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

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August 30, 2018

Abstract

We provide evidence that technology shocks linked with shale oil development play an important role in explaining the aggregate stock market run-up from 2012 to 2015. This evidence comes from a novel empirical method employed to identify the effect of unobservable fundamental shocks on stock market prices. Specifically, we rely on the cross section of returns on days of important news announcements to quantify exposures to these fundamental shocks, and utilize these exposures to construct mimicking portfolios. Applying our method to monetary policy shocks we find they can explain the stock market recovery after the crisis, but not the increases post-2011.

*We thank Ing-Haw Cheng, John Cochrane, Thomas Covert, Stefano Giglio, Wayne Ferson, Michael Johannes, Lars Hansen, John Heaton, Marcin Kacperczyk, Ryan Kellogg, Christopher Knittel, Leonid Kogan, Owen Lamont, Erin Mansur, Luboš Pastor, Dimitris Papanikolaoau, Lasse Pedersen, Amit Seru, Andrei Shleifer, Amir Sufi, Pietro Veronesi, Ivo Welch, Toni Whited, 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, Binghampton, Cass Business School, Chicago Booth, Copenhagen Business School, Goethe University Frankfurt, University of Michigan (Ross), Norwegian School of Management, Oxford (Said), Richmond Fed, 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

Identifying sources of common variation in stock returns is one of the key challenges in asset pricing. Motivated by recent literature that focuses on important economic announcements, we propose an alternative approach based on exploiting cross-sectional variation in returns on announcement days that are likely to capture important sources of common shocks.[1] The intuition for this approach is that returns on important announcement days contain large amounts of information about economic fundamentals, relative to "noise," and thus help reveal the underlying economic shocks driving asset prices.[2] We utilize this methodology to quantify to candidate sources of variation in aggregate stock prices over the recent period: monetary policy shocks and innovations in shale oil technology.

Our approach relies on the familiar Fama-MacBeth regression methodology. It is well known that slopes of cross-sectional regressions of returns on characteristics and/or covariances (betas) are themselves returns on trading strategies constructed to emphasize a particular characteristic (while controlling for others).[3] We utilize announcement day returns as such "characteristics" in constructing portfolios that track common sources of variation that they capture (alternatively, we also use covariances estimated on sets of announcement days).[4] The key identifying assumption is that returns on an announcement day are dominated by the common shock that originates from the announcement itself, rather than asset-specific

[1]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 policy announcements, e.g. Bernanke and Kuttner (2005), Savor and Wilson (2014), and Lucca and Moench (2015).

[2]This intuition is formalized by Andrei, Cujean and Wilson (2018), who show that it can rationalize the findings of Savor and Wilson (2014) that CAPM betas line up well with average returns on Federal Open Market Committee (FOMC) decision announcement days.

[3]The intuition for relying on cross-sectional variation to construct factor-mimicking portfolios goes back at least to Fama (1976). Back, Kapadia and Ostdiek (2013) show that using characteristics rather than covariances as right-hand-side variables, which comprise the weights of individual assets in these portfolios helps alleviate the errors-in-variables problem that plagues beta estimation.

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

"noise." Thus announcement day returns serve as proxies for the assets' loadings on the *unobserved* common factor(s).

We begin by focusing on monetary policy news, as a potential driver of stock market valuation through either a discount rate (e.g., Drechsler, Savov and Schnabl (2018)) or cash-flow (e.g., Ozdagli and Weber (2017)) channel.[5] Specifically, we focus on the days when the Federal Reserve announced outcomes of FOMC meetings and, in particular, its decisions to conduct large asset purchases ("quantitative easing" or QE henceforth). There is considerable interest in understanding and quantifying the impact of monetary policy (conventional and unconventional) on asset prices.[6] Indeed, the strong equity market responses to accommodative policy announcements by the Federal Reserve, as originally documented by Bernanke and Kuttner (2005), suggest that monetary policy shocks are an important driver of commonality in asset price fluctuations. Yet for an econometrician these shocks are difficult to observe directly, especially outside of the announcements themselves, which are the focus of much of the literature (e.g., Gorodnichenko and Weber (2016), Ozdagli and Velikov (2017), English, Van den Heuvel and Zakrajek (2018)). News about future monetary policy might be revealed between meetings, in the form of speeches by FOMC members, release of meeting minutes and of new macroeconomic data, etc., but isolating their impact on asset prices directly in the presence of a multitude of coincident sources of news is a daunting task, which is obviated by our approach.

Using a large cross-section of industry portfolio returns we show that returns on the FOMC announcement days do a good job of capturing market betas of industries, especially during the period of the financial crisis and the Great Recession. These announcement day returns

[5] In models with financial frictions where monetary policy affects the cost of external finance the two channels are intertwined, e.g. Ozdagli (2017).

[6] In particular, there is an active ongoing debate in the literature about the magnitude of QE impact on *bond* prices, e.g. Krishnamurthy and Vissing-Jorgensen (2011), Wright (2012), Neely (2014), D'Amico and King (2013), Gorodnichenko and Ray (2017), and Greenlaw, Hamilton, Harris and West (2018), among others.

(or their betas) serve us as weights, yielding a portfolio that goes long industries exhibiting a positive response on these days and short those that have a negative response (relative to the average), in proportion to their magnitude. Such a portfolio tracks the aggregate stock market index very closely both before the financial crisis and throughout the Great Recession, consistent with a view that aggregate macroeconomic conditions constituted the main factor affecting asset price fluctuations during the late 2000-s. However, such a portfolio cannot explain any of the market run-up after mid-2011, suggesting that accommodative monetary policy was not the primary driver of asset market valuations during this more recent time period.[7] Thus, we pursue an alternative candidate driver of common variation: technology.

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.[8] 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. As with monetary policy shocks discussed above, our 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 sometimes

[7]Our findings are in sharp contrast with a popular view that lax monetary policy helped "inflate" stock prices post-2011, even though that view may appear consistent with some existing evidence from earlier time periods, e.g. Bekaert, Hoerova and Duca (2010), Christiano, Ilut, Motto and Rostagno (2010). However, it is largely consistent with the evidence in Chodorow-Reich (2014) that the effect of unconventional monetary policy on risk-taking by financial institutions, the key element of the "discount rate" channel, did not extend beyond 2013.

[8]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.

the *arrival* of relevant public news announcements on technology innovations is observable.[9] Using the stock market reaction to the news allows us to estimate the exposures of various assets to the underlying unobservable shocks.

As a salient example of technology shocks that can have economy-wide consequences, we focus on innovations in the production of petroleum. Beginning in 2012 the United States began to experience a technological revolution in hydraulic fracturing ("fracking") and horizontal drilling for the extraction of oil, leading to a doubling of domestic oil production. Between 2012 and 2016 $455 billion of crude oil was extracted with fracking technology in the United States, while an additional $4.2 trillion of technically recoverable reserves have been identified.[10] To estimate the total contribution of shale oil technology to the fluctuations in the aggregate U.S. stock market index over time we construct a "shale mimicking portfolio" designed to track the unobservable innovations in shale technology over time. To construct the mimicking portfolio, we rely each industry's stock price changes in response to the disclosure of a major breakthrough in shale oil extraction in the summer of 2013. This breakthrough represents the largest shale oil discovery to date, amounting to a 35% increase in expected recoverable oil reserves from the second largest oil field in the world.

We use this Shale Discovery 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

[9] 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 (2017) linking news on patented technologies to equity returns.

[10] Technically recoverable reserves are based on reserves estimated by the U.S. Energy Information Administration in its World Shale Resources Assessment dated September 24, 2015, and March 2017 oil prices of $53.83/BBL.

create such an asset, again building on the classic approach of 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 unobservable innovations in shale technology, and assess the explanatory power of this portfolio for market returns over different time periods.

We find that exposure to the Shale Discovery portfolio has strong explanatory power for aggregate stock market returns from 2012 to Q3 2015. In total, based on the point estimate of our regressions, shale oil development is responsible for $3.8 trillion of the increase in stock market value during this time period.[11] While this effect is large relative to the pre-2012 U.S. stock market capitalization of $15.62 trillion, it is consistent with the size of the reserves that have been found ($4.2 trillion). However, one should take care in comparing this magnitude to the overall realized increase in U.S. stock market capitalization, as there are likely other countervailing shocks and favorable shocks that affected the overall change in stock market capitalization. The effect we identify should be viewed as the effect that shale technology has holding all other factors constant.

We undertake several exercises to assess alternative explanations of our results in order to validate the empirical methodology based on announcement returns. We demonstrate that the Shale Discovery portfolio is indeed closely linked with real measures of shale activity contemporaneously and predicts future rig count changes, which would be expected to vary in response to innovations in the shale technology.Thus a confounding factor affecting stock prices in our announcement estimation would also need to be correlated with real measures of shale activity over time. In fact, we find that the shale discovery day is the only day in our sample period that can be used to construct a factor that explains the time-series variation in

[11] We perform two sets of robustness exercises on this magnitude. First we construct a mimicking portfolio based on firms directly involved in shale extraction and obtain similar economic magnitudes. Second, we estimate magnitudes while allowing the market exposure to the shale oil mimicking portfolio to change over time by estimating rolling betas during the shale oil time period, and obtain similar results.

both the aggregate market return, returns on shale oil firms, as well as predict shale-related real activity in a statistically robust way. At the same time, we demonstrate that the cross-sectional variation in returns experienced by industry portfolios on this day is unrelated to measures of aggregate risk exposure such as market betas over the prior (pre-shale) period or to industry returns experienced on days of major macroeconomic announcements, such as the FOMC meetings. Lastly, we estimate our main specifications for earlier time periods as a falsification and find that our shale exposure mimicking portfolio has no explanatory power in the time periods when shale oil production was virtually nonexistent.

