, suggesting that the shale announcement return is not picking up industries with (persistently) high (and low) market betas. Note that average returns over the short subsamples that drive the Fama-MacBeth coefficients we estimate need not represent *expected* returns. The effect of shale is likely driven by a series of positive surprises - technological shocks that have a first order effect on current and future cash flows of a range of industries but may or may not change their exposure to systematic risk and expected returns.

3.2 Constructing the Oil Factor Portfolios

The key question we want to ask is what is the contribution of the shale technology shock to the variation in equity market returns over the shale oil period. Consider an economy that is subject to three types of shocks: aggregate productivity (or demand) shocks a_t, shale oil shocks z_t^{Shale}, and other shocks to oil supply, z_t^{Other}. Then the (log-linearized) returns to the aggregate equity market can be written as a sum of innovations weighted by appropriate loadings:

$$r_{t+1}^{Mkt} = E_t\left(r_{t+1}^{Mkt}\right) + \beta_a^{Mkt}\left(E_{t+1} - E_t\right)a_{t+1} + \beta_{Shale}^{Mkt}\left(E_{t+1} - E_t\right)z_{t+1}^{Shale} + \beta_{Other}^{Mkt}\left(E_{t+1} - E_t\right)z_{t+1}^{Other}$$

The toy model described in Appendix 1 presents an example of such an economy and derives this representation. We are interested in estimating the exposure of the aggregate stock market to the shale shock, β_{Shale}^{Mkt}, in particular.

While the previous analysis relies primarily on the cross-sectional variation in average returns on industries across time periods, the same identification strategy can be used to extract information about the time-series behavior of returns within each of the subsamples, and therefore shed additional light on the nature of the oil shocks that we recover. This information is contained in the time-series of the cross-sectional slopes of the Fama-MacBeth regressions. It is well known (going back to Fama (1976)) that the coefficients of the individual cross-sectional regressions of returns on characteristics can be interpreted as portfolio returns, since these slopes are given by

$$\boldsymbol{\lambda}_t = W_t' R_{t+1}^x,$$

where R_{t+1}^x is the vector of excess returns on the test assets and the matrix of portfolio weights is given by

$$W_t = X_t\left(X_t' X_t\right)^{-1}$$

Table 1: Fama-Macbeth Regression of Industry Returns on Announcement Day Return

Panel A: All Industries

	Pre-Crisis (01/2003 - 07/2008)			Crisis (07/2008 - 06/2009)			Post-Crisis (06/2009 - 01/2012)			Shale Oil Period (01/2012 - 03/2015)		
OPEC Announc. Ret.	-0.155***		-0.167***	0.140		0.124	-0.002		-0.005	0.124***		0.138***
	(0.056)		(0.055)	(0.292)		(0.300)	(0.067)		(0.063)	(0.045)		(0.044)
Shale Discovery Ret.		0.001	-0.025		-0.044	-0.011		0.029	0.032		0.058**	0.079***
		(0.018)	(0.020)		(0.094)	(0.100)		(0.028)	(0.028)		(0.026)	(0.027)
Pre-Crisis Beta			0.060			-0.066			0.009			-0.020
			(0.042)			(0.138)			(0.050)			(0.034)
Crisis Beta			-0.004			-0.071			-0.022			-0.000
			(0.029)			(0.335)			(0.067)			(0.032)
Constant	0.262**	0.320**	0.071	-0.356	-0.343	0.120	0.375	0.330	0.354**	0.375***	0.237*	0.338***
	(0.122)	(0.124)	(0.088)	(0.843)	(0.816)	(0.558)	(0.266)	(0.268)	(0.145)	(0.139)	(0.137)	(0.121)
Observations	21,804	21,804	21,804	3,634	3,634	3,634	9,956	9,956	9,956	12,388	12,388	12,388
Number of Weeks	276	276	276	46	46	46	131	131	131	163	163	163

Panel B: All Industries Excluding Shale Oil, Shale Gas, and S&P Integrated Oil and Gas

	Pre-Crisis (01/2003 - 07/2008)			Crisis (07/2008 - 06/2009)			Post-Crisis (06/2009 - 01/2012)			Shale Oil Period (01/2012 - 03/2015)		
OPEC Announc. Ret.	-0.156***		-0.160***	0.137		0.123	0.003		-0.008	0.140***		0.133***
	(0.055)		(0.052)	(0.288)		(0.276)	(0.069)		(0.061)	(0.046)		(0.043)
Shale Discovery Ret.		-0.067**	-0.049*		0.003	-0.001		0.037	0.039		0.113***	0.093***
		(0.033)	(0.027)		(0.184)	(0.148)		(0.041)	(0.037)		(0.033)	(0.032)
Pre-Crisis Beta			0.069			-0.073			0.004			-0.028
			(0.042)			(0.146)			(0.049)			(0.033)
Crisis Beta			-0.014			-0.062			-0.016			0.009
			(0.030)			(0.341)			(0.067)			(0.033)
Constant	0.261**	0.406***	0.100	-0.357	-0.401	0.106	0.376	0.321	0.346**	0.377***	0.169	0.322***
	(0.122)	(0.130)	(0.090)	(0.844)	(0.887)	(0.562)	(0.266)	(0.280)	(0.143)	(0.139)	(0.145)	(0.119)
Observations	20,976	20,976	20,976	3,496	3,496	3,496	9,956	9,956	9,956	12,388	12,388	12,388
Number of groups	276	276	276	46	46	46	131	131	131	163	163	163

Fama-Macbeth Standard errors in parentheses

This table shows results from Fama-Macbeth Regressions on the cross-section of 79 weekly industry returns over different subsamples. The explanatory variables are the industry return on the Shale Discovery Day (8/01/2013), the Opec Announcement Day (11/28/2014), as well as market betas calculated for both the pre-crisis and crisis periods. In Panel A all 79 industries are used, while in Panel B, three oil specific industries are excluded (Shale Gas, Shale Oil, and S&P Integrated Oil & Gas Producers). Betas and announcement day returns are adjusted to have unit standard deviation. Returns are weekly.

with matrix X_t containing all of the characteristics on the right-hand side of the Fama-Macbeth regression, with the first column containing ones (for the cross-sectional intercept). Since $W_t'X_t = I$ the first column of W_t gives weights of a unit investment portfolio and all others correspond to zero investment portfolios that have a weighted average value of one for a given characteristic and zero for all the other characteristics. Back, Kapadia and Ostdiek (2013) refer to these as "characteristic pure play portfolios" since they are maximally diversified in the sense of minimizing the sum of squared weights across test assets, while isolating the effect of a given characteristic on the cross-section of returns by controlling for other characteristics (including betas).

Here, we start by treating the returns of industry portfolios on the shale discovery announcement day (and similarly OPEC announcement day) as the characteristic (that remains constant over time) and use this approach to construct a trading strategy that essentially goes long industries exhibiting a positive response to the shale announcement and short industries with negative return responses. In addition to the shale and OPEC announcement returns, we can use the pre-crisis and crisis market beta estimates as characteristics as well, constructing portfolios that capture the (potential) market rewards for exposure to beta risk. Thus, we are essentially using individual slopes that produce the Fama-MacBeth coefficients reported in the Table 1 above.

3.3 Extracting Shocks: from Cross-Section to Time Series

In order to understand the intuition behind this strategy, it is useful to examine it in the context of our simple model. Consider a cross-section of N industries. Assume that the return innovation to industry $j \in [1, N]$ is given by

$$(E_{t+1} - E_t)\, r_{t+1}^j = \beta_a^j\, (E_{t+1} - E_t)\, a_{t+1} + \beta_{Shale}^j\, (E_{t+1} - E_t)\, z_{t+1}^{Shale} + \beta_{Other}^j\, (E_{t+1} - E_t)\, z_{t+1}^{Other} + \epsilon_{t+1}^j$$

We want to use this cross-section of industries to construct "Characteristic Portfolios" that mimic the structural shocks. To do this we will need measures related to the exposures of industries to each fundamental shock, which is not directly observed. For estimates of exposures to the two oil productivity shocks we focus on the announcement day returns. The first day is August 1, 2013, the first trading day after the Pioneer announcement on July 31, 2013, the largest shale productivity shock in our sample. We assume that the return to industry j on this day is only driven by the shale shock (with tildes indicating innovations):

$$\tilde{r}^j_{ShaleAnn} = \beta^j_{Shale}\tilde{z}^{Shale}_{ShaleAnn}.$$

This is our key identification assumption in the sense that β^j_{Shale} is the primary source of variation in industry returns on that day (i.e., the other shocks - to aggregate non-oil productivity and non-shale oil supply - are small).

The second day is the OPEC announcement on November 28th, 2014. We view this day as clearly having a shock to z^{Other}, but we may also allow that this announcement signaled an increased willingness of OPEC to allow very low prices and may have had separate news about the viability of shale production. This yields

$$\tilde{r}^j_{OPECAnn} = \beta^j_{Shale}\tilde{z}^{Shale}_{OPECAnn} + \beta^j_{Other}\tilde{z}^{Other}_{OPECAnn}.$$

Note that we assume that the idiosyncratic shocks on these days are zero. We do this because the fundamental shocks on these days are very large, minimizing the relative importance of idiosyncratic shocks.

We do not impose orthogonality between the shale shock and the OPEC announcement return ($\tilde{z}^{Shale}_{OPECAnn} = 0$), although we assume that the other shocks are absent on the OPEC announcement day. In fact we can expect the innovation in $z^{Shale}_{OPECAnn}$ to be negative, as it creates positive correlation between the Shale and OPEC announcement day characteristic portfolios consistent with the data. Intuitively, the impact of the OPEC decision on the industries that benefit from shale through the supply chain and local spill-overs is negative since the sustained OPEC supply and falling prices were expected to reduce the viability of shale production. This explains the fact that the total stock market return on the OPEC announcement day is essentially zero, despite the fact that a number of industries clearly benefit from lower oil prices.

We then assume that the industry-specific shocks ϵ^j_{t+1} are idiosyncratic, or at least uncorrelated with the shocks to aggregate productivity and oil productivity, or equivalently that market beta of an industry is completely captured by the three fundamental shocks:

$$\beta^j_{Mkt} = \frac{\beta^j_a \beta^{Mkt}_a \sigma^2_a + \beta^j_{Shale} \beta^{Mkt}_{Shale} \sigma^2_{Shale} + \beta^j_{Other} \beta^{Mkt}_{Other} \sigma^2_{Other}}{\sigma^2_{Mkt}} \tag{1}$$

If we focus on a period prior to the shale revolution, where would expect the shale volatility to be zero, this simplifies to

$$\beta^j_{Mkt,PreShale} = \frac{\beta^j_a \beta^{Mkt}_a \sigma^2_a + \beta^j_{Other} \beta^{Mkt}_{Other} \sigma^2_{Other}}{\sigma^2_{Mkt}}$$

Now consider the standard Fama-Macbeth cross-sectional regression of industry returns on our three characteristic variables, $r^j_{ShaleAnn}$, $r^j_{OPECAnn}$, and $\hat{\beta}^j_{Mkt,Preshale}$. The slope of the regression in each period is $(X'X)^{-1} X'\bar{r}_t$, where $X = [\iota, \bar{r}_{ShaleAnn}, \bar{r}_{OPECAnn}, \bar{\beta}_{Mkt,Preshale}]$ is an $N \times 4$ matrix. The slope coefficient for each of the three characteristic variables at time t can be equivalently considered as the return on a portfolio where the portfolio weights are the corresponding column entries of $(X'X)^{-1} X'$. These portfolios are the maximally diversified zero investment portfolios which have a loading of one on the characteristic considered and a loading of zero on all other characteristics. Let $W = [\bar{w}_1, \bar{w}_{ShaleAnn}, \bar{w}_{OPECAnn}, \bar{w}_{MarketBeta}] = (X'X)^{-1} X'$. Thus, the Shale Discovery portfolio has a return of one on the Shale announcement day and return of zero on the OPEC announcement day, while the reverse is true for the OPEC Announcement portfolio. Both of these portfolios are constructed to be orthogonal to the market in the pre-shale period.

Without loss of generality we can normalize the characteristics so that $\tilde{z}^{Shale}_{ShaleAnn} = \tilde{z}^{Other}_{OPECAnn} = \beta^{Mkt}_a = 1$. The returns to the three characteristic portfolios are then given by

$$\begin{aligned}
R^{ShaleAnn}_{t+1} &= E_t\left(R^{ShaleAnn}_{t+1}\right) + \tilde{z}^{Shale}_t + \Gamma^{Other}_{ShaleAnn} \tilde{z}^{Other}_{t+1} + \Gamma^a_{ShaleAnn} \tilde{a}_{t+1} + \bar{w}'_{ShaleAnn} \bar{\epsilon}_{t+1}, \\
R^{OPECAnn}_{t+1} &= E_t\left(R^{OPECAnn}_{t+1}\right) + \tilde{z}^{Other}_{t+1} + \Gamma^a_{OPECAnn} \tilde{a}_{t+1} + \bar{w}'_{OPECAnn} \bar{\epsilon}_{t+1}, \\
R^{MarketBeta}_{t+1} &= E_t\left(R^{MarketBeta}_{t+1}\right) + \Gamma^a_{MarketBeta} \tilde{a}_{t+1} + \bar{w}'_{MarketBeta} \bar{\epsilon}_{t+1},
\end{aligned}$$

where

$$\Gamma^{Other}_{ShaleAnn} = -z^{Shale}_{OPECAnn}$$
$$\Gamma^{a}_{ShaleAnn} = \frac{z^{Shale}_{OPECAnn}\beta^{Other}_{Mkt}\sigma^2_{Other}}{\sigma^2_a}$$
$$\Gamma^{a}_{OPECAnn} = -\frac{\beta^{Other}_{Mkt}\sigma^2_{Other}}{\sigma^2_a}$$
$$\Gamma^{a}_{MarketBeta} = 1 + \frac{(\beta^{Other}_{Mkt})^2\sigma^2_{Other}}{\sigma^2_a}.$$

Details are provided in Appendix 3.

If we assume that the characteristic portfolios are well diversified in the cross-section ($\bar{w}\bar{\epsilon}_t = 0$), we can identify the value β^{Shale}_{Mkt} using a regression of the market return on the three characteristic portfolios. This method essentially takes the characteristic portfolios as the fundamental shocks, and asks how much of the market return can be explained by the shale announcement characteristic portfolio after controlling for the other two portfolios, and since any idiosyncratic error is likely to bias estimates downward through a standard Errors-in-Variables argument, we view this as the conservative approach.

The individual values of the announcement returns and market betas, as well as the resulting portfolio weights are reported in Table 11. We exclude the three oil and gas indices from the portfolio construction, so that we can use the returns on these indices to validate that the shocks constructed using other industries do indeed contain information relative to shale oil. Note that since all of the characteristic pure play portfolios are zero cost, the weights add up to one even though the characteristics do not. In particular, the industries that receive a negative weight in the Shale Discovery portfolio do not necessarily experience a negative return on the day of the Pioneer announcement, but could simply have a weaker than average positive response (since the market return on the day was positive).

The most prominent industries in terms of their announcement return responses and portfolio weights, reported in Table 11, are quite intuitive. Industries that receive the largest positive weights in the Shale Discovery are Oil and Gas Drilling (that act as subcontractors for both shale and non-shale oil producers), Business Services and Engineering Services (that are also heavily involved in shale exploration and production, directly or indirectly). Railroads are also naturally sensitive to shale as the boom in oil production in the areas of the U.S. that are far from the available refining capacity or pipelines saw a dramatic rise in the shipment of oil across the country. The most negative weights such as for Coal and Gold Mining are also intuitive, at least for coal, which is a major substitute for oil in heating, etc. Consumer-oriented industries, such as Clothes, receive positive weights because they have large shale announcement shocks likely due to the importance of gasoline prices in consumer budgets, as corroborated by strong positive OPEC announcement effects of such industries. For industries like Ground Transportation there is also a clear effect of the complementarity with oil. Some industries that have strong shale announcement responses receive relatively low weights in the Shale Discovery mimicking portfolio due to the effect of controls. For example, Passenger Airlines have a well-above average Shale announcement return of 1.9 percent but receive essentially a zero weight in the portfolio because their response to the OPEC announcement is even stronger, 5.64 percent, which is natural given the key role of fuel prices for airline profits. This industry also has a historical market beta well above one, potentially further reducing its weight in the shale portfolio. Note that the OPEC announcement returns line up very closely with the OPEC announcement returns, loading up most on industries that benefit from low oil prices, and going short industries that benefit the most from U.S. domestic oil production, such as Oil and Gas Drilling, Mining Equipment, Oil Pipelines, and Railroads.

3.4 Exploring the Time-series

With our mimicking portfolios, we first construct an index which reflects returns attributable to shale oil innovations by examining the residual returns to the shale discovery portfolio after controlling for the OPEC announcement portfolio and the two market beta portfolios. To verify that the return path of this index is broadly consistent with the timing of shale innovations, we plot the cumulative return of this index along with measures of output and productivity from the three major shale oil plays. Figure 2 plots the time series of this index. As the figure shows, the large rise in the shale index captured in the Fama-Macbeth regressions of Table 1 coincides with the rise of shale oil production. Starting in 2011, shale oil wells began a rapid increase, corresponding with increases in the productivity of individual wells. The number of wells leveled off in late 2012, coinciding with a pause in the rise of the shale index, which then subsequently rose again as productivity and overall output continued to increase. While the monthly nature of the announcements makes direct statistical attribution difficult, the figure provides evidence that the index is broadly consistent with increasing shale oil output.

To provide further validation that our shocks our indeed capturing information related to shale oil and other oil shocks, we examine their correlation with the major oil-related variables that were explicitly excluded from their construction: the oil price and the returns to the three oil and gas indices. These results are reported in Table 2. Panel A shows results from regressing the weekly WTI oil price changes on the OPEC Announcements portfolio, the Shale Discovery portfolio, the two market beta-based portfolio and the aggregate stock market return itself. The OPEC Announcement return is extremely strongly negatively correlated with oil prices, as expected, since it is capturing the returns to firms benefitting from low oil prices and hurt by high oil prices. This result is robust across all time periods, with coefficients between -3 and -5.5 in magnitude. This means that a one percentage point return on the OPEC portfolio corresponds to a three to five percent fall in the oil price. The effects of the total market return variables are not consistent over time and across specifications.

The coefficient of the Shale Discovery portfolio is positive and statistically significant only in the recent shale oil period, with a positive shale return of 1% corresponding to around a 3 percentage point rise in the oil price. This positive coefficient suggests that the Shale Discovery portfolio is primarily driven by industries that benefit from the positive spillovers generated by the shale oil production, more so than by firms benefitting from a potential effect of shale on the oil price. This validates our use of the OPEC announcement as a control for non-U.S. oil supply that drives much of the variation in the oil prices. Indeed, the R^2 of these regressions are between 40 and 60 percent, with most of the explanatory power coming from the OPEC Announcement returns.

Panel B presents results from regressing the S&P Integrated Oil & Gas Index returns on the same variables. The evidence here is similar, as the OPEC Announcement portfolio is picking up the variation in the oil prices, which drive much of the fluctuations in the oil firm returns. The Shale Discovery portfolio is positively correlated with the integrated producers' returns during both the crisis and the shale periods, but not after controlling for the market return, when the effect becomes negative (and marginally significant in the recent period). Panel C presents similar evidence for the Shale Gas index, suggesting that while shale oil and gas might benefit from the same forces that increase global oil prices, there is not particularly strong direct connection between the two.

Finally, Panel D shows the same regressions for the Shale Oil Index. Here the effect of the Shale Discovery portfolio is markedly different, even thought the OPEC announcement effect is very similar to those above. The two shale variables are extremely strongly correlated during the shale period, with coefficients between 2.5 and 4, approximately (the smaller coefficient when controlling for the market return). During the other time periods the correlation is much weaker and not robustly significant, as expected. This suggests that, even though the Shale Discovery portfolio return explicitly does not include any shale oil firms, it loads strongly on industries that benefit from the shale revolution.

3.5 Explaining the Stock Market Performance

Ultimately, we would like to understand the role of the technological innovations in the shale oil sector on the U.S. stock market as a whole. A natural way to do this is via performance attribution, which, in our case, amounts to regressing the market return on the same portfolios we used to correlate with the oil price and oil and gas indices above. Table 3 presents the results.

In Panel A, we regress the market return on only the two announcement day characteristic portfolios. Since the pre-crisis and crisis betas are included in the Fama-Macbeth regressions, the correlation of these two portfolios to the market return is zero by construction in these two periods, as is shown in the first two columns. In the second two columns, this is no longer the case. However, in the post-crisis period we see that the Shale Discovery Portfolio still has very little explanatory power for the market, while the opec portfolio is now very negatively correlated with the market, due to the fact that in this period the aggregate market returns

Figure 2: Cumulative Returns on Mimicking Portfolios

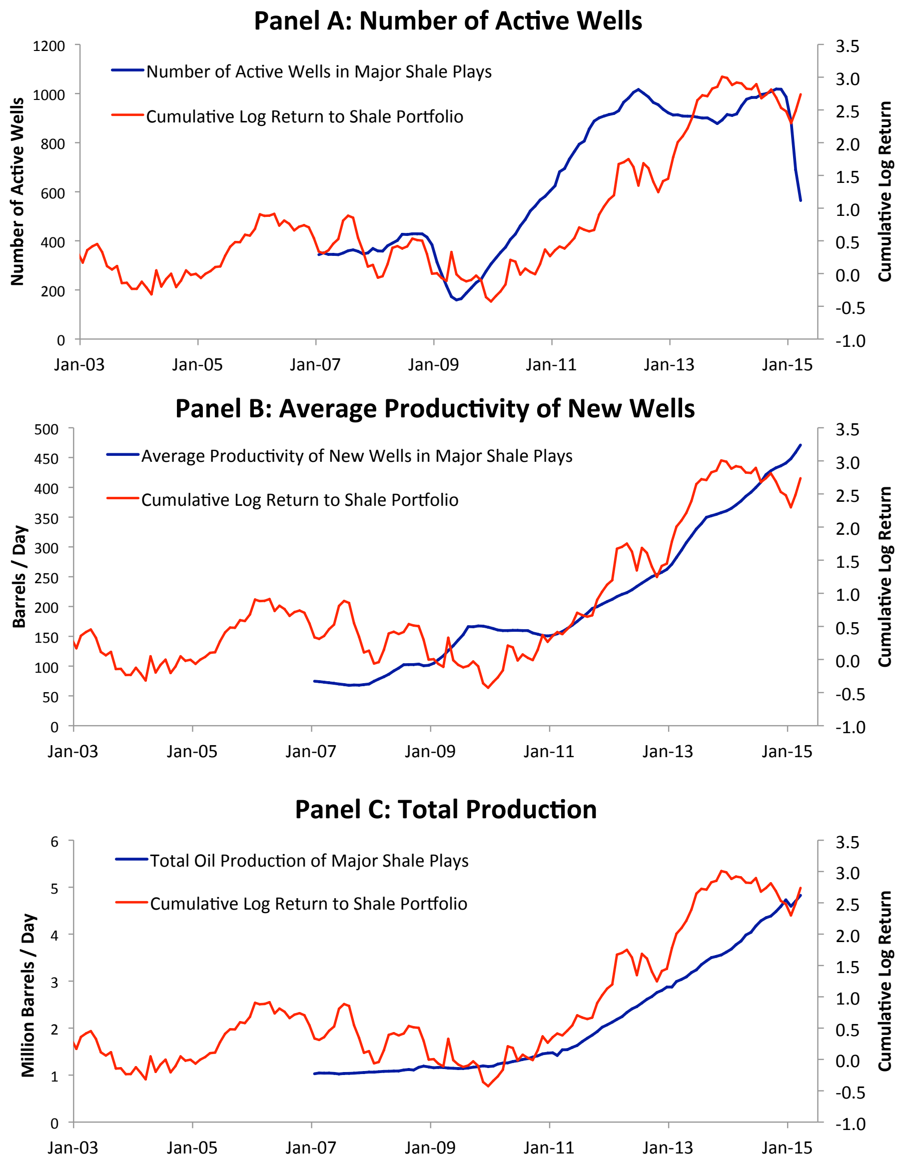


Figure plots the cumulative return attributable to the Shale Discovery Portfolio against various measures of productivity for the combined Backen, Eagle Ford, and Permian shale plays. The cumulative return is calculated after controlling for returns to the OPEC Announcement and Market Beta Characteristic portfolio using a single regression of the weekly Shale Discovery Portfolio returns on the returns to the other characteristic portfolios. The four characteristic portfolio returns are the weekly slopes of the Fama-Macbeth regressions reported in Table 1. Oil production data is from the EIA.