Our final empirical exercise measures whether the economic impact of shale oil that we measure using asset prices corresponds to 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 the aggregate, we estimate that during the shale oil period 4,600,000 (net) new jobs are linked with the development of shale oil technology. This represents a 4.2% increase in the number of jobs across the industries in our study, compared to the aggregate number of jobs at the beginning of the shale oil period.[12] The benefits of the shale technology shock do not all accrue to a single firm or industry. Our Shale Discovery portfolio based on announcement returns captures the set of direct and indirect industry spillovers associated with this technology. For example, the railroads that benefit because they transport crude oil, or the manufacturers that provide inputs for well construction benefit from a "supply-chain effect.' In terms of the direct cash flow effect shale oil has had on the economy thus far, $455

[12]These magnitudes are consistent with estimates in the existing literature for the effects of shale gas (primarily) on employment (Hausman and Kellogg (2015), Feyrer, Mansur and Sacerdote (2015), and Allcott and Keniston (2014)). We discuss this in detail in section 3.7.

billion of crude oil has been produced, of which $100 billion has been paid out directly as royalty payments to individual mineral owners.[13] These dollar values are on the same order of magnitude as other major economic stimuli, such as QE1 ($600 billion, Nov 2008), QE1 ($1.15 trillion, March 2009), QE2 ($600 billion), Bush 2001, 2002, and 2003 tax cuts ($188 billion). This is a comparison only of the direct cash flow that has been generated thanks to the technology so far, not the $4.2 trillion endowment of reserves that has been created, but yet to be extracted, of which $918 billion will accrue to individual mineral owners. Such effects linked with the income derived from shale can be thought of as an "income effect.'[14] 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."

Our empirical findings are meant to illustrate the fact that announcement day returns can be useful for extracting time series of economy-wide shocks from the cross-section of asset returns, despite not being able to observe these shocks directly. Undoubtedly, shale oil technology has not been the only source of technological innovation that had a non-trivial effect on asset prices in the recent decade, nor has it likely been the only important common shock to affect asset prices. We believe our empirical design provides a framework to facilitate the exploration of economically important common shocks that affect asset prices more broadly.

[13] Royalty rates typically equate to 18.75% to 25% of the value of the crude oil extracted. This figure is based on the midpoint of these royalty rates.

[14] There is a large literature attempting to quantify the economic impact of oil shocks on the real economy as well as asset prices, e.g. Hamilton (1983), Jones and Kaul (1996), 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), Ready (2016), and numerous others. Hausman and Kellogg (2015) estimate the benefits of the shale *gas* revolution on consumers. Arezki, Ramey and Sheng (2015) use large oil discoveries across countries to analyze the effect of news about *future* productivity on economic activity. Since asset prices are forward looking, the stock market should capture news about both short- and long-run productivity innovations (e.g., Beaudry and Portier (2006)).

2 Monetary Policy News

In this section we introduce our methodology by examining the impact of monetary policy on stock market returns around the Financial Crisis. A number of recent papers study the behavior of asset prices around FOMC meetings and find that monetary policy news is important for asset prices. In particular, Bernanke and Kuttner (2005) find that the aggregate stock market responds significantly to the announcements made after these meetings. However, these papers typically examine the small subset of FOMC meeting days, and are thus ill-suited to evaluate the aggregate effects of monetary policy on stock valuations. Another strand of recent literature focuses on Federal Funds futures (FFF) market as a measure of monetary policy shocks perceived by financial market participants, both on an outside of announcement days - e.g., Campbell, Evans, Fisher and Justiniano (2012). However, the focus of the Federal Reserve on unconventional monetary policy targeting long-term assets (such as Treasury bonds and mortgage-backed securities) through both QE and forward guidance during the "zero lower bound" period suggests that short-term-rate futures may not be the most informative about the direction and broad effects of policy during this time period.

In order to try and quantify these effects, including the impact of news about monetary policy that occurs outside of FOMC meeting dates, we utilize characteristic portfolios in the manner of Back et al. (2013). The returns to these portfolios are constructed as the period-by-period slopes of Fama-Macbeth style cross-sectional regressions, using a firm or portfolio characteristic as the independent variable. However instead of using firm characteristics such as size or book-to-market, we instead use measures of industry exposure FOMC announcements.[15] We can then examine the aggregate performance of these portfolios on all days, including those outside FOMC annoucnements.

We pursue two different, but similar, approaches to constructing these portfolios. First

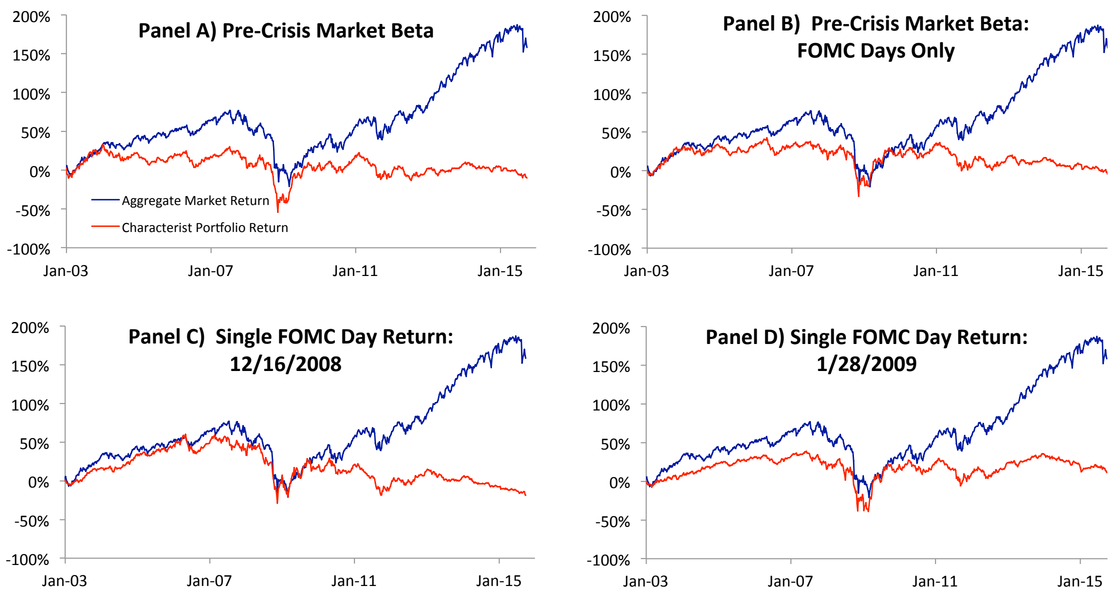
[15] See Appendix 3 for description of our industry portfolios.

we rely on the observation of Savor and Wilson (2014) that returns on FOMC days generally align with market betas. Specifically, we measure the market beta of each industry using all weekly returns in the pre-crisis period (01/2003 to 06/2008). To focus specifically on FOMC days, we then repeat this exercise but calculate industry market betas using only days in the pre-crisis period with FOMC announcements. Panels A and B of of Figure 1 plot the cumulative returns to these two portfolios along with the aggregate stock market return over this period. As the plots show, the returns to these portfolio largely track the market in the periods before and during the financial crisis of 2008 and the recovery of 2009. However, these policy-mimicking portfolios have no positive returns after 2010, a period in which the U.S. equity market capitalization nearly doubled. Another notable result from these plots is that FOMC beta portfolio, constructed using a much smaller set of days, has remarkably similar patterns to the first portfolio.

This evidence suggests that one does not to observe returns on a large number of days to generate a portfolio which captures the underlying dynamic behavior of a common source of asset price fluctuation. To emphasize this, we go further and construct two portfolios that each use a *single day's* return as the characteristic to construct the portfolio. Here we focus on the subset of FOMC announcements with news about the Federal Reserve's Quantitative Easing (QE) as identified by Wright (2012), and use the two days during the crisis period with the largest positive stock market reaction (December 16th, 2008 and January 28th, 2009). The returns on these days, scaled by the market return on each day, are our characteristics used to construct portfolios. Intuitively, these portfolios go long industries with large positive returns on these days, and short industries with low or negative returns.