Table 2: Explaining Oil Prices and Index Returns with Characteristic Portfolio Returns

Panel A: Oil Price Change

VARIABLES	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
OPEC Announc. Portfolio Return	-3.421***	-3.362***	-5.583***	-5.469***	-3.152***	-3.092***	-4.366***	-4.257***
	(0.292)	(0.283)	(1.213)	(1.321)	(0.543)	(0.489)	(0.555)	(0.552)
Shale Discovery Portfolio Return	0.281	0.337	3.286*	3.191	-0.421	-0.887	2.250***	1.801***
	(0.526)	(0.508)	(1.804)	(1.902)	(0.678)	(0.666)	(0.526)	(0.558)
Pre-Crisis Beta Portfolio Return	-1.029**	-0.079	-2.952**	-2.918**	0.488	-1.285*	-0.089	-0.623
	(0.410)	(0.546)	(1.187)	(1.188)	(0.603)	(0.757)	(0.461)	(0.560)
Crisis Beta Portfolio Return	0.446	0.983*	2.258***	1.961*	1.968***	0.343	1.509***	0.931
	(0.496)	(0.525)	(0.457)	(1.052)	(0.343)	(0.472)	(0.476)	(0.594)
Market Return		-0.419*		0.150		0.785***		0.313*
		(0.241)		(0.524)		(0.177)		(0.182)
Constant	0.199	0.210	-0.412	-0.376	0.463*	0.199	-0.043	-0.139
	(0.213)	(0.206)	(1.103)	(1.106)	(0.263)	(0.253)	(0.242)	(0.249)
Observations	276	276	46	46	131	131	163	163
R-squared	0.428	0.440	0.543	0.544	0.523	0.591	0.445	0.458

Panel B: S&P Integrated Oil & Gas Index

VARIABLES	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
OPEC Announc. Portfolio Return	-1.922***	-2.077***	-1.773***	-1.127***	-1.442***	-1.344***	-1.720***	-1.344***
	(0.160)	(0.106)	(0.506)	(0.389)	(0.333)	(0.186)	(0.348)	(0.224)
Shale Discovery Portfolio Return	0.227	0.080	-0.836	-1.373**	0.910*	0.149	1.270***	-0.273
	(0.317)	(0.246)	(0.789)	(0.632)	(0.529)	(0.275)	(0.415)	(0.242)
Pre-Crisis Beta Portfolio Return	1.470***	-1.026***	-1.523*	-1.327**	1.566***	-1.331***	0.550*	-1.286***
	(0.184)	(0.241)	(0.807)	(0.511)	(0.414)	(0.297)	(0.315)	(0.211)
Crisis Beta Portfolio Return	1.729***	0.318	1.526***	-0.155	1.944***	-0.709***	1.672***	-0.313
	(0.306)	(0.219)	(0.269)	(0.462)	(0.347)	(0.213)	(0.335)	(0.208)
Market Return		1.102***		0.852***		1.282***		1.077***
		(0.077)		(0.254)		(0.063)		(0.056)
Constant	0.086	0.057	-0.168	0.037	0.341*	-0.091	0.175	-0.155
	(0.117)	(0.083)	(0.575)	(0.473)	(0.195)	(0.105)	(0.146)	(0.094)
Observations	276	276	46	46	131	131	163	163
R-squared	0.538	0.753	0.597	0.712	0.549	0.870	0.338	0.754

Panel C: Shale Gas Index

VARIABLES	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
OPEC Announc. Portfolio Return	-3.520***	-3.664***	-6.263***	-4.996***	-2.570***	-2.475***	-3.310***	-2.975***
	(0.195)	(0.192)	(0.911)	(0.687)	(0.615)	(0.543)	(0.582)	(0.537)
Shale Discovery Portfolio Return	0.394	0.258	2.700*	1.646	-0.025	-0.760	2.095***	0.714
	(0.421)	(0.399)	(1.466)	(1.120)	(0.881)	(0.747)	(0.619)	(0.633)
Pre-Crisis Beta Portfolio Return	1.987***	-0.329	-1.445	-1.061	1.040*	-1.756**	-0.157	-1.799***
	(0.260)	(0.389)	(1.100)	(0.740)	(0.624)	(0.712)	(0.598)	(0.629)
Crisis Beta Portfolio Return	2.228***	0.919**	3.819***	0.519	4.107***	1.546**	2.973***	1.198*
	(0.366)	(0.393)	(0.475)	(0.902)	(0.513)	(0.674)	(0.587)	(0.611)
Market Return		1.022***		1.672***		1.238***		0.963***
		(0.127)		(0.393)		(0.208)		(0.180)
Constant	0.203	0.176	-0.105	0.299	0.279	-0.138	0.175	-0.120
	(0.160)	(0.141)	(0.953)	(0.812)	(0.336)	(0.287)	(0.246)	(0.228)
Observations	276	276	46	46	131	131	163	163
R-squared	0.635	0.711	0.769	0.858	0.584	0.686	0.353	0.462

Panel D: Shale Oil Index

VARIABLES	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
OPEC Announc. Portfolio Return	-3.478***	-3.621***	-5.283***	-4.261***	-3.041***	-2.962***	-3.834***	-3.432***
	(0.198)	(0.198)	(0.672)	(0.543)	(0.508)	(0.442)	(0.466)	(0.342)
Shale Discovery Portfolio Return	0.802*	0.668*	2.349**	1.499*	0.542	-0.069	4.042***	2.389***
	(0.412)	(0.383)	(1.127)	(0.795)	(0.728)	(0.610)	(0.602)	(0.533)
Pre-Crisis Beta Portfolio Return	1.557***	-0.729**	-2.086**	-1.776***	1.299**	-1.027	1.665***	-0.301
	(0.203)	(0.329)	(0.865)	(0.565)	(0.543)	(0.643)	(0.480)	(0.462)
Crisis Beta Portfolio Return	1.949***	0.657**	2.981***	0.319	3.367***	1.236***	3.248***	1.122**
	(0.339)	(0.329)	(0.336)	(0.650)	(0.383)	(0.452)	(0.549)	(0.496)
Market Return		1.009***		1.349***		1.029***		1.153***
		(0.117)		(0.273)		(0.154)		(0.122)
Constant	0.112	0.086	-0.142	0.183	0.564**	0.217	0.491**	0.137
	(0.150)	(0.132)	(0.743)	(0.601)	(0.265)	(0.222)	(0.220)	(0.174)
Observations	276	276	46	46	131	131	163	163
R-squared	0.622	0.706	0.774	0.868	0.653	0.742	0.554	0.706

Standard Errors in Parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

are much more positively correlated with oil prices. The more interesting results come in the shale oil period. In this period, which saw high returns to both the shale portfolio and the market, we also see a large significant exposure of the market to the shale portfolio. Including the shale portfolio in a regression leads to a 6% increase in R^2 .

Panel B repeats this analysis, but this time including the two market beta characteristic portfolios. Prior to the crisis we see insignificant positive exposure of the market to the Shale Discovery Portfolio, suggesting that it has little explanatory power for the market in these periods, although this is largely by construction.

In the post-crisis and shale periods, we see that our pre-crisis and crisis beta portfolios exhibit large positive correlations with the market. In particular, these portfolios explain 70% of the variation in market returns during the post-crisis period, and essentially drive out the explanatory power of the OPEC Announcement Portfolio in this period. Again in this period, we see very little impact of the Shale Discovery Portfolio on the market.

The most striking results again occur in the shale period. In this period, while the two market beta portfolios are still significantly correlated with the market return, they no longer explain as much of the total variation in the market. When the Shale Discovery Portfolio is included in the regression, the beta of the market on shale is again much higher (roughly 1.5) and highly statistically significant. Moreover, adding the Shale Discovery Portfolio to the regression increases the R^2 from 0.32 to 0.43, suggesting that during this period news about shale oil are responsible for about 11% of the variation in the aggregate stock market. In the other periods the contribution of shale to the market variance is essentially zero.

3.6 Economic Magnitudes

We can use the coefficients in Table 3 to estimate the overall value effect of shale oil development. The last row of each panel in Table 3 gives the change in the constant term in the regression of the market return on the characteristic portfolios that is created by including the shale portfolio. In the full regression including the beta controls, this value is 9.7 basis points. Therefore, over the 163 week shale oil period, the total cumulative return is 9.7 basis points $\times$ 163 = 15.81%. Therefore, the overall value effect of shale, implied by asset prices is 15.81% of the U.S. total equity market capitalization as of the beginning of the shale period.

Table 3: Explaining Market Returns with Characteristic Portfolio Returns

Panel A: No Market Beta Characteristic Portfolios

	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
Shale Discovery Portfolio		0.000		0.000		0.217		1.26***
		(0.292)		(1.398)		(0.600)		(0.396)
OPEC Announc. Portfolio	0.000	0.000	0.000	0.000	-1.180***	-1.240***	-0.981***	-1.251***
	(0.154)	(0.159)	(0.337)	(0.694)	(0.304)	(0.356)	(0.247)	(0.255)
Constant	0.136	0.136	-0.440	-0.440	0.327	0.318	0.482***	0.401***
	(0.117)	(0.117)	(0.754)	(0.753)	(0.228)	(0.235)	(0.134)	(0.138)
Observations	276	276	46	46	131	131	163	163
R-squared	0.000	0.000	0.000	0.000	0.091	0.092	0.040	0.100
				Market Return Explained by Shale Portfolio				
Change in Intercept						0.01		0.088**
						(0.039)		(0.044)

Panel B: With Market Beta Characteristic Portfolios

	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
Shale Discovery Portfolio		0.13		0.63		0.59*		1.43***
		(0.22)		(0.59)		(0.35)		(0.32)
OPEC Announc. Portfolio	0.18*	0.14	-0.49*	-0.76**	0.07	-0.08	-0.09	-0.35
	(0.10)	(0.10)	(0.26)	(0.37)	(0.18)	(0.21)	(0.24)	(0.22)
Pre-Crisis Beta Portfolio	2.26***	2.27***	-0.26	-0.23	2.23***	2.26***	1.60***	1.71***
	(0.12)	(0.12)	(0.53)	(0.53)	(0.24)	(0.25)	(0.30)	(0.24)
Crisis Beta Portfolio	1.26***	1.28***	1.96***	1.97***	2.07***	2.07***	1.69***	1.84***
	(0.21)	(0.23)	(0.20)	(0.19)	(0.21)	(0.20)	(0.31)	(0.28)
Constant	0.03	0.03	-0.28	-0.24	0.36***	0.34***	0.40***	0.31***
	(0.07)	(0.07)	(0.35)	(0.35)	(0.13)	(0.13)	(0.11)	(0.11)
Observations	276	276	46	46	131	131	163	163
R-squared	0.61	0.61	0.79	0.79	0.71	0.72	0.32	0.43
				Market Return Explained by Shale Portfolio				
Change in Intercept		-0.001		-0.037		0.024		0.097**
		(0.004)		(0.072)		(0.023)		(0.047)

Standard Errors in Parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table shows time series regressions of aggregate stock market returns on characteristic portfolio returns in four subperiods. The characteristic portfolio returns are constructed as the weekly slope coefficients in a Fama-Macbeth regression of the cross-section of industry returns on the OPEC Announcement Return, the Shale Discovery Return, and industry market betas calculated in both the pre-crisis and crisis periods. The three oil indices are not included in the original cross-sectional regressions. Panel A shows regressions of market returns on the two announcement day characteristic portfolios. The exposure of the market to these two portfolios are zero by construction in the pre-crisis and crisis periods. Panel B repeats the exercise but this time including all four characteristic porfolios.

The total market value at the beginning of the shale period was \$16 trillion, therefore the total value effect derived from our methodology is $15.81\% \times \$16$ trillion = \$2.5 trillion.

How plausible is this figure? As a back of the envelope check on this, we can compare this figure to the estimated value of the capital expenditures being spent on shale over time. According to the Oil & Gas Journal, capital spending by the Oil and Gas Industry in the U.S. was estimated to be \$338 billion in 2014. The Baker Hughes rig count implies that roughly 78% of this activity is associated with shale oil development. Despite the recent downturn in prices, the EIA expects shale oil development to persist for many years. Assuming a 15 year life on this development and a 10% annual discount rate, suggests that the present value of cash flows associated with shale oil development is \$2 trillion. However, the 15 year life assumption above is based on existing shale oil production relative to proved reserves, as outlined by the EIA. The extent to which new discoveries are made, or reserves increase, the higher the expected life of the development will be and the greater the value of the resource. Given this back of the envelope calculation, the \$2.5 trillion implied by asset prices using our methodology seems plausible.

Moreover, our method does not distinguish between the impacts on the market from reductions in oil prices or long-run oil supply uncertainty and the direct impact from the value of the shale oil. Given the potential counterfactual levels of oil prices in the absence of Shale Oil, as well as the size of the shale industry, these findings seem if anything conservative.