Panels C and D of Figure 1 plot the cumulative returns to these portfolios along with the aggregate return to the stock market from January 2003 to September of 2015. Again we find that the patterns of these portfolios is remarkably similar to the portfolios constructed using

Figure 1: Market Beta and FOMC Characteristic Portfolios Cumulative Returns



This figure shows cumulative returns to four characteristic portfolios related to Market Betas and FOMC meeting days. The characteristic portfolios are the weekly slope coefficients from cross-sectional regressions of 79 industry returns on the chosen characteristic. For the first portfolio, the characteristic is each industry's market beta measured using weekly returns in the pre-crisis period (01/2003 to 06/2008). The second portfolio repeats this exercise but uses betas measured using only FOMC day returns in the pre-crisis period. These two portfolios' cumulative returns are plotted in Panels A and B respectively. For the last two portfolios, the characteristics are each industry's daily return on two single FOMC days with major announcements related to the Federal Reserve's Quantitative Easing program (12/16/2008, 1/28/2009). These two portfolios' cumulative returns are plotted in Panels C and D respectively. The cumulative market return is also plotted in each panel. All characteristic portfolio returns are scaled so they have the same standard deviation as the market return over the period.

betas. These portfolios appear to capture the stock market decline during the financial crisis as well its subsequent recovery, but cannot explain the large increases in market valuations since 2010.

Table 1 provides further support for these findings. Panel A shows the correlation matrix of the four characteristic portfolios. All of the portfolio returns are highly correlated with each other. For instance, the correlations of the two portfolios constructed from individual FOMC day returns and the FOMC beta portfolio are both above 0.85. Interestingly, these portfolios are more strongly correlated with the FOMC beta portfolio than with the full-sample market beta portfolio (roughly 0.8), suggesting that focusing on FOMC days does provides a better measure of industries' exposure to the subsequent monetary policy announcements.

To examine how these portfolios relate to aggregate stock returns, Panels B and C of Table 1 show the results of univariate time series regressions of the aggregate market returns on returns to the six characteristic portfolios. Here we further split the period into four subperiods. We focus on a "pre-crisis" period from January 2003 to June of 2008, the "crisis" period from July 2008 to June 2009, which encompasses both the onset of the financial crisis and the initial recovery, the "post-crisis" period from July 2009 to December 2011, and finally the more recent period from January 2012 to September 2015. All of the portfolios yield similar findings. The aggregate market moves closely with the various characteristic portfolios across all sub periods, with the exception of the the most recent time period. In this period the R^2 of the characteristic portfolios falls, while at the same time the market exhibits large positive returns which are unexplained by increases in the FOMC characteristic portfolios.

Taken together these results suggest that using these approaches yields consistent characteristic portfolios, and this is true even if we rely upon a single day's returns (as long as that day contains particularly important news). Moreover, when this method is used in the context of FOMC announcements, we see that these portfolios can explain the immediate recovery after the crisis, but cannot explain the large increase in stock market valuations since 2012.[16] In the remainder we provide evidence of an alternative driver of aggregate fluctuations reflected in asset prices, in particular a series of technological innovations in the U.S. energy production, and utilize our method of characteristic portfolios to quantify this effect.

3 Technological Innovations: Fracking and Drilling

3.1 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

[16] We do not take a stand here on the *causal* impact of monetary policy on asset prices. It is possible that the sensitivity of asset prices to announcements made by the Federal Reserve is due to the information channel emphasized by Nakamura and Steinsson (2013). In either case, however, the evidence is consistent with the view that macroeconomic conditions are the driving force of asset price fluctuations.

Table 1: FOMC and Market Beta Characteristic Portfolios

This table shows correlations and regression results for four characteristic portfolios related to Market Betas and FOMC meeting days. The characteristic portfolios are the weekly slope coefficients from cross-sectional regressions of 79 industry returns on the chosen characteristic. For the first portfolio, the characteristic is each industry's market beta measured using weekly returns in the pre-crisis period (01/2003 to 06/2008). The second portfolio repeats this exercise but uses betas measured using only FOMC day returns in the pre-crisis period. For the last two portfolios, the characteristics are each industry's daily return on two single FOMC days with major announcements related to the Federal Reserve's Quantitative Easing program (12/16/2008, 1/28/2009). Panel A shows the correlations of the four portfolios across the entire sample. Panel B shows the results of time-series regressions of weekly aggregate market returns on the weekly returns to the two beta characteristic portfolios for four subperiods: the pre-crisis period, the financial crisis (07/2008 to 06/2009), post-crisis (07/2009 to 12/2011), and the shale period (12/2012 to 09/2015). Panel C repeats these regressions using the two Single Day FOMC portfolios as independent variables.

Panel A: Covariance Matrix for Characteristic Portfolios

	Market Betas		Single FOMC Day Returns	
	Pre-Crisis Period	Pre-Crisis Period FOMC Days	12/16/08	1/28/09
Market Betas				
Pre-Crisis Period	1.000			
Pre-Crisis FOMC Days	0.950	1.000		
Single FOMC Day Returns				
12/16/08	0.784	0.880	1.000	
1/28/09	0.805	0.853	0.803	1.000

Panel B: Regressions of Market Returns on Market Beta Characteristic Portfolios

	Market Return				Market Return			
Market Betas	Pre-Crisis	Crisis	Post-Crisis	Shale Period	Pre-Crisis	Crisis	Post-Crisis	Shale Period
Pre-Crisis period	0.56***	0.65***	0.81***	0.55***				
	(0.03)	(0.09)	(0.05)	(0.05)				
Pre-Crisis FOMC Days					0.74***	0.80***	0.97***	0.55***
					(0.04)	(0.10)	(0.06)	(0.06)
Constant	0.12	-0.18	0.33**	0.27***	0.08	-0.28	0.38***	0.28***
	(0.07)	(0.50)	(0.13)	(0.08)	(0.07)	(0.48)	(0.13)	(0.09)
Observations	276	46	131	302	276	46	131	302
R-squared	0.58	0.56	0.69	0.32	0.56	0.59	0.70	0.23

Panel C: Regressions of Market Returns on Single FOMC Day Return Characteristic Portfolios

	Market Return				Market Return			
Single FOMC Days	Pre-Crisis	Crisis	Post-Crisis	Shale Period	Pre-Crisis	Crisis	Post-Crisis	Shale Period
12/16/08	1.16***	1.17***	1.55***	0.84***				
	(0.10)	(0.14)	(0.11)	(0.11)				
1/28/09					2.26***	1.97***	2.62***	1.43***
					(0.17)	(0.18)	(0.15)	(0.15)
Constant	0.10	-0.36	0.45***	0.28***	0.10	-0.33	0.33**	0.28***
	(0.09)	(0.46)	(0.15)	(0.09)	(0.09)	(0.40)	(0.13)	(0.09)
Observations	276	46	131	302	276	46	131	302
R-squared	0.33	0.62	0.63	0.16	0.39	0.72	0.70	0.23

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

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 2 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.

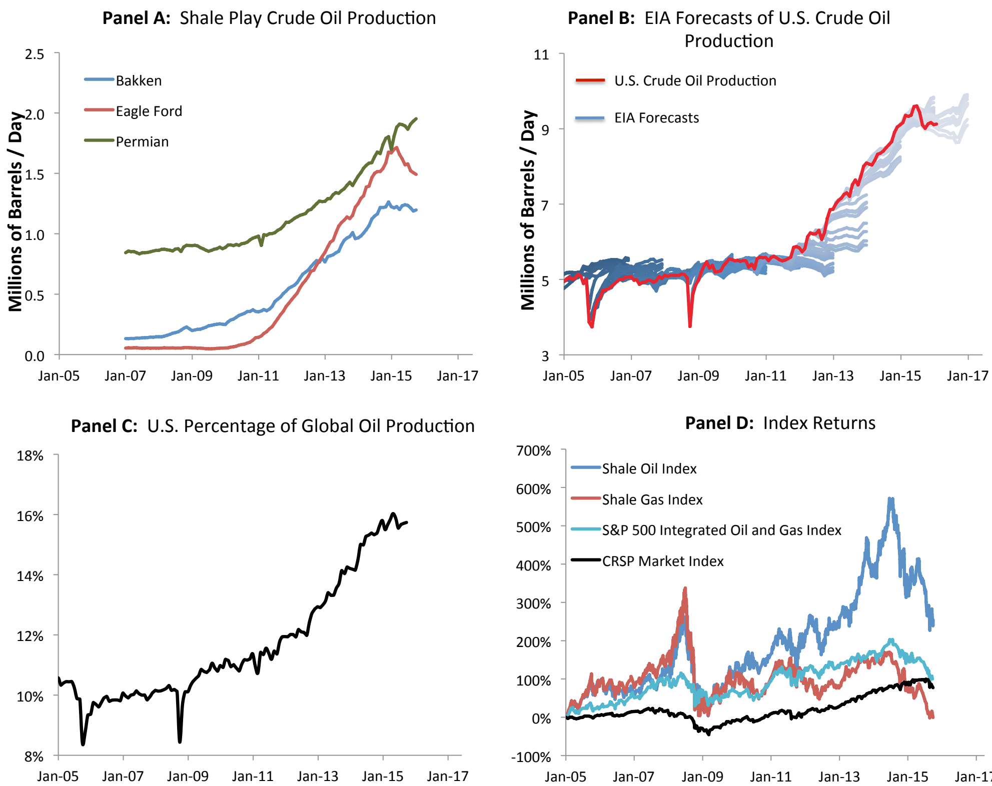
The second important feature of the boom is its magnitude. While increased productivity is clearly a benefit for shale oil producers, its importance for the rest of the economy hinges on the fact that this production increase is significant relative to total world supply. Panel C of Figure 1 illustrates that the increase in U.S. oil production driven by shale deposits amounts to roughly 5% of total world oil production, and a roughly 50% 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 the 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. Oil prices begin to drop in the latter part of our sample period, and then fall precipitously in the wake of the OPEC decision in November 2014, which we discuss in detail below. At the end of our sample period the level of prices is roughly half of its most recent peak.

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 Appendix 3, the second is a "Non U.S. E&P Index", which consists of oil exploration and production 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.

3.2 Identification Approach: Shale News and Stock Returns

A simple 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 to identify these innovations empirically, since both shale oil productivity and all other shocks simultaneously drive returns to both shale oil firms and other firms in the economy (in a more general model, this would include changing discount

Figure 2: U.S. Oil Production and Stock Returns



This figure plots data related to shale oil production and stock returns in different panels. Panel A plots the production of oil from the three major shale oil fields in the United States, the Bakken, the Eagle Ford, and the Permian fields. Panel B plots aggregate U.S. oil production relative to forecasts of production from the U.S. government Energy Information Administration (EIA). Panel C plots the percentage of global oil production being produced from the United States. Panel D plots the stock returns of different market composite indices, including the Shale Oil Index (defined in Appendix Table A-1), the Shale Gas Index (defined in Appendix Table A-1), the S&P Integrated Oil and Gas Index, and the CRSP Market Index. All oil production and forecast data is from the EIA and all stock price data is from the Center for Research in Security Prices (CRSP) rates, e.g. through time varying aggregate uncertainty, expectations, or preference shocks).

Our approach to overcoming this challenge involves using stock returns around news announcements pertaining to oil supply, both from shale and from non-shale sources. 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.

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.

Hydraulic fracturing and horizontal drilling provide the basic building blocks for shale development. However, companies that apply these techniques typically need to calibrate them 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 ex ante. 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 largest of these announcements in the sample is the announcement of Pioneer Natural Resources DL Hutt C #2H 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 #2H, 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 Spraberry/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. The announcement of these positive well results represent a unique opportunity to assess how other firms, including in non-shale industries, respond to unexpected announcements of significant improvements in shale supply. We use industry portfolio return on this single announcement day as a proxy for an industry's exposure to increases in shale productivity.

One concern regarding our reliance on this announcement is that we might overstate the contribution of shale oil shocks to the performance of industries that are sensitive to oil prices during our sample period, since its magnitude can be affected by non-shale oil supply shocks. 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 an attractive event for identifying the impact of non-shale supply shocks on oil prices. On November 28, 2014, the OPEC released the outcome of the 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. The return on this announcement day 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.

4 Empirical Evidence for Shale Oil News

4.1 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 use betas estimated during both of these periods to control for any potential change in the source of market variation during the financial crisis. We do not control for contemporaneous betas since those may be endogenous to the shale shock as industries' relative importance in the market portfolio changes:

$$r_{t+1}^{j} = \lambda_t^0 + \lambda_t^1 r_{ShaleDisc}^{j} + \lambda_t^2 r_{OPECAnn}^{j} + \lambda_t^3 \beta_{PreCrisis}^{j} + \lambda_t^4 \beta_{Crisis}^{j} + \epsilon_{t+1}^{j}. \quad (1)$$

Table 2 presents the results of these regressions across four subperiods: Pre-Crisis (01/2003 - 06/2008), Crisis (07/2008 - 06/2009), Post-Crisis (07/2009 - 12/2011), and the Shale Oil Period (01/2012 - 09/2015). 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 $\boldsymbol{\lambda}_t = [\lambda_t^0, \lambda_t^1, ...]$ 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 -0.146 suggests that a one standard deviation increase in an industry's sensitivity to the OPEC shock translates into a 14.6 basis point per week (or, about 7.6 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 0.142 (or 0.156 if oil firms are excluded). This is a clear manifestation of the fact that the falling oil prices during this period 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 Discovery 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 statistically significant, with a coefficient of 0.052, in the full sample, and even more strongly significant, with a coefficient of 0.117, 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 in the most recent part of the sample. Indeed, when we control for the OPEC Announcement return the shale coefficient becomes strongly significant in both samples, with the similar magnitudes (0.077 and 0.095). 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's stock return over the shale period by about 3 to 4 percent per annum. 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.

Finally, results from these regressions also show that industry market betas are not significantly related to the cross-section of realized returns over the post-crisis or shale oil periods. This is somewhat surprising, as both of these periods saw large positive returns to the market as a whole, but consistent with our earlier findings in Section 2.

4.2 Constructing the Oil Factor Portfolios

The key question we want to ask is what is the contribution of the shale oil 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

Table 2: Fama-Macbeth Regression of Industry Returns on Announcement Day Returns

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 Announcement 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 energy producer industries are excluded (Shale Gas, Shale Oil, and S&P Integrated Oil & Gas Producers). Returns are weekly.

Panel A: All Industries

	Pre-Crisis (01/2003 - 06/2008)			Crisis (07/2008 - 06/2009)			Post-Crisis (07/2009 - 12/2011)			Shale Oil Period (01/2012 - 09/2015)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Shale Discovery Ret.	0.001		-0.023	-0.055		-0.024	0.034		0.034	0.052**		0.077***
	[0.037]		[-1.271]	[-0.615]		[-0.233]	[1.160]		[1.227]	[2.100]		[3.123]
OPEC Announc. Ret.		-0.146***	-0.161***		0.169	0.142		-0.010	-0.005		0.142***	0.147***
		[-2.779]	[-3.303]		[0.529]	[0.455]		[-0.152]	[-0.085]		[2.703]	[2.929]
Pre-Crisis Beta			0.194			-0.110			-0.027			-0.031
			[1.238]			[-0.188]			[-0.149]			[-0.281]
Crisis Beta			0.018			-0.215			-0.013			-0.065
			[0.246]			[-0.206]			[-0.069]			[-0.858]
Constant	0.343***	0.288**	0.094	-0.418	-0.438	-0.047	0.351	0.400	0.393***	0.149	0.284**	0.276**
	[2.785]	[2.387]	[1.065]	[-0.399]	[-0.417]	[-0.085]	[1.237]	[1.409]	[2.914]	[1.177]	[2.125]	[2.318]
Observations	21,804	21,804	21,804	3,555	3,555	3,555	10,349	10,349	10,349	14,931	14,931	14,931
Number of Weeks	276	276	276	46	46	46	131	131	131	189	189	189

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

	Pre-Crisis (01/2003 - 06/2008)			Crisis (07/2008 - 06/2009)			Post-Crisis (07/2009 - 12/2011)			Shale Oil Period (01/2012 - 09/2015)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Shale Discovery Ret.	-0.063**		-0.047*	0.005		-0.010	0.039		0.043	0.117***		0.095***
	[-2.103]		[-1.936]	[0.026]		[-0.056]	[0.987]		[1.199]	[3.451]		[3.119]
OPEC Announc. Ret.		-0.148***	-0.156***		0.157	0.136		-0.005	-0.008		0.156***	0.142***
		[-2.873]	[-3.329]		[0.482]	[0.461]		[-0.071]	[-0.135]		[3.005]	[2.941]
Pre-Crisis Beta			0.234			-0.146			-0.045			-0.071
			[1.500]			[-0.237]			[-0.251]			[-0.657]
Crisis Beta			-0.011			-0.188			-0.001			-0.035
			[-0.155]			[-0.179]			[-0.005]			[-0.463]
Constant	0.424***	0.288**	0.118	-0.492	-0.438	-0.057	0.345	0.401	0.386***	0.069	0.286**	0.259**
	[3.361]	[2.381]	[1.311]	[-0.430]	[-0.416]	[-0.101]	[1.157]	[1.410]	[2.874]	[0.507]	[2.137]	[2.199]
Observations	20,976	20,976	20,976	3,420	3,420	3,420	9,956	9,956	9,956	14,364	14,364	14,364
Number of groups	276	276	276	46	46	46	131	131	131	189	189	189

Fama-Macbeth T-statistics in Brackets
*** p<0.01, ** p<0.05, * p<0.1

market to the shale shock, β^{Mkt}_{Shale}, 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

$$\boldsymbol{\lambda}_t = W_t' R^x_{t+1},$$

where $R^x_{t+1} = [r^1_{t+1}, ..., r^j_{t+1}, ...]$ is the vector of excess returns on the test assets and the matrix of portfolio weights is given by

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

with matrix X_t containing all of the characteristics on the right-hand side of the Fama-Macbeth regression (1), including the constant. 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 et al. (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 announcement day and short industries with negative return responses, while exhibiting a zero return on the other announcement day and zero market beta over the prior periods. 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 using the time series of individual weekly slopes λ_t that produce the Fama-MacBeth coefficients reported in the Table 2 above.

4.3 Extracting Shocks: from Cross-Section to Time Series

In order to understand the intuition behind our empirical 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

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

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):

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

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). We provide empirical support for this assumption by comparing Shale Discovery returns of industry portfolios with their sensitivities to a variety of aggregate economic shocks in Section 5.