3.7 Shale Announcement Returns and Employment Growth

So far we have documented a substantial effect of shale oil on equity market values. Ultimately, the economic impact of shale must be channeled through real activity. In order to verify that this is indeed the case we examine employment growth over our sample period at the level of industries that were used in our industry portfolio construction. We build a detailed dataset of month-by-month employment by industry from the Bureau of Labor Statistics, and then calculate the aggregate growth in different industries across the time periods we focus on in our study. In Table 4 we report the results of regressions where we estimate the effect of the return from the shale discovery announcement day on annual employment growth during different time periods. As can be seen from the results there is a positive and statistically significant coefficient on the announcement return. The economic interpretation of the coefficient is that if an industry's return on the shale discovery announcement day is one standard deviation higher, it experiences a 0.59% increase in average annual employment growth over the shale oil period (the announcement returns are not standardized, with a standard deviation of 0.77). As a falsification, we show that during earlier, non-shale oil time periods, there is no statistically significant relationship between the return an industry experiences on the shale discovery announcement day and an industry's employment growth. Taken together, the evidence presented in Table 4 suggests that, shale not only influenced asset prices, but had important real effects on the economy.

Table 4: Industry Shale Exposure and Employment Growth

	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
Shale Discovery Return	-0.155	0.193	-1.398	-1.114	-0.680	-0.360	0.624**	0.763**
	[0.544]	[0.493]	[1.103]	[1.016]	[0.620]	[0.569]	[0.307]	[0.305]
Opec Announcement Return		-0.613***		0.279		-0.778***		-0.151
		[0.159]		[0.328]		[0.184]		[0.099]
Pre-Crisis Beta		-0.005		-0.016*		0.007		-0.005
		[0.005]		[0.009]		[0.005]		[0.003]
Crisis Beta		0.004		-0.021**		-0.003		0.000
		[0.005]		[0.010]		[0.006]		[0.003]
Constant	0.008	0.008	-0.067***	0.057	0.011	-0.021	-0.001	0.013
	[0.009]	[0.017]	[0.018]	[0.035]	[0.010]	[0.020]	[0.005]	[0.011]
R-squared	0.001	0.242	0.021	0.235	0.016	0.238	0.053	0.137
Observations	76	76	76	76	76	76	76	76

This table reports regressions of employment growth on the shale discovery return. We aggregate up employment growth over each of the different time periods of our study: pre-crisis, crisis, post-crisis, and shale oil. Therefore, unit of observation in these regressions is at the time period-industry level. Each time period is normalized to reflect the average annual employment growth during that time period. Data on employment was collected from the Bureau of Labor Statistics.

We also study employment trends at the state-industry level, to see whether the effects of employment growth are concentrated in the major shale oil states (Texas, Oklahoma, North Dakota, Colorado, and New Mexico). As can be seen in Table 5 the effects of the Shale Announcement return are concentrated in the shale states, though both shale states and non-shale states have positive and statistically significant coefficients in the shale oil period.

Table 5: Industry Shale Exposure and State Level Employment

	Pre-Crisis			Crisis			Post-Crisis			Shale Oil		
	All	Non-Shale	Shale	All	Non-Shale	Shale	All	Non-Shale	Shale	All	Non-Shale	Shale
Shale Discovery Return	0.583	0.375	0.791	-0.565	-0.802	-0.329	0.212	-0.113	0.537	1.393***	0.958*	1.828***
	[0.405]	[0.493]	[0.634]	[1.038]	[0.997]	[1.841]	[0.537]	[0.685]	[0.822]	[0.384]	[0.483]	[0.582]
Opec Announcement Return	-0.542***	-0.430***	-0.655***	0.423	0.176	0.670	-0.621***	-0.525**	-0.717***	-0.076	0.152	-0.304
	[0.124]	[0.151]	[0.194]	[0.324]	[0.311]	[0.574]	[0.165]	[0.210]	[0.252]	[0.121]	[0.151]	[0.183]
Pre-Crisis Beta	-0.004	-0.006	-0.002	-0.017*	-0.017*	-0.017	0.007	0.007	0.008	-0.005	-0.008*	-0.003
	[0.004]	[0.004]	[0.005]	[0.009]	[0.009]	[0.016]	[0.005]	[0.006]	[0.007]	[0.003]	[0.004]	[0.005]
Crisis Beta	0.002	0.001	0.004	-0.021**	-0.024**	-0.018	-0.006	-0.006	-0.005	-0.001	0.002	-0.004
	[0.004]	[0.005]	[0.006]	[0.010]	[0.009]	[0.017]	[0.005]	[0.006]	[0.008]	[0.004]	[0.005]	[0.005]
Constant	0.007	0.018	-0.004	0.062*	0.062*	0.063	-0.011	-0.009	-0.013	0.020	0.024	0.016
	[0.014]	[0.017]	[0.022]	[0.036]	[0.035]	[0.064]	[0.018]	[0.023]	[0.028]	[0.013]	[0.016]	[0.020]
R-squared	0.173	0.170	0.211	0.141	0.275	0.100	0.099	0.090	0.120	0.107	0.112	0.160
Observations	142	71	71	148	74	74	146	73	73	148	74	74

*** p <0.01, **p <0.05, * p <0.10

This table reports regressions of employment growth on the shale discovery return. Employment growth for each industry is aggregated across shale and non-shale states separately. We aggregate up employment growth over each of the different time periods of our study: pre-crisis, crisis, post-crisis, and shale oil. Therefore, unit of observation in these regressions is at the time period-industry level. Data on employment was collected from the Bureau of Labor Statistics.

4 Robustness Tests

4.1 Bootstrap placeholder

4.2 Falsification: European Stock Market Returns

To provide further evidence that our measure is capturing exposure to Shale, we now repeat the exercise in Table 3 but instead of U.S. stock market returns, we use returns on the MSCI European Total Return index as our dependent variable. European firms presumably do not benefit from the direct effect of increased shale production, and while European GDP is roughly equal to that of the U.S., its total oil consumption is roughly one third less than that of the U.S., so that the indirect benefit of low oil prices may be smaller as well. Given these differences, we would expect the exposure of the European stock market to shale oil to be less than that of the U.S. market. The results in Table 6 show that this is in fact the case. In no period does the Shale Discovery portfolio have a significantly positive relation with the European index. Interestingly, the OPEC Announcement portfolio has a negative relation to the index during all periods, suggesting that the drops in oil prices may be a net negative for European firms as a whole (possibly to a fairly large weight of energy companies, such as BP, in the market index).

4.3 Industry Market Betas and Shale Period Returns

In this section we reexamine the returns during the shale period from the perspective of market betas. We show that industry market betas, estimated both prior to the shale period or during the shale period, are not enough to explain the large positive returns to the market post 2012.

The primary argument put forward in this paper is that the positive returns to the aggregate market post-2012 were driven by technological innovations in shale oil. Industries exposed to this shock experienced positive returns, while at the same time becoming systematically important to the market as a whole. For this reason, traditional “high beta” industries did not experience positive returns over this period.

As an illustration of this we first perform a simple exercise. We construct a characteristic

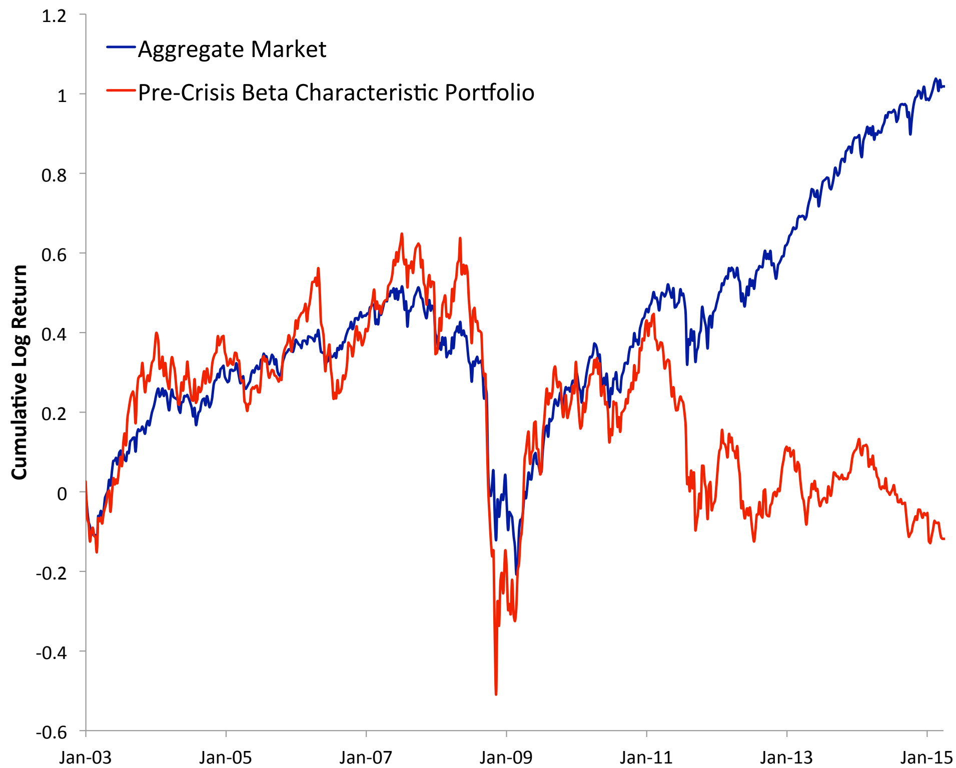
Table 6: Explaining European Market Returns with Characteristic Portfolio Returns

	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
Shale Discovery Portfolio		-0.81**		0.70		-0.40		0.54
		(0.32)		(0.91)		(0.67)		(0.39)
OPEC Announc. Portfolio	-0.41**	-0.19	-0.56**	-0.86*	-0.60	-0.50	-0.75***	-0.85***
	(0.17)	(0.17)	(0.25)	(0.49)	(0.39)	(0.42)	(0.27)	(0.28)
Pre-Crisis Beta Portfolio	1.90***	1.89***	0.41	0.45	1.90***	1.88***	1.59***	1.63***
	(0.22)	(0.21)	(0.65)	(0.62)	(0.43)	(0.44)	(0.35)	(0.35)
Crisis Beta Portfolio	1.60***	1.50***	2.08***	2.09***	2.66***	2.66***	2.24***	2.30***
	(0.30)	(0.28)	(0.30)	(0.28)	(0.32)	(0.33)	(0.43)	(0.42)
Constant	0.07	0.06	-0.62	-0.58	0.13	0.15	0.20	0.17
	(0.11)	(0.11)	(0.50)	(0.48)	(0.23)	(0.22)	(0.14)	(0.15)
Observations	276	276	46	46	131	131	163	163
R-squared	0.36	0.384	0.69	0.7	0.54	0.54	0.35	0.36
	Market Return Explained by Shale Portfolio							
Change in Intercept		0.01		-0.04		-0.02		0.04
		(0.02)		(0.08)		(0.03)		(0.03)

Standard Errors in Parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table shows time series regressions of U.S. dollar returns to the MSCI Europe Index on the characteristic portfolio returns in four subperiods. The characteristic portfolio returns are constructed as the weekly slope coefficients in a Fama-Macbeth regression of the cross-section of industry returns on the OPEC Announcement Return, the Shale Discovery Return, and industry market betas calculated in both the pre-crisis and crisis periods. The three oil indices are not included in the original cross-sectional regressions.

Figure 3: Pre-Crisis Market Betas and Cumulative Returns



This figure plots the cumulative aggregate stock market return against the cumulative return to the pre-crisis market beta characteristic portfolio. The return on the characteristic portfolio in each week is the slope from a Fama-Macbeth regression of that week's industry returns on a constant and each industry's market beta, where the market beta is calculated over the pre-crisis period (01/2003 - 06/2008).

portfolio using the cross-section of market betas estimated in the pre-crisis period, and examine cumulative returns to this portfolio over the sample. Figure 3 plots the results. As the figure shows, this portfolio tracks the performance of the market very closely in the pre-crisis period by construction. More interestingly, the portfolio also tracks the market return very closely during the crisis and post-crisis recovery, but subsequently exhibits a large divergence from the market beginning in 2012, consistent with the hypothesis that a new shock was driving market returns.

One potential concern however is that our announcement day identification strategy is simply picking up industries which have a high market beta in the shale period. To address

Table 7: Market Betas and Industry Returns in Shale Period

	Industry Shale Period Returns				
Pre-Crisis Market Beta	0.06	-0.01			
	(0.03)	(0.04)			
Crisis Market Beta	-0.00		-0.04		
	(0.03)		(0.04)		
Post Crisis Market Beta	-0.12**			-0.05	
	(0.05)			(0.05)	
Shale Years Market Beta	0.04				-0.03
	(0.05)				(0.05)
Constant	0.32**	0.36***	0.45***	0.49***	0.47***
	(0.13)	(0.12)	(0.11)	(0.12)	(0.15)
Observations	12,388	12,388	12,388	12,388	12,388
Number of groups	163	163	163	163	163

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

This table shows results from Fama-Macbeth regressions of the cross-section of industry returns on industry market betas over the shale period (01/2012 - 03/2015). Industry Market Betas are calculated in each of the four subperiods.

this concern we perform cross-sectional Fama-Macbeth regressions simply using market betas (instead of Shale Announcement returns). Table 7 shows the results of these regressions. As we can see the returns in the shale period are not explained by market betas. This suggests that an aggregate market shock is still driving a large amount of market variation (i.e., $\tilde{a}$ in our simple model), but is not responsible for the large positive returns over this period.