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 for a possibility that this announcement signaled an increased willingness of OPEC to allow very low prices for an extended period of time, which could potentially threaten the viability of shale production in the long run, i.e. a negative shock to z^{Shale}. 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 also assume that the other aggregate shocks are absent on the OPEC Announcement day. This is consistent with 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. 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. In the aggregate, this negative effect roughly offsets the positive effect on the industries that benefit through the price channel.

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:

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

If we focus on a period prior to the shale revolution, where we 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, $r^j_{ShaleDisc}$, $r^j_{OPECAnn}$, and $\hat{\beta}^j_{Mkt,Preshale}$. The slope of the regression in each period is $(X'X)^{-1} X'\bar{r}_t$, where $X = [\iota, \bar{r}_{ShaleDisc}, \bar{r}_{OPECAnn}, \bar{\beta}_{Mkt,Preshale}]$ 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 $W = [\bar{w}_1, \bar{w}_{ShaleDisc}, \bar{w}_{OPECAnn}, \bar{w}_{MarketBeta}] = (X'X)^{-1} X'$. 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 $z^{Shale}_{ShaleDisc} = z^{Other}_{OPECAnn} = \beta^{Mkt}_a = 1$. The returns to the three characteristic portfolios are then given by

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

where

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

Details are provided in Appendix 2.

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_{Mkt}^{Shale} using a regression of the market return on the three characteristic portfolios.

This method essentially takes the characteristic portfolios as functions of 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 Appendix Table A-2. We exclude the three oil and gas indices from the portfolio construction, so that we can use the returns on these indices to validate our assumption 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 A-2, are quite intuitive. Industries that receive the largest positive weights in the Shale Discovery are Oil and Gas Drilling (firms in this sector act as subcontractors for both shale and non-shale oil producers) and Business Services and Engineering Services (these two sector include a wide range of firms, many of which are 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 via rail. The most negative weights such as for Coal and Gold Mining are also intuitive, as coal is a major substitute for oil in heating, and prices are strongly positively correlated with oil prices over this period. 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 portfolio weights, 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.

4.4 Exploring the Time-series

In order to verify that the Shale Discovery Portfolio return helps us to identify the shale technology shocks that we are interested in, we begin by examining the time-series behavior of this portfolio together with the other mimicking portfolios that we constructed.

We first construct an index which reflects returns attributable to shale oil innovations $\hat{z}^{Shale}$ by examining the residual returns to the shale discovery portfolio after controlling for the OPEC announcement portfolio and the two market beta portfolios using a time-series regression over the full sample period:

$$R_{t+1}^{ShaleDisc} = \psi_0 + \psi_1 R_{t+1}^{OPECAnn} + \psi_2 R_{t+1}^{PreCrisisBeta} + \psi_3 R_{t+1}^{CrisisBeta} + \hat{z}_{t+1}^{Shale}. \tag{3}$$

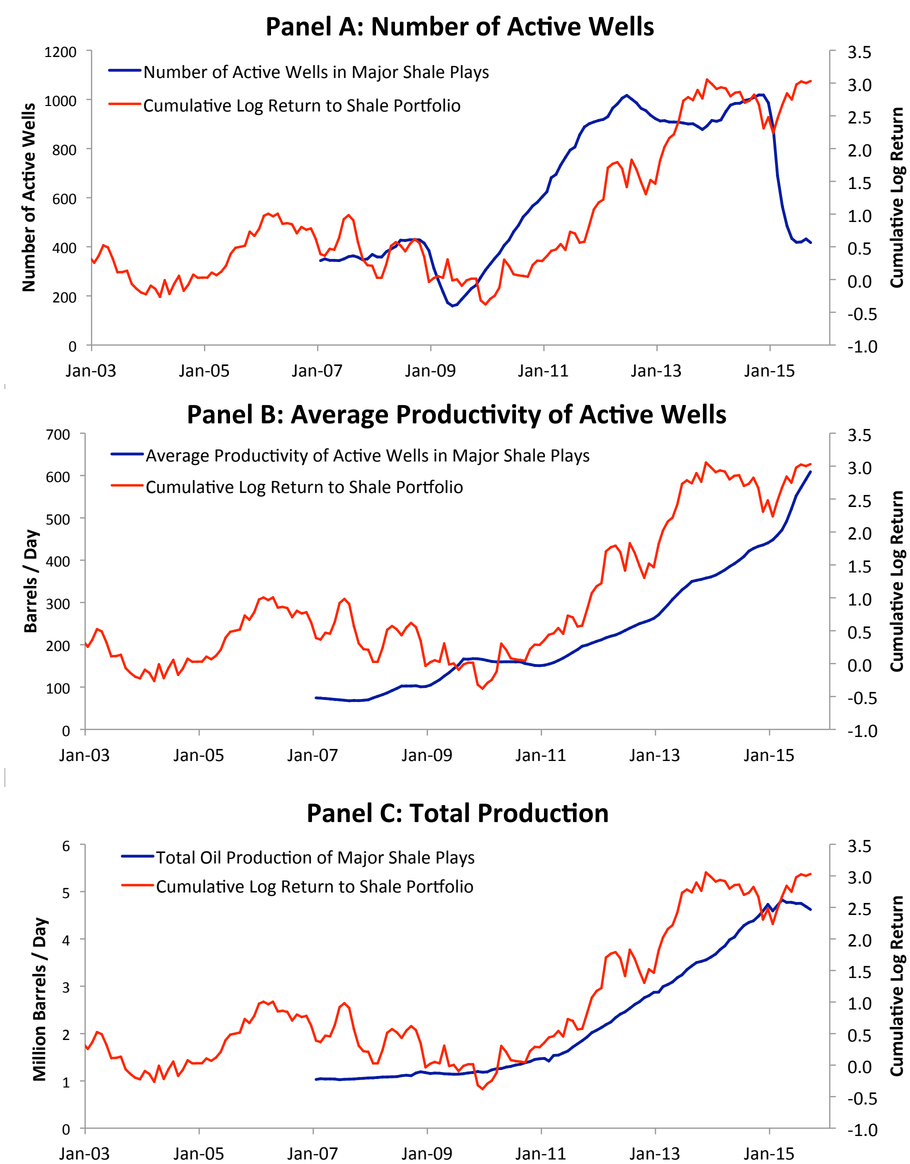
We then use this regression to construct a "Shale Mimicking Portfolio" whose returns in each week are equal to $\hat{z}_{t+1}^{Shale} = R_t^{ShaleDisc} - \psi_1 R_t^{OPECAnn} - \psi_2 R_t^{PreCrisisBeta} - \psi_3 R_{t+1}^{CrisisBeta}$. In order to verify that the cumulative return path of this mimicking portfolio 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 in Figure 3. As the figure shows, the positive returns that can be attributed to the Shale Discovery announcement captured in the Fama-Macbeth regressions of Table 2 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 figures are illustrative, ideally we would like to evaluate the ability of our measure of shale innovations extracted using from asset prices to track shale oil production and investment activity at a relatively high frequency. One such high-frequency measure of shale activity that we focus on is the monthly series of rig counts in the three main shale plays shown in the third panel of Figure 3. Drilling rigs represent the equipment that is used to construct and drill new shale wells. The drilling rig count as a key indicator of the capital invested by shale firms. Table 3 shows the results of regressions during our post-2012 shale oil period, in which next month's increase in rig count ΔRC_{t+1} is the dependent variable:

$$\Delta RC_{t+1} = \delta_0 + \delta_1 \Delta RC_t + \delta_2 R_t^{ShaleDisc} + \delta_3 R_t^{OPECAnn} + \delta_4 R_t^{PreCrisisBeta} + \delta_4 R_t^{CrisisBeta} + \epsilon_{t+1}^{RC}. \tag{4}$$

As shown by the first column, there is large amount of persistence the changes in rig counts at the monthly frequency, with the current month's growth in rig counts explaining roughly 70% of the variation in the next month's. Controlling for this month's change, the second column shows that this months Shale Discovery Portfolio return strongly predicts next months variation in rig counts. The remaining columns show that this relation holds controlling for the returns on the other three mimicking portfolios, which don't contribute

Figure 3: Cumulative Returns on the Shale Mimicking Portfolio



This figure plots the cumulative return on a Shale Mimicking Portfolio against various measures of productivity for the combined Bakken, Eagle Ford, and Permian shale plays. The weekly return to the Shale Mimicking Portfolio is calculated as the return to the Shale Discovery Portfolio less the returns to positions in the OPEC Announcement and Market Beta Characteristic portfolios:

$$\hat{z}_{t+1}^{Shale} = R_t^{ShaleDisc} - \psi_1 R_t^{OPECAnn} - \psi_2 R_t^{PreCrisisBeta} - \psi_3 R_{t+1}^{CrisisBeta}$$

The relative positions ψ_j in the other characteristic portfolios are the slope coefficients form a single regression of the weekly Shale Discovery Portfolio returns on the returns to the other characteristic portfolios for the full 2003 to 2015 sample. The four characteristic portfolio returns are the weekly slopes of the Fama-Macbeth regressions reported in Table 2. Oil production and rig count data is from the EIA.

Table 3: Shale Discovery Portfolio and Shale Oil Rig Counts

This table plots the results for regressions of next month's growth in rig count in the three main shale plays (Bakken, Eagle Ford, and Permian) on this month's growth in rig count and the characteristic portfolio returns. Data are monthly from 01/2012 to 09/2015. Newey-West standard errors with one lag in parentheses.