4.4 Monetary Policy Announcements

One concern in interpreting the regressions of the total stock market return on the Shale Discovery portfolio return is that it may be simply picking up the changing market beta of the shale mimicking portfolio itself. While this change is likely driven by the fact that shale oil became a more important part of the U.S. economy, we would like to avoid spuriously attributing market-wide shocks originating elsewhere in the economy to shale simply due to the increased covariation between the two.

In order to address this concern we include an additional control variable that helps identify shocks that are exogenous to shale news. Savor and Wilson (2014) show that market beta is a good predictor of expected returns on stocks during days of the announcements by the Federal Open Market Committee, which are the days when the bulk of the equity risk premium is realized. Given the potential importance of monetary policy (and the Quantitative Easing program) during the shale period these FOMC announcement days are ideal for identifying non-shale shocks to U.S. stocks.[11] We repeat our main tests, the Fama-MacBeth regressions of industry returns on the shale and OPEC announcements, including as an additional control industry betas estimated over the 12 FOMC announcement days in our sample.

Table 8 presents the results in Panel A. It is clear that the estimated impact of the shale announcement returns is completely unaffected by the control, as all of the coefficients are essentially the same and the FOMC beta has no significant impact on the cross-section of industry returns. Nevertheless, we construct a new set of mimicking portfolios using the slopes from this regression, and repeat our analysis of the time-series performance of the total stock market. Panel B of the table shows that the FOMC beta portfolio is indeed quite strongly correlated with the market return over the shale period, with the beta equal essentially to one, as expected. However, it only helps strengthen the effect of the Shale portfolio on the market return, raising the coefficient to 1.68, with a contribution to the market portfolio of 10.7 basis points per week. This shows that the covariation between the shale innovations that we identify using the Shale Discovery portfolio and the aggregate stock returns is not likely to be driven by variables that are altogether outside the shale oil sector, providing further validation for our approach.

The exercise above is justified by the fact that the FOMC announcement day returns are indeed very closely related to industry market betas over the shale period, is illustrated by the regression in Figure 4 (panel C), which shows that the latter explain 34 percent of variation in the latter. Market betas are also positively related to the shale announcement

[11]Unreported results for days using important announcements regarding the FOMC Quantitative Easing program as in Krishnamurthy and Vissing-Jorgensen (2012) are essentially equivalent to the findings for FOMC days.

Table 8: Robustness Check: Effect of Shale Year FOMC days on Returns and Market Beta

Panel A: Fama-Macbeth Regressions of Industry Returns

	Industry Average Returns			
	Pre-Crisis	Crisis	Post-Crisis	Shale Years
Shale Discovery Returns	-0.049*	0.006	0.034	0.096***
	(0.027)	(0.151)	(0.037)	(0.031)
OPEC Announc. Returns	-0.160***	0.143	-0.021	0.142***
	(0.055)	(0.294)	(0.064)	(0.045)
Pre-Crisis Beta	0.069*	-0.067	0.000	-0.025
	(0.042)	(0.143)	(0.049)	(0.033)
Crisis Beta	-0.014	-0.077	-0.006	0.002
	(0.029)	(0.340)	(0.066)	(0.030)
FOMC Announc. Returns	-0.001	0.053	-0.035	0.022
	(0.024)	(0.113)	(0.031)	(0.029)
Constant	0.102	-0.061	0.455**	0.251*
	(0.114)	(0.609)	(0.186)	(0.140)
Observations	20,976	3,496	9,956	12,388
R-squared	0.279	0.381	0.289	0.224
Number of Weeks	276	46	131	163

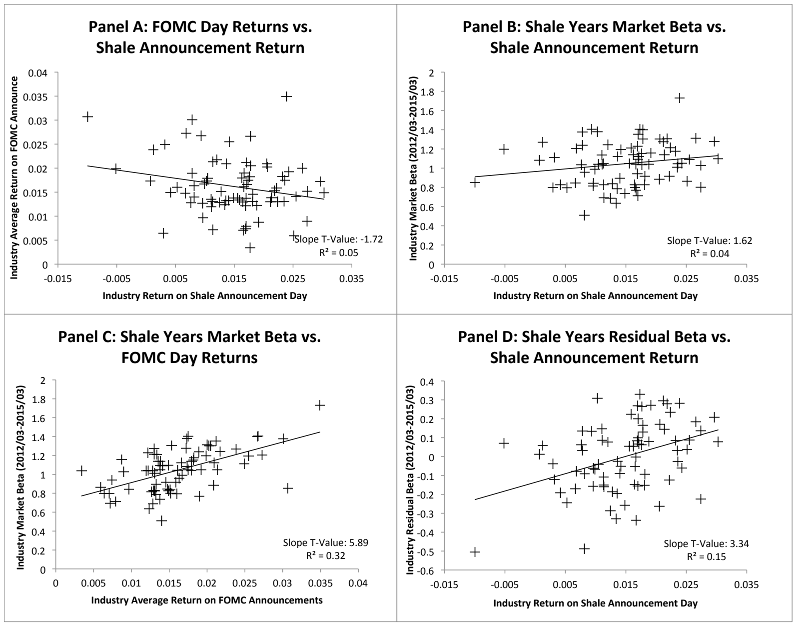
Panel B: Explaining Aggregate Market with Characteristic Portfolios

	Aggregate Market Returns			
	Pre-Crisis	Crisis	Post-Crisis	Shale Years
Shale Discovery Portfolio	0.137	-0.805	0.544	1.532***
	(0.104)	(0.506)	(0.346)	(0.317)
OPEC Announc. Portfolio	0.139	0.704	-0.000	-0.408*
	(0.226)	(0.808)	(0.219)	(0.223)
Pre-crisis Beta Portfolio	2.266***	-0.209	2.161***	1.764***
	(0.124)	(0.538)	(0.236)	(0.245)
Crisis Beta Portfolio	1.273***	1.974***	2.187***	1.615***
	(0.230)	(0.189)	(0.217)	(0.298)
FOMC Announc. Portfolio	0.100	0.961	-0.618	0.866***
	(0.234)	(0.758)	(0.404)	(0.328)
Constant	0.026	-0.242	0.309**	0.295***
	(0.075)	(0.360)	(0.127)	(0.107)
Weeks	276	46	131	163
R-squared	0.61	0.80	0.73	0.45
	Market Return Explained by Shale Portfolio			
Change in Intercept	0.000	-0.034	0.021	0.106**
	-0.004	(0.077)	(0.021)	(0.048)

Standard Errors in Parentheses
*** p<0.01, ** p<0.05, * p<0.1

Panel A shows the results of Fama-Macbeth regressions of average returns on the same variables as in table 1 but also including the industry market beta calculated using returns on the 12 FOMC announcement days in the Shale Year period. Panel B repeats the regressions of Table 3 but using the FOMC Beta characteristic portfolio as an additional control.

Figure 4: Shale Announcement Returns, Market Betas, and the FOMC



returns, presumably due to the growing importance of shale in the U.S. economy, albeit the relationship is not very strong (panel B). In fact, shale announcement returns are able to explain a substantial of the variation in market betas not captured by the FOMC announcements (panel D shows the regression of residuals from the panel C regression vis-a-vis the Shale announcement returns). What is crucial for the validity of our identification though is that the FOMC announcement returns do not line up with the shale announcement returns. If anything, they are negatively correlated, albeit weakly. Thus, it is not likely that the shale announcement returns are picking up some common macroeconomic shock that drives up asset prices over the shale period.

5 Conclusion

In a matter of a few years the technological innovations associated with fracking have revolutionized the U.S. oil market. The long run impact of this technology is uncertain, however. The continued ability of shale companies to reduce costs of extraction is actively debated, as are the amounts of the recoverable hydrocarbons trapped in shale rock. Its importance for future economic growth also depends on the economy's long-run response to oil supply shocks, which is difficult to estimate. We use information contained in asset prices to evaluate the contribution of shale oil to the U.S. economy, to the extent that it is captured in the aggregate stock market capitalization. We find that technological shocks to shale supply capture a substantial fraction of total stock market fluctuations, suggesting that shale oil is an important contributor to the future U.S. economic growth.

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Appendix

Appendix 1 Model

In this section we develop a simple toy model of oil production and demand that motivates the use of asset prices to extract technology shocks.

Demand for Oil A representative firm produces consumption goods via a Cobb-Douglas production technology

$$Y_{t+1} = A_{t+1} O_{t+1}^{1-\alpha} K_t^{\alpha},$$

where A_{t+1} is an aggregate productivity shock, O_{t+1} is oil, which plays the role of an intermediate good, and K_t is capital, where the time subscript refers to the fact that capital is chosen one period ahead (i.e. before the productivity shock is realized). Capital depreciates fully after the period's production is complete. The firm acts competitively, therefore maximizing profits implies that oil prices must satisfy

$$P_t^O = (1-\alpha) A_t O_t^{-\alpha} K_t^{\alpha}$$

given the aggregate supply of oil O_t (we assume this production technology is the only source of domestic demand for oil).

Oil Supply Total oil supply is a sum of supply generated by two oil (sub)sectors:

$$O_t = S_t^{Shale} + S_t^{Other}$$

The two sectors are:

1. shale oil: S_t^{Shale}
2. all other oil production (OPEC, Large Integrated Oil Producers, international Oil Production, net of foreign demand, etc.): S_t^{Other}

There is a continuum of competitive price-taking firms in each sector, each sharing a common, sector-specific productivity shock Z_t^i and using competitively supplied factor input L_i ('leases') at a price w_i.

Oil Company Production is given by

$$S_t^i = Z_t^i L_i^\nu, 0<\nu<1$$

Oil Company Profits

$$\Pi_t^i = P_t^O S_t^i - w_i L_i, \text{ which implies}$$

$$\Pi_t^i = P_t^O S_t^i (1-\nu)$$

Assuming marginal cost of deploying one lease w_i is fixed, we have $\nu P_t^O Z_t^i L_i^{\nu-1} = w_i$ so that sector output is equal

$$S_t^i = Z_t^i L_i^\nu = \left(Z_t^i\right)^{\frac{1}{1-\nu}} \left(\frac{w_i}{\nu P_t^O}\right)^{\frac{\nu}{\nu-1}}$$

and

$$\Pi_t^i = \left(P_t^O Z_t^i\right)^{\frac{1}{1-\nu}} (1-\nu) \left(\frac{w_i}{\nu}\right)^{\frac{\nu}{\nu-1}}.$$

The intuition behind this production function is that while the costs of drilling are roughly the same across locations, some of the drilled wells are much more productive than others and therefore are profitable to operate at lower levels of oil prices, while less productive leases are utilized only when prices are sufficiently high.

We assume that the sectors differ in their productivity Z_t^i as well as marginal cost of production w_i, which jointly determine the relative importance of each sector in total oil supply. While in general different oil sectors may differ in the degree of decreasing returns, this assumption simplifies exposition without driving any of the implication.

Assume for simplicity that one unit of capital must be invested at the beginning of the period to operate the technology, with full depreciation by the end of the period. Then returns on firms in sector i equal profits: $R_{t+1}^i = \Pi_{t+1}^i$.

We assume that all of the productivity shocks, A_t, Z_t^{Shale}, and Z^{Other}, together with innovations to an exogenously given stochastic discount factor M_t, are jointly lognormally distributed.

Asset Pricing The value of capital invested in the aggregate production sector is just the present value of next period's profits:

$$V_t^i = \alpha E_t \left[M_{t+1} A_{t+1} O_{t+1}^{1-\alpha} K_t^{\alpha}, \right]$$

assuming full depreciation between periods. In the absence of adjustment costs (so that $V_t^i = K_t^i$) this implies that the returns to an average firm are

$$R_{t+1}^a = \frac{\alpha A_{t+1} O_{t+1}^{1-\alpha} K_t^{\alpha}}{V_t^i} = \frac{A_{t+1} O_{t+1}^{1-\alpha} K_t^{\alpha}}{E_t \left[M_{t+1} A_{t+1} O_{t+1}^{1-\alpha} K_t^{\alpha} \right]} = A_{t+1} O_{t+1}^{1-\alpha} K_t^{\alpha-1}$$

or, in logs,

$$\begin{aligned} r_{t+1}^a &= \Delta a_{t+1} + o_{t+1} + p_{t+1} - g_A - (1-\alpha) E o_{t+1} + \alpha k_t + r_t - \frac{1}{2} Var \left[\log \left(M_{t+1} A_{t+1} O_{t+1}^{1-\alpha} K_t^{\alpha} \right) \right] \\ &= (E_{t+1} - E_t) a_{t+1} + (1-\alpha)(E_{t+1} - E_t) o_{t+1} + r_t - \frac{1}{2}\sigma_m^2 + rp^a + \frac{1}{2}\sigma_a^2 \\ &= (E_{t+1} - E_t) o_{t+1} + (E_{t+1} - E_t) p_{t+1} + r_t + rp^a - \frac{1}{2}\sigma_a^2, \end{aligned}$$

where the aggregate market equity risk premium

$$rp^a = -Cov(m_{t+1}, \Delta o_{t+1}) - Cov(m_{t+1}, \Delta p_{t+1})$$

is assumed constant for simplicity, as is the corresponding return volatility

$$\sigma_a^2 = Var(\Delta o_{t+1} + \Delta p_{t+1})$$

and the risk-free rate is $r_t^f = E_t m_{t+1} - \frac{1}{2}\sigma_m^2$.

Similarly, excess returns to oil producers in sector i are given by

$$r_{t+1}^i - r_t^f + \frac{1}{2}\sigma_a^2 = \frac{1}{1-\nu}(E_{t+1} - E_t) z_{t+1}^i + \frac{1}{1-\nu}(E_{t+1} - E_t) p_{t+1} + rp_t^i, \qquad \text{(A-1)}$$

where the risk premium rp^i is determined by the conditional covariances of the shocks with the SDF innovations.

We approximate the log of total supply as

$$o_t = \xi^{Shale} s_t^{Shale} + (1-\xi^{Shale}) s_t^{Other}$$

Innovations in supply are then

$$\begin{aligned}
(E_{t+1}-E_t)\,o_{t+1} &\approx \xi^{Shale}\,(E_{t+1}-E_t)\,s_{t+1}^{Shale} + \left(1-\xi^{Shale}\right)(E_{t+1}-E_t)\,s_{t+1}^{Other} \\
&= \frac{1}{1-\nu}\xi^{Shale}\,(E_{t+1}-E_t)\,z_{t+1}^{Shale} \\
&\quad +\frac{1}{1-\nu}\left(1-\xi^{Shale}\right)(E_{t+1}-E_t)\,z_{t+1}^{Other} - \frac{\nu}{1-\nu}\,(E_{t+1}-E_t)\,p_{t+1}
\end{aligned}$$

where $\xi^{Shale} = E\left[\frac{S_t^{Shale}}{O_t}\right]$, and we assume that Σ is a constant variance-covariance matrix of S_t^{Shale} and S_t^{Other} so that the convexity adjustment $\frac{1}{2}\left(\xi^{Shale}, 1-\xi^{Shale}\right)\Sigma\left(\xi^{Shale}, 1-\xi^{Shale}\right)'$ drops out.

Then final good sector return innovations can be approximated as

$$\begin{aligned}
(E_{t+1}-E_t)\,r_{t+1}^a &\approx \frac{1}{1-\nu}\xi^{Shale}\,(E_{t+1}-E_t)\,z_{t+1}^{Shale} \\
&+ \frac{1}{1-\nu}(1-\xi^{Shale})\,(E_{t+1}-E_t)\,z_{t+1}^{Other} + \frac{1-2\nu}{1-\nu}\,(E_{t+1}-E_t)\,p_{t+1}
\end{aligned} \tag{A-2}$$

Appendix 2 Shock identification in the model

Using the definition of oil prices and the log approximation of o_t, we can express innovations in oil prices in terms of fundamental shocks

$$\begin{aligned}
(E_{t+1}-E_t)\,p_{t+1} &= (1-\mu\nu)\Delta a_{t+1} \\
&- \mu\xi^{Shale}\,(E_{t+1}-E_t)\,z_{t+1}^{Shale} - \mu(1-\xi^{Shale})\,(E_{t+1}-E_t)\,z_{t+1}^{Other},
\end{aligned}$$

where $\mu = \frac{\alpha}{1-\nu+\alpha\nu} \in (0,1)$. Now we can approximate all of the log-return innovations as linear functions of the fundamental shocks

$$
\begin{aligned}
(E_{t+1} - E_t)\, r^a_{t+1} &\approx \frac{1-2\nu}{1-\nu}(1-\mu\nu)\Delta a_{t+1} \\
&+ \frac{\xi^{Shale}}{1-\nu}(1-(1-2\nu)\mu)\,(E_{t+1} - E_t)\, z^{Shale}_{t+1} \\
&+ \frac{1-\xi^{Shale}}{1-\nu}(1-(1-2\nu)\mu)\,(E_{t+1} - E_t)\, z^{Other}_{t+1}
\end{aligned}
$$

The producer return is therefore driven by both aggregate productivity shocks, and also by shocks to oil productivity, which reduce the price of the oil input. Using the approximation of o_t, the returns to the oil producing sectors are given by

$$
\begin{aligned}
(E_{t+1} - E_t)\, r^{Shale}_{t+1} &\approx \frac{1-\mu\nu}{1-\nu}\Delta a_{t+1} \\
&+ \frac{1-\mu\xi^{Shale}}{1-\nu}\,(E_{t+1} - E_t)\, z^{Shale}_{t+1} \\
&- \frac{\mu(1-\xi^{Shale})}{1-\nu}\,(E_{t+1} - E_t)\, z^{Other}_{t+1} \\
(E_{t+1} - E_t)\, r^{Other}_{t+1} &\approx \frac{1-\mu\nu}{1-\nu}\Delta a_{t+1} \\
&+ \frac{1-\mu(1-\xi^{Shale})}{1-\nu}\,(E_{t+1} - E_t)\, z^{Other}_{t+1} \\
&- \frac{\mu\xi^{Shale}}{1-\nu}\,(E_{t+1} - E_t)\, z^{Shale}_{t+1}
\end{aligned}
$$

We now consider the market return. Since we primarily focus on the U.S. market, we simplify here to define the market portfolio as the sum of the final producing sector and the shale oil sector. While it is relatively straightforward to include a separate, non-shale, domestic oil sector, we think it is unlikely that productivity shocks to other types of U.S. oil producers had a material impact over this period.

Therefore innovations in market return can be defined as

$$\begin{aligned}(E_{t+1}-E_t)\, r_{t+1}^{Mkt} &= (E_{t+1}-E_t)\,(1-\zeta_{Mkt}^{Shale}) r_{t+1}^{a} + (E_{t+1}-E_t)\,\zeta_{Mkt}^{Shale} r_{t+1}^{Shale} \\ &= \beta_a^{Mkt}\,(E_{t+1}-E_t)\, a_{t+1} + \beta_{Shale}^{Mkt}\,(E_{t+1}-E_t)\, z_{t+1}^{Shale} + \beta_{Other}^{Mkt}\,(E_{t+1}-E_t)\, z_{t+1}^{Other}\end{aligned}$$

Where ζ_{Market}^{Shale} is the relative market value of the shale sector in the market portfolio. Since in principle the oil sector as described by our model includes all of the firms involved in the production of oil, this quantity is not directly observable. In fact, the supply chain of shale oil extraction can involve firms in a number of upstream industries. Thus, ζ_{Market}^{Shale} should be thought of as capturing the fraction of total market value attributable to the supply of shale oil. It does not, however, capture the value of shale oil to the rest of the economy (in particular, r_{t+1}^{a} captures the effect of increased oil supply on oil-demanding industries that benefit from lower oil prices). We assume that all firms in the economy are exposed to shale oil through either one or both of these channels (e.g., by operating the two technologies in different proportions).

The exposure of the aggregate market portfolio to a shock to shale production is given by

$$\beta_{Shale}^{Mkt} = (1-\zeta_{Mkt}^{Shale})\frac{\xi^{Shale}}{1-\nu}(1-(1-2\nu)\mu) + \zeta_{Mkt}^{Shale}\frac{1-\mu\xi^{Shale}}{1-\nu}$$

The first term is an "indirect" effect, by which increased shale production lowers the oil price for producers of the final good. The second term is a "direct" effect, reflecting increased value of the shale industry.

In this paper we focus on estimating the value added to the market by increases in z_{t+1}^{Shale}. While it is clear that shale productivity increased over the recent time period, we want to examine if this had an effect on aggregate market returns - i.e., is $\beta_{Shale}^{Mkt} > 0$? What is the contribution of shocks to z_{t+1}^{Shale} to the variation in aggregate stock market returns? To answer these questions, we pursue two related strategies.

In our first strategy, we identify earnings announcement days for prominent shale firms on which we can observe shocks to z_t^{Shale}. The revenue surprises for these firms are then used as a proxy for innovations to z_t^{Shale}. We then examine market returns on these days and show that the market returns do have a significant response to these announcements. This approach allows us to ascertain whether the market responds to shale-specific shocks, but since we do not believe that these announcements were the only innovations over the period, it does not allow us address the quantitative question. In our second method we rely on the time-series and cross-section of industry returns to construct a proxy for the time-series of shocks to shale oil. Here again we find evidence that these shocks were large and had a significant impact on the market.

Appendix 3 Characteristic Portfolios

We have three "characteristics":

1. $R^j_{OPECAnn}$: The return of industry j on the OPEC announcement day
2. $R^j_{ShaleAnn}$: The return of industry j on the Shale Announcement day
3. $\beta^j_{PreShale}$: The market beta of industry j in the pre-shale period

Let

$$X = [\iota \;\; \bar{r}_{ShaleAnn} \;\; \bar{r}_{OpecAnn} \;\; \bar{\beta}_{PreShale}],$$

where the overbar indicates an N x 1 vector of the industry characteristics. The goal is to construct maximally diversified portfolios with industry weights $\bar{w}_{ShaleAnn}$, $\bar{w}_{OPECAnn}$, $\bar{w}_{MarkeBeta}$ for 3 "characteristic portfolios". The return to each portfolio at time t will be

$$R^k_t = \sum_{j=1}^{N} w^j_k r^j_t$$

For a characteristic k, the solution which minimizes $w'_k w_k$ subject to $X' w_k = e_k$ (here e_k is a 4 x 1 vector with a one in the position of the column in X of characteristic k and zero otherwise), is $w_k = X(X'X)^{-1} e_k$.

Consider first the Market Beta characteristic portfolio. The weights solve:

$$0 = \sum_{j=1}^{N} w^j_{MarketBeta}$$

$$1 = \sum_{j=1}^{N} w^j_{MarketBeta} \beta^j_{Mkt,PreShale}$$

$$0 = \sum_{j=1}^{N} w^j_{MarketBeta} r^j_{ShaleAnn}$$

$$0 = \sum_{j=1}^{N} w^j_{MarketBeta} r^j_{OPECAnn}$$

Likewise for the Shale Announcement Portfolio the weights solve:

$$0 = \sum_{j=1}^{N} w^j_{ShaleAnn}$$

$$0 = \sum_{j=1}^{N} w^j_{ShaleAnn} \beta^j_{Mkt,PreShale}$$

$$1 = \sum_{j=1}^{N} w^j_{ShaleAnn} r^j_{ShaleAnn}$$

$$0 = \sum_{j=1}^{N} w^j_{ShaleAnn} r^j_{OPECAnn}$$

And finally for the OPEC Announcement Portfolio:

$$0 = \sum_{j=1}^{N} w^j_{OPECAnn}$$

$$0 = \sum_{j=1}^{N} w^j_{OPECAnn} \beta^j_{Mkt,PreShale}$$

$$0 = \sum_{j=1}^{N} w^j_{OPECAnn} r^j_{ShaleAnn}$$

$$1 = \sum_{j=1}^{N} w^j_{OPECAnn} r^j_{OPECAnn}$$

Up until now we have not relied on the model, as all of the above can be done regardless of the underlying structure of returns. We now assume that all industry returns are given by

$$\left(E_{t+1}-E_t\right) r^j_{t+1} = \beta^j_a \left(E_{t+1}-E_t\right) a_{t+1} + \beta^j_{Shale} \left(E_{t+1}-E_t\right) z^{Shale}_{t+1} + \beta^j_{Other} \left(E_{t+1}-E_t\right) z^{Other}_{t+1} + \epsilon^j_{t+1}$$

The identifying assumptions we make are based on the returns on the announcement days (tildes indicate innovations), and the market beta in the pre-shale period.

$$\begin{aligned} \tilde{r}^j_{ShaleAnn} &= \beta^j_{Shale} \tilde{z}^{Shale}_{ShaleAnn} \\ \tilde{r}^j_{OPECAnn} &= \beta^j_{Shale} \tilde{z}^{Shale}_{OPECAnn} + \beta^j_{Other} \tilde{z}^{Other}_{OPECAnn} \\ \beta^j_{Mkt,PreShale} &= \frac{\beta^j_a \beta^{Mkt}_a \sigma^2_a + \beta^j_{Other} \beta^{Mkt}_{Other} \sigma^2_{Other}}{\sigma^2_a + (\beta^{Other}_{Mkt})^2 \sigma^2_{Other}} \end{aligned}$$

Here we assume that the market return pre-shale is $\tilde{r}^{Mkt}_t = \tilde{a}_t + \beta^{Mkt}_{Other} \tilde{z}^{Other}_t$. (This imposes $\beta^{Mkt}_a = 1$, so in effect it normalizes the fundamental a shocks so that the market has an exposure of 1 to these innovations.)