	$\Delta RigCount_{t+1}$				
	(1)	(2)	(3)	(4)	(5)
$\Delta RigCount_t$	0.851***	0.860***	0.856***	0.877***	0.788***
	[7.007]	[7.255]	[6.650]	[6.864]	[10.220]
Shale Disc. Portfolio		0.088**		0.102**	0.114***
		[2.336]		[2.423]	[2.663]
OPEC Ann. Portfolio			-0.009	-0.029	-0.003
			[-0.342]	[-1.214]	[-0.138]
Pre-Crisis Beta Portfolio					0.004
					[0.492]
Crisis Beta Portfolio					0.054*
					[1.727]
Constant	-0.443	-0.838	-0.373	-0.668	-0.951*
	[-1.046]	[-1.625]	[-0.999]	[-1.517]	[-1.831]
Observations	45	45	45	45	45
R-squared	0.710	0.737	0.710	0.743	0.771

Newey-West T-Statistics in Brackets
*** p<0.01, ** p<0.05, * p<0.1

much explanatory power. These results suggest that our constructed time series proxy is in fact strongly related to increased activity in the major shale plays.

To provide further validation that our shocks are 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 equity indices. In particular, we run the following time-series regressions

$$Y_{t+1}^j = \gamma_0^j + \gamma_1^j R_{t+1}^{ShaleDisc} + \gamma_2^j R_{t+1}^{OPECAnn} + \gamma_3^j R_{t+1}^{PreCrisisBeta} + \gamma_4^j R_{t+1}^{CrisisBeta} + \gamma_4^j R_{t+1}^{Mkt} + \omega_{t+1}^j, \quad (5)$$

where $j = \{WTI, S\&PInt, ShaleGas, ShaleOil\}$. These results are reported in Table 4. 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 -2.8 and -4.5 in magnitude. This means that a one percentage point return on the OPEC portfolio corresponds to a (roughly) three to four 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 2 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 price of oil. Indeed, the R^2 of almost all of these regressions are between 40 and 60 percent, with most of the explanatory power coming from the OPEC Announcement returns. A notable exception is the post-crisis period, when the U.S. equity market return captures a large part of variation in the WTI price, suggesting an important role for the strong demand for oil driving up the prices as the economy recovers from the Great Recession.

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 drives much of the fluctuations in the oil firm returns. The Shale Discovery portfolio is positively correlated with the integrated producers' returns during the shale period, but not after controlling for the market return, when the effect becomes insignificant - and marginally negative 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 a particularly strong direct connection between the two during the shale oil period that we focus on.

Finally, Panel D shows the same regressions for the Shale Oil Index. Here the effect of the Shale Discovery Portfolio is markedly different, even though the OPEC Announcement effect is very similar to those above. The two shale-related portfolio returns are extremely strongly correlated during the shale period, with coefficients between 2 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.

4.5 Explaining 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:

$$R_{t+1}^{Mkt} = \gamma_0^{Mkt} + \gamma_1^{Mkt} R_{t+1}^{ShaleDisc} + \gamma_2^{Mkt} R_{t+1}^{OPECAnn} + \gamma_3^{Mkt} R_{t+1}^{PreCrisisBeta} + \gamma_4^{Mkt} R_{t+1}^{CrisisBeta} + \omega_{t+1}^{j}, \tag{6}$$

Table 5 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

Table 4: Explaining Oil Prices and Index Returns with Characteristic Portfolio Returns

This table plots time series regressions where log oil price changes and returns to three energy producer indices as the dependent variables. The Shale Oil Index is constructed from oil and gas E&P firms primarily involved in shale oil extraction. The Shale Gas Index is constructed from E&P firms primarily involved in shale gas extraction. The S&P Oil and Gas Producer Index is comprised of energy majors in the S&P 500 index. Weekly log oil price changes and the index returns are regressed against returns to characteristic portfolios. The characteristic portfolios are the weekly slope coefficients from cross-sectional regressions of 76 industry returns (not including the three producer indices) on the industry Shale Discovery Day (8/1/2013) return, the OPEC Announcement day (11/28/2014) return, the industry market beta estimated in the Pre-Crisis period (01/2003 - 06/2008), and the industry market beta estimated in the Crisis period (07/2008 - 06/2009). In all specifications the original cross-sectional regressions are done using all four independent variables. The time-series regressions are conducted both with and without the Shale Discovery Portfolio return in each of our four subperiods. Data are weekly.

Panel A: Oil Price Change

	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Shale Discovery Portfolio	-0.967	-0.964	-1.522	-0.017	-0.616	-0.826	2.293***	1.225**
	[-1.284]	[-1.299]	[-0.651]	[-0.008]	[-0.614]	[-1.282]	[3.829]	[2.314]
OPEC Announc. Portfolio	-2.892***	-2.875***	-3.297**	-3.912***	-3.271***	-3.102***	-4.404***	-4.072***
	[-8.908]	[-8.721]	[-2.157]	[-2.799]	[-4.578]	[-5.746]	[-8.679]	[-8.516]
Pre-Crisis Beta Portfolio	-0.311***	-0.213	-0.924**	-0.975***	-0.340	-0.342**	-0.216	-0.410***
	[-3.300]	[-1.430]	[-2.218]	[-2.626]	[-1.198]	[-1.970]	[-1.434]	[-2.848]
Crisis Beta Portfolio	-0.138	-0.094	0.453***	-0.175	0.117	0.040	0.175	0.172
	[-0.801]	[-0.536]	[3.006]	[-0.552]	[0.421]	[0.228]	[0.764]	[0.796]
Market Return		-0.187		0.853**		1.054***		0.652***
		[-0.793]		[2.190]		[12.300]		[5.157]
Constant	0.107	0.114	-1.509	-0.973	0.449	0.060	-0.045	-0.183
	[0.440]	[0.480]	[-1.090]	[-0.749]	[1.189]	[0.227]	[-0.184]	[-0.767]
Observations	276	276	45	45	131	131	189	189
R-squared	0.301	0.304	0.390	0.446	0.184	0.605	0.435	0.503

Panel B: S&P Integrated Oil & Gas Index

	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Shale Discovery Portfolio	0.430	0.243	-2.341**	-1.794***	0.914	0.121	1.747***	-0.103
	[1.144]	[0.987]	[-2.556]	[-3.154]	[1.579]	[0.457]	[4.423]	[-0.464]
OPEC Announc. Portfolio	-1.806***	-2.029***	-0.442	-0.634*	-1.412***	-1.328***	-2.165***	-1.727***
	[-10.728]	[-18.033]	[-0.904]	[-1.806]	[-5.109]	[-7.918]	[-8.287]	[-10.906]
Pre-Crisis Beta Portfolio	0.316***	-0.334***	-0.267	-0.404***	0.410***	-0.449***	0.062	-0.442***
	[5.582]	[-6.692]	[-1.593]	[-3.956]	[3.711]	[-5.268]	[0.716]	[-7.018]
Crisis Beta Portfolio	0.740***	0.171**	0.702***	0.060	0.755***	-0.333***	0.581***	0.021
	[6.097]	[2.216]	[11.817]	[0.735]	[6.817]	[-3.712]	[5.303]	[0.276]
Market Return		1.094***		0.784***		1.267***		1.072***
		[16.807]		[7.790]		[15.303]		[18.084]
Constant	0.137	0.063	-0.451	-0.127	0.343*	-0.115	0.147	-0.095
	[1.165]	[0.746]	[-1.036]	[-0.389]	[1.906]	[-1.182]	[1.024]	[-1.110]
Observations	276	276	45	45	131	131	189	189
R-squared	0.465	0.711	0.775	0.887	0.597	0.885	0.432	0.799

Table 4: Explaining Oil Prices and Index Returns with Characteristic Portfolio Returns (Continued)

Panel C: Shale Gas Index

	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Shale Discovery Portfolio	0.549	0.340	2.139	3.215**	0.074	-0.579	1.508**	-0.556
	[0.963]	[0.793]	[1.488]	[2.065]	[0.085]	[-0.783]	[2.331]	[-1.008]
OPEC Announc. Portfolio	-3.538***	-3.788***	-5.520***	-5.898***	-2.977***	-2.908***	-3.663***	-3.174***
	[-13.485]	[-15.380]	[-8.180]	[-12.234]	[-5.828]	[-6.003]	[-9.077]	[-10.095]
Pre-Crisis Beta Portfolio	0.309***	-0.420***	-0.303	-0.574***	0.144	-0.563***	-0.074	-0.636***
	[3.840]	[-4.617]	[-1.110]	[-4.477]	[0.800]	[-2.699]	[-0.406]	[-3.525]
Crisis Beta Portfolio	0.936***	0.298**	1.487***	0.223	1.729***	0.832***	1.232***	0.608**
	[4.873]	[2.082]	[8.153]	[0.782]	[12.579]	[3.264]	[5.580]	[2.511]
Market Return		1.225***		1.544***		1.044***		1.196***
		[10.016]		[5.645]		[5.250]		[6.596]
Constant	0.262	0.179	-0.253	0.384	0.326	-0.052	0.152	-0.119
	[1.534]	[1.234]	[-0.315]	[0.776]	[1.107]	[-0.189]	[0.624]	[-0.549]
Observations	276	276	45	45	131	131	189	189
R-squared	0.553	0.676	0.838	0.926	0.676	0.738	0.419	0.568