Now consider each characteristic portfolio's return as a function of the fundamental shocks

$$\tilde{R}^k_t = \Gamma^k_a \tilde{a}_t + \Gamma^k_{Other} \tilde{z}^{Other}_t + \Gamma^k_{Shale} \tilde{z}^{Shale}_t + \nu_t,$$

where

$$\begin{aligned} \Gamma^k_a &= \sum_{j=1}^{N} w^j_k \beta^j_{Other} \\ \Gamma^k_{Other} &= \sum_{j=1}^{N} w^j_k \beta^j_{Shale} \\ \Gamma^k_{Shale} &= \sum_{j=1}^{N} w^j_k \beta^j_a \\ \nu_t &= \sum_{j=1}^{N} w^j_k \epsilon^j_t \end{aligned}$$

The linear nature of the model means that the constraints on the weights of the characteristic portfolios can be recast as constraints on the values of Γ. First consider the weighted sum of the pre-shale market betas:

$$\begin{aligned}
&\sum_{j=1}^{N} w_k^j \beta^j_{Mkt,PreShale} \\
&= \sum_{j=1}^{N} w_k^j \left[\frac{\beta_a^j \sigma_a^2 + \beta^j_{Other} \beta^{Mkt}_{Other} \sigma^2_{Other}}{\sigma_a^2 + (\beta^{Other}_{Mkt})^2 \sigma^2_{Other}} \right] \\
&= \frac{\left(\sum_{j=1}^{N} w_k^j \beta_a^j \right) \sigma_a^2 + \left(\sum_{j=1}^{N} w_k^j \beta^j_{Other} \right) \beta^{Mkt}_{Other} \sigma^2_{Other}}{\sigma_a^2 + (\beta^{Other}_{Mkt})^2 \sigma^2_{Other}} \\
&= \frac{\Gamma_a^k \sigma_a^2 + \Gamma^k_{Other} \beta^{Mkt}_{Other} \sigma^2_{Other}}{\sigma_a^2 + (\beta^{Other}_{Mkt})^2 \sigma^2_{Other}}
\end{aligned}$$

Next consider the Shale announcement day return, recall that $r^j_{ShaleAnn} = \beta^j_{Shale} z^{Shale}_{ShaleAnn}$ by our identifying assumption, and that for simplicity it is assumed that $z^{Shale}_{ShaleAnn} = 1$:

$$\sum_{j=1}^{N} w_k^j r^j_{ShaleAnn} = \sum_{j=1}^{N} w_k^j \beta^j_{Shale} = \Gamma^k_{Shale}.$$

Finally, consider the OPEC announcement day return. Again notice that, with the normalization of $z^{Other}_{OPECAnn} = 1$, we have $r^j_{OPECAnn} = \beta^j_{Other} + \beta^j_{Shale} z^{Shale}_{OPECAnn}$, so

$$\begin{aligned}
&\sum_{j=1}^{N} w_k^j r^j_{OPECAnn} \\
&= \sum_{j=1}^{N} w_k^j (\beta^j_{Other} + \beta^j_{Shale} z^{Shale}_{OPECAnn}) \\
&= \Gamma^k_{Other} + \Gamma^k_{Shale} z^{Shale}_{OPECAnn}
\end{aligned}$$

Going back to the original systems of constraints we get a system of equations that must be satisfied for each portfolio.

Consider first the Market Beta characteristic portfolio. The loadings solve:

$$
\begin{aligned}
1 &= \frac{\Gamma_a^{MarketBeta}\sigma_a^2 + \Gamma_{Other}^{MarketBeta}\beta_{Other}^{Mkt}\sigma_{Other}^2}{\sigma_a^2 + (\beta_{Mkt}^{Other})^2\sigma_{Other}^2} \\
0 &= \Gamma_{Shale}^{MarketBeta} \\
0 &= \Gamma_{Other}^{MarketBeta} + \Gamma_{Shale}^{MarketBeta} z_{OPECAnn}^{Shale}
\end{aligned}
$$

The solutions to this are $\Gamma_{Shale}^{MarketBeta} = \Gamma_{Other}^{MarketBeta} = 0$ and $\Gamma_a^{MarketBeta} = 1 + \frac{(\beta_{Mkt}^{Other})^2\sigma_{Other}^2}{\sigma_a^2}$

Consider next the Shale Announcement characteristic portfolio; the loadings solve

$$
\begin{aligned}
0 &= \frac{\Gamma_a^{ShaleAnn}\sigma_a^2 + \Gamma_{Other}^{ShaleAnn}\beta_{Other}^{Mkt}\sigma_{Other}^2}{\sigma_a^2 + (\beta_{Mkt}^{Other})^2\sigma_{Other}^2} \\
1 &= \Gamma_{Shale}^{ShaleAnn} \\
0 &= \Gamma_{Other}^{ShaleAnn} + \Gamma_{Shale}^{ShaleAnn} z_{OPECAnn}^{Shale}
\end{aligned}
$$

The solutions to this are $\Gamma_{Shale}^{ShaleAnn} = 1$, $\Gamma_{Other}^{ShaleAnn} = -z_{OPECAnn}^{Shale}$, and $\Gamma_a^{ShaleAnn} = \frac{z_{OPECAnn}^{Shale}\beta_{Other}^{Mkt}\sigma_{Other}^2}{\sigma_a^2}$.

Lastly, consider the Opec Announcement characteristic portfolio; the loadings solve

$$
\begin{aligned}
0 &= \frac{\Gamma_a^{OPECAnn}\sigma_a^2 + \Gamma_{Other}^{OPECAnn}\beta_{Other}^{Mkt}\sigma_{Other}^2}{\sigma_a^2 + (\beta_{Mkt}^{Other})^2\sigma_{Other}^2} \\
0 &= \Gamma_{Shale}^{OPECAnn} \\
1 &= \Gamma_{Other}^{OPECAnn} + \Gamma_{Shale}^{OPECAnn} z_{OPECAnn}^{Shale}
\end{aligned}
$$

The solutions to this are $\Gamma_{Shale}^{OPECAnn} = 0$, $\Gamma_{Other}^{OPECAnn} = 1$, $\Gamma_a^{OPECAnn} = \frac{-\beta_{Other}^{Mkt}\sigma_{Other}^2}{\sigma_a^2}$.

Appendix 4 Shale Indices

Some of our analysis relies on two indices that we construct, one of companies with high involvement in shale oil production, and another of companies with high exposure to shale gas production. Here we explain the construction in detail.

Shale Oil Index The objective of our index construction is to create an asset pricing measure of shale oil development. Therefore we begin with a list of all firms that may have

Table 9: Construction of Shale Oil Index and Shale Gas Index

This table provides details on the components of the Shale Oil Index used in this study and Shale Gas Index used in this study. The firms in these indices are comprised of firms in SIC 1311 (Crude Petroleum and Natural Gas), that have significant asset focus on either Shale Oil or Shale Gas. Asset information was hand collected from company 10-Ks to make the determination whether a firm is shale oil or shale gas. Asset values are as of December 31, 2013.

Shale Oil Index

Ticker	Company Name	Primary Assets	Size (Assets in $ Millions)
EOG	EOG RESOURCES INC	Eagle Ford (Oil), Bakken (Oil)	30,574
PXD	PIONEER NATURAL RESOURCES CO	Permian (Oil), Eagle Ford (Oil)	12,293
CLR	CONTINENTAL RESOURCES INC	Bakken (Oil)	11,941
CXO	CONCHO RESOURCES INC	Permian (Oil)	9,591
WLL	WHITING PETROLEUM CORP	Bakken (Oil)	8,833
EGN	ENERGEN CORP	Permian (Oil)	6,622
HK	HALCON RESOURCES CORP	Bakken (Oil)	5,356
OAS	OASIS PETROLEUM INC	Bakken (Oil)	4,712
KOG	KODIAK OIL & GAS CORP	Bakken (Oil)	3,924
ROSE	ROSETTA RESOURCES INC	Bakken (Oil), Eagle Ford (Oil)	3,277
CRZO	CARRIZO OIL & GAS INC	Eagle Ford (Oil)	2,111
NOG	NORTHERN OIL & GAS INC	Bakken (Oil)	1,520
AREX	APPROACH RESOURCES INC	Permian (Oil)	1,145
CPE	CALLON PETROLEUM CO	Permian (Oil)	424
USEG	U S ENERGY CORP	Bakken (Oil), Eagle Ford (Oil)	127

Shale Gas Index

Ticker	Company Name	Primary Assets	Size (Assets in $ Millions)
CHK	CHESAPEAKE ENERGY CORP	Barnett Shale (Gas), Haynesville Shale (Gas)	41,782
RRC	RANGE RESOURCES CORP	Marcellus Shale (Gas)	7,299
COG	CABOT OIL & GAS CORP	Marcellus Shale (Gas)	4,981
XCO	EXCO RESOURCES INC	Haynesville Shale (Gas)	2,409
CRK	COMSTOCK RESOURCES INC	Haynesville Shale (Gas)	2,139
MHR	MAGNUM HUNTER RESOURCES CORP	Marcellus Shale (Gas), Utica Shale (Gas)	1,857
KWK	QUICKSILVER RESOURCES INC	Barnett Shale (Gas)	1,370
FST	FOREST OIL CORP	Haynesville Shale (Gas)	1,118
REXX	REX ENERGY CORP	Marcellus Shale (Gas), Utica Shale (Gas)	991
GDP	GOODRICH PETROLEUM CORP	Haynesville Shale (Gas)	974

direct shale oil exposure, that is, those firms that are SIC 1311 (Crude Petroleum and Natural Gas). We then manually collect data from the 10-Ks of these firms to assess whether a firm's assets are primarily located in areas of significant shale oil development. We exclude firms that have significant international or offshore assets, as well as firms with significant shale or non-shale natural gas assets and non-shale oil exposure. We then verify that the remaining firms have significant operating assets in the Eagle Ford Shale (TX), the Bakken Shale (ND), or the Permian Basin (TX), as these are the primary areas of shale oil development in the United States. In Table 1 we list the firms that met these criteria and report where the index components have assets.

Shale Gas Index The shale gas index was constructed in a similar manner to the shale oil index. The primary objective of our shale gas index is to have an asset pricing measure of firms with a significant asset focus on shale gas. We start with the full set of firms that are SIC 1311 (Crude Petroleum and Natural Gas) and manually collect data on a firm's assets. We only include firms in our index that have assets in the major shale gas basins: Marcellus Shale (PA, WV), Barnett Shale (TX), Haynesville Shale (TX, LA), and Utica Shale (OH). Any firm whose asset focus could not be definitively categorized in these basins was excluded. Therefore, international firms, offshore firms, shale and non-shale oil firms, and non-shale natural gas firms are all excluded from this index. In Table 1 we list the firms that met the above criteria, we also report which shale gas basins firms have assets in.

Appendix 5 Shale Oil Earnings Announcements and Aggregate Stock Returns

A potential approach to estimating the contribution of shale oil to the stock market would be to directly use the returns to shale oil firms described above. In order to address the issue of causality, we would like to identify exogenous shocks to shale oil firm values that can act as an instrument for returns to the Shale Oil Index. An ideal instrument would be an announcement, or series of announcements, which provide information about shale oil production without providing material information about other important economic shocks (e.g., Savor and Wilson (2014) show that announcement dates capture the bulk of priced shocks to firm cash flows). Unfortunately, while there are announcements made by government agencies regarding oil production, they do not appear to have a material impact on the returns to oil firms, suggesting that they are not a source of new information. Instead we look at information provided by the shale oil companies' themselves as part of their regular earnings announcements, which should be private prior to the announcements as it is material to the value of the companies.

For this exercise we focus on the last two years of the sample, during which the R^2 of the market return on the Shale Shock is high and we see the largest increase in shale oil production. Though we have many companies in the Shale Index, the information released by different companies over a short time period is likely highly correlated, and therefore may become rapidly redundant. To this end, we focus on the two largest companies (in terms of shale oil assets) in the index, EOG Resources (EOG) and Pioneer Resources (PXD). To construct a measure of new information in the earnings reports, we focus on a measure of unanticipated revenue surprise, which is simply the log of the ratio of actual reported revenue to the average analyst projected revenue in the Thomson Reuters' IBES database.