Panel D: Shale Oil Index

	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Shale Discovery Portfolio	1.014**	0.824**	-0.305	0.649	1.373**	0.670	4.019***	1.987***
	[2.108]	[2.271]	[-0.205]	[0.859]	[1.967]	[1.226]	[7.666]	[4.366]
OPEC Announc. Portfolio	-3.464***	-3.691***	-3.298***	-3.633***	-3.170***	-3.096***	-4.179***	-3.698***
	[-14.748]	[-16.656]	[-4.924]	[-9.283]	[-6.916]	[-8.110]	[-11.716]	[-12.642]
Pre-Crisis Beta Portfolio	0.175**	-0.487***	-0.249	-0.489***	0.271*	-0.491***	0.306**	-0.248**
	[2.516]	[-6.594]	[-1.325]	[-4.642]	[1.723]	[-2.758]	[2.128]	[-2.090]
Crisis Beta Portfolio	0.732***	0.152	1.231***	0.111	1.558***	0.593***	1.245***	0.631***
	[4.226]	[1.205]	[11.971]	[0.884]	[15.121]	[3.321]	[6.524]	[3.750]
Market Return		1.113***		1.369***		1.124***		1.178***
		[10.782]		[10.520]		[6.779]		[12.830]
Constant	0.175	0.099	-0.434	0.131	0.534**	0.128	0.450**	0.184
	[1.165]	[0.782]	[-0.688]	[0.333]	[2.131]	[0.594]	[2.243]	[1.243]
Observations	276	276	45	45	131	131	189	189
R-squared	0.561	0.686	0.838	0.946	0.718	0.800	0.608	0.756

T-Statistics in Brackets

*** p<0.01, ** p<0.05, * p<0.1

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 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 15% 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 1.73) and highly statistically significant. Moreover, adding the Shale Discovery Portfolio to the regression increases the R^2 from 0.25 to 0.40, suggesting that during this period news about shale oil is responsible for about 15% of the variation in the aggregate stock market. In the other periods the contribution of shale to the market variance is essentially zero.

The other interesting finding in this table relates to the OPEC Announcement portfolio. Once we control for innovations to the market wide shocks proxied by the market beta portfolios, we see little impact of the returns to this portfolio on the aggregate market in the Post-Crisis period. However, in the Shale Oil period, when the oil industry's share of the aggregate U.S. economy is high, these returns are negatively correlated with the aggregate market, suggesting that low oil prices driven by outside shocks are bad news for the U.S. economy as whole. This is in contrast to the the Pre-Crisis period, when oil long-run oil uncertainty was high, where we see a positive relation, suggesting that low oil prices driven by outside oil shocks were good news for the aggregate market.

4.6 Economic Magnitudes

We can use the coefficients in Table 5 to estimate the overall value effect of shale oil development. The last row of each panel in Table 5 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, $\Delta\gamma_0^{Mkt} = \gamma_0^{Mkt} - \gamma_0^{Mkt}|_{\gamma_1^{Mkt}=0}$. Here the restricted model ($\gamma_1^{Mkt} = 0$) is estimated jointly with the unrestricted one, and standard errors for the difference are obtained via GMM. In the full regression including the beta controls (i.e., as in Panel B), this value is 11.6 basis points for the shale period. Therefore, over the 189 week shale oil period, the total cumulative return is 24.5%. As a robustness exercise we allow for time-varying exposures of the market return to the mimicking portfolios by estimating rolling regressions and obtain similar results (these are reported in the Appendix).

The estimates above imply that the overall value effect of shale, implied by asset prices is 24.5% of the U.S. total equity market capitalization as of the beginning of the shale period. The total market value at the beginning of the shale period was \$15.62 trillion, therefore the total value effect derived from our methodology is 24.5% $\times$ \$15.62 trillion = \$3.8 trillion. The

Table 5: Explaining Market Returns with Characteristic Portfolio Returns

This 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.

Panel A: No Market Beta Characteristic Portfolios

	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Shale Discovery Portfolio		0.000		0.000		1.107*		1.749***
		[0.000]		[0.000]		[1.699]		[4.768]
OPEC Announc. Portfolio	0.000	-0.000	-0.000	-0.000	-1.572***	-1.780***	-0.521**	-0.862***
	[0.000]	[-0.000]	[-0.000]	[-0.000]	[-4.661]	[-5.026]	[-2.347]	[-3.024]
Constant	0.161	0.161	-0.553	-0.553	0.345	0.296	0.355***	0.237*
	[1.394]	[1.392]	[-0.581]	[-0.586]	[1.476]	[1.269]	[2.773]	[1.883]
Observations	276	276	46	46	131	131	189	189
R-squared	0.000	0.000	0.000	0.000	0.146	0.167	0.037	0.187
Market Return Explained by Shale Portfolio								
Change in Intercept						0.049		0.118**
						[0.992]		[2.144]

Panel B: With Market Beta Characteristic Portfolios

	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Shale Discovery Portfolio		0.171		-0.697		0.626*		1.726***
		[0.602]		[-0.975]		[1.734]		[5.738]
OPEC Announc. Portfolio	0.248**	0.204*	-0.093	0.245	0.076	-0.066	-0.067	-0.408*
	[2.426]	[1.939]	[-0.485]	[0.676]	[0.371]	[-0.318]	[-0.357]	[-1.957]
Pre-Crisis Beta Portfolio	0.594***	0.595***	0.189	0.175	0.692***	0.678***	0.475***	0.470***
	[14.056]	[13.504]	[1.442]	[1.312]	[9.882]	[9.594]	[6.628]	[6.445]
Crisis Beta Portfolio	0.514***	0.521***	0.815***	0.819***	0.861***	0.859***	0.526***	0.522***
	[5.547]	[5.126]	[11.830]	[11.858]	[11.813]	[12.068]	[5.076]	[5.984]
Constant	0.067	0.068	-0.359	-0.413	0.390***	0.362***	0.342***	0.226**
	[0.900]	[0.916]	[-0.903]	[-1.072]	[3.221]	[2.998]	[2.985]	[2.075]
Observations	276	276	45	45	131	131	189	189
R-squared	0.594	0.595	0.815	0.819	0.769	0.776	0.249	0.395
Market Return Explained by Shale Portfolio								
Change in Intercept		-0.001		0.054		0.029		0.116**
		[-0.244]		[0.668]		[1.138]		[2.211]

T-Statistics in Brackets
*** p<0.01, ** p<0.05, * p<0.1

standard error on this point estimate does suggest a range of economic magnitudes. To be conservative, one could use the standard errors of our estimates and calculate a lower bound: for example, our estimates imply that shale oil development is responsible for at least $1 trillion of the increase in the stock market with 90% confidence.

How plausible are these figures? As an additional way to assess the magnitude of shale's contribution to U.S. industries solely through its supply chain we can compare this figure to an estimated value of the capital expenditures in shale oil extraction 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 statistics imply 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, and does not include probable and possible reserves. The extent to which these additional reserves are produced or new discoveries are made, the higher the expected life of the development will be and the greater the value of the resource. While the amount above potentially includes payments to labor (with hard-to-estimate knock-on effects through income and consumer demand channels) as well as non-publicly-traded suppliers, this back of the envelope calculation is broadly consistent with the $3.8 trillion magnitude implied by asset prices.

Moreover, our method does not distinguish between the market impact of the reductions in oil prices and a decrease in long-run oil supply uncertainty, which likely resulted from the emergence of shale oil. Given the potentially quite high counterfactual levels of oil prices in the absence of shale, as well as the size of the shale industry, both of these factors would be consistent with a large effect on asset prices.

4.7 Shale Discovery Announcement Returns and Employment Growth

So far we have documented a substantial effect of shale oil on equity market values. We also assess whether the shale oil technology shock is 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 6 we report the results of regressions where we estimate the effect of the return from the shale discovery announcement day on average annual employment growth during different time periods ($\Delta Empl_t^j$).

$$\Delta Empl_t^j = \lambda_E^0 + \lambda_E^1 r_{ShaleDisc}^j + \lambda_E^2 r_{OPECAnn}^j + \lambda_E^3 \beta_{PreCrisis}^j + \lambda_E^4 \beta_{Crisis}^j + \epsilon_t^j. \quad (7)$$

As can be seen from the results in Table 6 there is a positive and statistically significant coefficient on the announcement return during the shale oil period. The economic interpretation of the coefficient in specification (7) of Table 5 is that if an industry's return on the shale discovery announcement day is one standard deviation higher, it experiences a 0.56% increase in average annual employment growth over the shale oil period (the announcement returns are not standardized by standard deviation, this estimate is based on the point estimate of 0.724 multiplied by the sample standard deviation of 0.77). To estimate aggregate employment effects we multiply an industry's announcement return by the point estimate of 0.724 in Table 6 and the number of years in the shale oil period, then scale an industry's 2012 employment by this estimate. We then sum up this net employment change across all industries, and find that overall employment increased by 4,600,000 jobs, due to industry exposures to shale technology. This figure is a 4.2% increase in the number of jobs, in aggregate, across the industries in our study during the shale oil time period. When we control for the OPEC Announcement return and industry betas, the coefficient increases to 0.928. However, when using this coefficient to construct aggregate job estimates to compare to actual job growth one needs to consider that the OPEC Announcement effect partially offsets the shale announcement effect for some some industries. Therefore the coefficient in specification (8) on shale announcement, is offset by job losses due to the OPEC Announcement when compared to actual changes in employment. Using the coefficient on shale discovery returns in specification (8) of Table 6, we calculate an aggregate employment effect linked to shale technology of 5,800,000 jobs. It is also important to note the standard errors on our point estimates. Using these we can construct a lower bound estimate for the effect of shale oil technology on employment using specification (8) of Table 6, and find that at least 1,600,000 new jobs are linked with shale oil development with 90% confidence.