We construct 15 observations, which represent announcements related to Q2 2012 to Q1 2014, with the exception of Pioneer's 2014 Q1, which is not in the IBES database. Since the earnings reports are released after market close on the announcement day, we match the revenue surprise measure to returns over the next trading day. The standard method for this analysis is a two stage least squares (2SLS) regression of R^{MKT} on $R^{ShaleOil}$, using the measure of revenue surprise as instrument for returns to the shale oil index. However, due to the well-known poor statistical properties of this procedure (especially acute in our very small sample), it may be preferable to focus on the reduced form specification of the IV regression, as suggested by Chernozhukov and Hansen (2008). Table 10 shows the results for both procedures. The OLS regressions of returns to the shale index, as well as returns to the aggregate market index, against the revenue surprise from the two firms' announcements, can be interpreted as the first stage and the reduced form specifications, respectively. Both variables show a clear positive relation with the revenue surprise of these shale firms. Even with only 15 observations, the relationship between both return variables and the revenue surprise variable is significant at the 5% level, and in fact at 1% level for the shale index return. The reduced form regression has a high R-squared of 19% for market returns on shale firms' revenue surprise. Consistent with the reduced form results, the 2SLS regression of the market excess return on the shale index return instrumented with the shale firms' surprise also recovers a strong, statistically significant relation.

As a confirmation that this relation between shale oil revenue surprise and the aggregate market return on these days is not being driven by other information revealed in the announcements, as a placebo test we repeat the analysis using the same 15 days' returns against the average revenue surprise across all firms reporting on these days. We find that there is no relation between these announcements and either shale oil returns or aggregate market returns (both the regression coefficients and the R-squared are essentially zero in all of the specifications), suggesting that information revealed in shale oil announcements is important for aggregate market returns.

Table 10: Stock Market Returns on Shale Announcement Days

	PXD and EOG Revenue Surprises			Market Avg. Revenue Surprises		
Method:	OLS	OLS	2SLS	OLS	OLS	2SLS
	$R^{ShaleOil}$	R^{Mkt}	R^{Mkt}	$R^{ShaleOil}$	R^{Mkt}	R^{Mkt}
Surprise	0.213***	0.040**		0.102	-0.043	
	(0.046)	(0.017)		(0.347)	(0.123)	
$R^{ShaleOil}$			0.186**			-0.418
			(0.074)			(3.089)
Constant	0.005	0.002	0.001	0.015**	0.003	0.010
	(0.005)	(0.002)	(0.002)	(0.006)	(0.002)	(0.046)
Observations	15	15	15	15	15	15
R-squared	0.550	0.190	0.551	0.003	0.006	0.001

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table shows results of regressions of both Shale Industry and Aggregate Market returns on 15 earnings announcements for EOG Resources (EOG) and Pioneer Resources (PXD) from second quarter 2012 to third quarter 2014. For each earnings announcement a revenue surprise measure is constructed using IBES estimates and realized revenue announcements. In the first two columns this revenue surprise is then used as the independent variable in regressions of the corresponding daily return to the Shale Oil Index $R^{ShaleOil}$, and the aggregrate R^{Mkt}. In the third column, the surprise is used as an instrument for $R^{ShaleOil}$ in a 2SLS regression with R^{Mkt} as the dependent variable. The last three columns repeat this analysis using the average revenue surprises from all other firms on those days as a placebo test.

Appendix 6 Announcement Returns, Betas, and Portfolio Weights

Table 11 reports the details of industry portfolio returns on the Shale Discovery Day as well as the OPEC Announcement Day, as well as the estimates of their betas with the market portfolio using the time periods 01/2003-07/2008 (Pre-Crisis) and 07/2008-06/2009 (Crisis). The right-hand side panel displays the corresponding characteristic portfolio weights of each industry in the Characteristic portfolios.

Table 11: Industry Announcement Returns, Betas, and Portfolio Weights

		Announcement Returns and Market Betas				Characteristic Portfolio Weights			
	Industry	Shale Discovery	OPEC Announc.	Pre-Crisis Beta	Crisis Beta	Shale Discovery	OPEC Announc.	Pre-Crisis Beta	Crisis Beta
	Shale Oil Producers	6.95	-10.36	0.81	1.48				
	S&P Integrated Oil & Gas	-0.04	-5.38	0.82	0.79				
	Shale Gas Producers	3.60	-6.89	0.93	1.88				
1	Oil and Gas Drilling	2.66	-9.04	0.90	1.43	3.71	-5.16	-0.64	-0.36
2	Business Services	3.03	0.05	1.10	1.09	3.54	-0.15	0.19	-0.59
3	Engineering Services	2.96	-2.70	1.43	1.46	3.44	-2.04	2.25	-1.13
4	Copper Production	2.74	-2.03	1.24	0.93	3.12	-2.36	2.64	-3.26
5	Clothes	2.74	1.29	1.10	1.26	2.65	1.31	-0.87	1.10
6	Railroads	2.32	-5.13	1.07	1.08	2.52	-3.59	1.33	-2.25
7	Guns and Weaponry	2.55	-0.28	1.25	1.07	2.40	-0.70	1.75	-1.73
8	Ground Transportation	2.51	2.06	0.95	0.88	2.23	1.35	-0.75	-0.22
9	Boxes and Containers	2.43	0.35	1.05	0.98	2.15	0.13	0.19	-0.80
10	Wholesale	2.35	-0.59	1.13	1.01	2.04	-0.66	0.99	-1.42
11	Construction Products	2.18	-3.78	1.14	1.33	1.90	-2.12	0.64	-0.52
12	Industrial Equipment	2.24	-2.39	1.31	1.14	1.87	-2.08	2.52	-2.33
13	Concrete and Cement Producers	2.39	-3.26	1.33	2.37	1.82	0.42	-2.20	5.49
14	Paper Products	2.36	0.45	1.21	1.54	1.69	1.27	-0.78	2.05
15	Stone Quarrying	2.22	-0.36	1.24	1.28	1.55	-0.03	0.77	-0.16
16	Car Manufacturing and Sales	2.12	0.20	1.29	1.43	1.17	0.65	0.47	0.73
17	Marine Transport	2.06	-0.27	1.19	1.48	1.11	0.74	-0.48	1.53
18	Gas Pipelines	1.64	-4.40	0.57	0.91	1.10	-1.91	-2.46	0.09
19	Mining Equipment	1.69	-7.31	0.95	1.72	1.08	-2.94	-1.73	2.10
20	Optical Equipment	2.14	2.10	1.44	1.33	0.95	1.36	1.71	-0.14
21	Game and Toy Manufacturing	2.05	1.69	1.22	1.32	0.90	1.66	-0.08	1.00
22	Tobacco	1.70	1.18	0.47	0.40	0.81	1.00	-2.57	-0.76
23	News Media	1.88	0.96	0.78	1.28	0.78	2.30	-3.57	3.23
24	Shipbuilding	1.77	0.50	0.89	0.86	0.69	0.59	-0.71	-0.44
25	Insurance	1.82	0.05	0.87	1.35	0.67	1.60	-2.81	2.82
26	Water Utility	1.67	-1.12	0.98	0.79	0.65	-1.01	0.85	-2.12
27	Radar and Sensor Systems	1.69	-0.16	0.96	0.80	0.59	-0.21	0.32	-1.52
28	Game and Toy Stores	1.81	1.23	0.97	1.14	0.56	1.60	-1.33	1.16
29	Oil Pipelines	1.36	-5.22	0.52	0.98	0.51	-2.08	-2.96	0.62
30	Design Firms	1.76	0.27	1.30	0.94	0.50	-0.50	2.67	-2.57
31	Furniture Production	1.78	-0.26	1.08	1.45	0.49	1.09	-1.34	2.10
32	Aircraft Production	1.70	-0.11	1.09	1.07	0.45	0.16	0.38	-0.53
33	Power Generation Equipment	1.73	-1.74	1.63	1.45	0.34	-1.52	3.98	-1.94
34	Research and Development	1.56	0.52	0.89	0.61	0.30	0.00	0.37	-2.13
35	Scientific Instruments	1.63	-0.02	1.21	0.92	0.27	-0.45	1.99	-2.18
36	Other Oil Firms	1.20	-8.69	0.84	1.45	0.25	-4.19	-1.16	0.50
37	Retail Banking	1.66	-0.29	1.11	1.37	0.24	0.78	-0.65	1.32
38	Media Entertainment	1.71	1.00	1.07	1.35	0.23	1.75	-1.23	1.88
39	Plastics	1.41	-2.58	1.11	0.89	0.13	-2.03	1.90	-2.66
40	Defense and Military	1.65	1.16	1.05	1.23	0.13	1.63	-0.96	1.29
41	Financials	1.78	0.20	1.54	1.77	0.12	1.00	1.25	1.57
42	Office Equipment	1.59	0.01	1.11	1.19	0.10	0.55	0.03	0.23
43	Passenger Airlines	1.91	5.64	1.42	1.22	0.05	3.74	1.14	0.52
44	Restaurants	1.48	1.02	0.99	0.79	-0.05	0.59	0.37	-1.33
45	Natural Gas Production	1.28	-2.85	0.75	1.01	-0.07	-0.90	-1.63	0.26
46	Home Products	1.34	1.06	0.53	0.51	-0.10	1.19	-2.49	-0.33
47	Hotels	1.70	0.92	1.15	2.05	-0.10	3.34	-3.46	6.12
48	Liquor Producers	1.40	1.83	0.68	0.66	-0.16	1.71	-2.00	0.01
49	Food Production	1.25	0.87	0.56	0.55	-0.33	1.10	-2.31	-0.33
50	Waste Management	1.14	-0.61	0.83	0.58	-0.53	-0.58	0.29	-2.28
51	Commercials Banking	1.36	-0.33	1.04	1.80	-0.60	2.17	-2.99	4.65
52	IT Services	1.13	-0.02	1.21	0.91	-0.90	-0.32	2.12	-2.20
53	Petroleum Refining	0.78	-6.85	0.86	1.30	-0.91	-3.15	-0.82	0.17
54	Communications	1.13	0.53	1.11	0.89	-0.91	0.31	1.16	-1.48
55	Medical Equipment	0.99	0.46	0.76	0.71	-1.02	0.78	-1.14	-0.55
56	Electrical Equipment	1.10	-0.44	1.31	1.19	-1.07	-0.14	1.90	-1.06
57	Personal Services	0.96	0.64	0.74	0.77	-1.13	1.14	-1.61	0.07
58	Telephone Communications	1.11	0.63	1.45	0.98	-1.16	-0.29	3.71	-2.92
59	Commercial Equipment	1.05	0.33	1.40	0.93	-1.23	-0.50	3.62	-3.08
60	Retail Sales	0.96	1.44	1.00	0.84	-1.37	1.20	0.17	-0.76
61	Agriculture and Farming	0.82	-0.79	0.72	1.02	-1.39	0.84	-2.37	1.30
62	Electricity Production	0.82	0.95	0.67	0.72	-1.46	1.47	-2.07	0.29
63	Home Construction	0.93	-1.61	1.44	1.47	-1.49	-0.55	2.21	-0.41
64	Rubber Products	1.03	0.34	1.49	1.73	-1.64	1.38	1.06	1.77
65	Pharmaceuticals	0.67	0.49	0.66	0.51	-1.67	0.66	-1.16	-1.20
66	Software	0.76	0.44	1.07	0.80	-1.73	0.24	1.26	-1.82
67	Aluminum Refining	0.78	-2.86	1.40	2.02	-1.91	0.16	-0.11	3.14
68	Other Metal Mining	0.68	-3.85	1.51	1.85	-2.00	-1.26	1.81	0.98
69	Real Estate Trusts	0.53	-0.37	0.80	1.07	-2.19	1.18	-1.99	1.40
70	Gas Stations	0.29	-0.25	0.82	0.51	-2.53	-0.20	0.54	-2.45
71	Farm Equipment	0.42	-0.77	1.28	1.44	-2.74	0.60	0.77	0.80
72	Lumber	0.32	0.40	1.19	1.45	-3.08	1.73	-0.30	1.82
73	Chemical Producers	0.07	-1.35	1.10	1.00	-3.23	-0.36	1.17	-1.18
74	Steel Production and Refining	0.12	-2.24	1.47	1.64	-3.41	-0.36	2.02	0.48
75	Coal Mining	-0.51	-3.69	1.34	1.69	-4.71	-0.71	1.12	1.16
76	Gold Mining	-0.99	-7.66	0.86	1.19	-4.97	-3.43	0.07	-0.63