The magnitudes we identify above are broadly consistent with recent studies that measure both direct and indirect effects of shale development on employment, mostly focusing on natural gas extraction (in contrast to our focus on shale oil). For example, Hausman and Kellogg (2015) find the indirect effects of shale gas on manufacturing employment alone of around 280,000 jobs, or a 2.6% increase (manufacturing accounts for roughly 10% of the overall private sector employment in our sample). Alternatively, Feyrer et al. (2015) estimate that the direct effects of shale gas and oil development contributed about 640,000 jobs through 2012 in the areas of shale discoveries. Allcott and Keniston (2014) find that counties with high resource endowments experience employment growth of 2.87% when employment in resource extraction doubles overall. Using recent prices and production data from the U.S. Energy Information Administration, we estimate the dollar value of shale oil production to be 2.5 times larger than that for shale gas production. To the extent this ratio is a rough proxy for the relative economic impact of shale oil versus shale gas, combining the indirect and direct estimates above, and applying the appropriate scaling yields values well within the confidence interval of our point estimates for aggregate employment growth.

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 6 suggests that shale not only influenced asset prices, but had important real effects on the economy.

Table 6: Industry Shale Exposure and Employment Growth

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, the 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.

	Pre-Crisis		Crisis		Post-Crisis		Shale Oil Period	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Shale Discovery Return	-0.157	0.196	-1.288	-1.026	-0.704	-0.371	0.724*	0.928**
	[-0.28]	[0.39]	[-1.26]	[-1.09]	[-1.10]	[-0.63]	[1.70]	[2.19]
OPEC Announcement Return		-0.623***		0.260		-0.807***		-0.253*
		[-3.85]		[0.86]		[-4.24]		[-1.85]
Pre-Crisis Beta		-0.005		-0.015		0.007		-0.005
		[-1.10]		[-1.66]		[1.34]		[-1.22]
Crisis Beta		0.004		-0.019**		-0.003		-0.001
		[0.77]		[-2.07]		[-0.57]		[-0.15]
Constant	0.009	0.008	-0.062***	0.053	0.011	-0.022	0.002	0.019
	[0.93]	[0.47]	[-3.65]	[1.61]	[1.03]	[-1.06]	[0.28]	[1.27]
R-squared	0.001	0.242	0.021	0.235	0.016	0.238	0.038	0.122
Observations	76	76	76	76	76	76	76	76

5 Robustness

How likely is it that our results are driven by a (potentially spurious) correlation between the cross-section of industry returns on the Shale Discovery day and their exposures to an omitted common factor? In order to answer this question in this section we consider exposures that are observable to an econometrician, as well as consider an alternative approach to measuring shale-driven innovations that does not rely on the Shale Discovery day. In addition, we conduct a placebo test, where we repeat our analysis using every trading day in our sample in place of the Shale Discovery day. We find that this day is by far the best in terms of its ability to generate a portfolio from the cross-section of industry returns that simultaneously captures significant amount of variation in the aggregate market return, in the Shale Index return, and in the real activity measures (both the time-series of shale rig count change and the cross-section of industry employment growth rates). These results are reported in the Appendix.

5.1 Industry Market Betas, FOMC Announcements and Shale Period Returns

In this section we reexamine the returns during the shale period from the perspective of market betas and exposure to monetary policy shocks. While Section 2 shows that pre-crisis market betas and FOMC exposures are unlikely to explain our results, in this section we extend the analysis to show that industry market betas and FOMC exposures, estimated either prior to the shale period or during the shale period, do not 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.

To highlight this intuition, we pursue a similar exercise as in Figure 1, but here we construct characteristic portfolios using the cross-section of market betas estimated in each of the four sub-periods, and examine cumulative returns to this portfolio over the sample. Figure 4 plots the results. As the figure shows, these portfolios all track the performance of the market very closely in the pre-crisis period, even those constructed using betas calculated in the latter half of the sample, and all subsequently exhibit a large divergence from the market beginning in 2012, consistent with the hypothesis that a new source of variation was driving positive market returns.[17]

In addition to reestimating betas during the shale period, we can also include industry reactions to monetary policy announcements during the shale oil period as a test for robustness to the possibility that the results regarding our Shale Discovery Portfolio are driven by monetary policy.

To proceed with these tests we extend our approach in section 2, and here examine FOMC several different sets of days related to monetary policy. In addition to our two FOMC days used in section 2 we include a third day with a large positive return after the crisis (8/9/2011). The other three metrics are calculated as beta slopes β_j^{FOMC} from subsample time-series regressions of industry j returns on market returns using a group of announcement days:

$$R_{t+1}^j = \alpha_j^{FOMC} + \beta_j^{FOMC} R_{t+1}^{Mkt} + \epsilon_{t+1}^{j,FOMC}. \tag{8}$$

Those groups are 22 QE announcement days from Wright (2012), the 95 days of FOMC announcements (both scheduled and unscheduled) across the whole sample, and the 12 FOMC days which occur during the shale period.

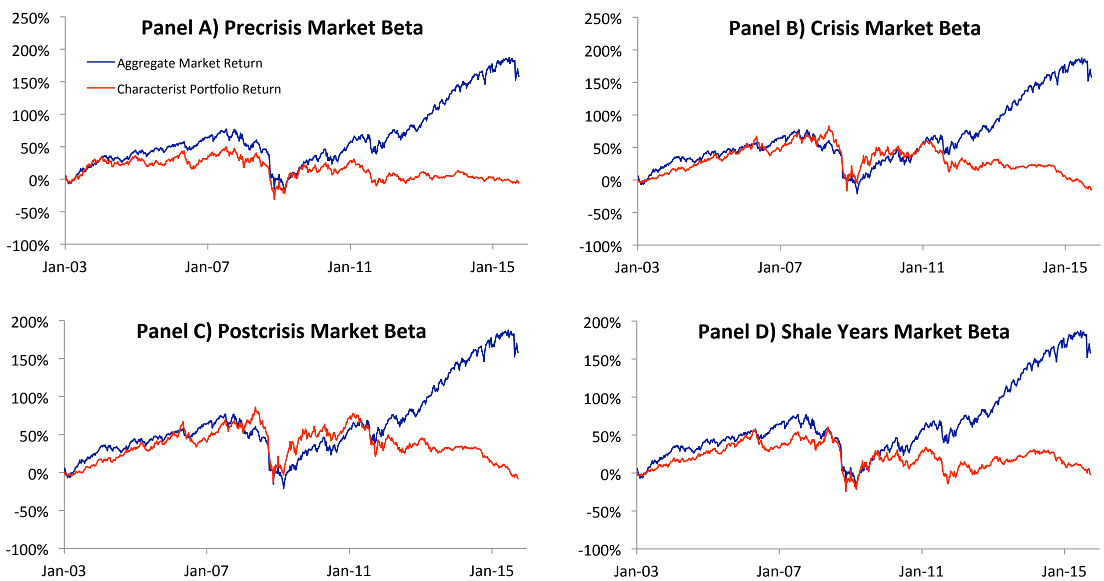
To show formally that these portfolios do not explain either the market returns or our findings regarding the shale discovery portfolio, we perform Fama-MacBeth regressions of industry returns on the shale and OPEC Announcements, this time including our three beta-based measures of of industry exposure to monetary policy announcements.

Table 7 presents the results of multivariate cross-sectional regressions in Panel A. It is

[17] Unreported regression results show that all four portfolios exhibit high weekly correlation with the market return in all periods, but as all have negative or small positive returns in the shale period, none can explain a significant portion of the market increase over this period.

Figure 4: Market Betas and Cumulative Returns

This figure plots the cumulative aggregate stock market return against the cumulative return to characteristic portfolios constructed using industry market betas form the four sub-periods. The return on the characteristic portfolio in each week is the slope from a univariate Fama-Macbeth regression of that week's industry returns on a constant and each industry's market beta. This exercise is repeated four times with market betas calculated over the pre-crisis period (01/2003 - 06/2008), crisis period (07/2008-06/2009), post-crisis period (07/2009-12/2011), and the shale period (01/2012-10/2015), in Panels A), B), C), and D) respectively.



clear that the estimated impact of the shale announcement returns is completely unaffected by any of three measures, as all of the coefficients are essentially the same and the various monetary policy betas have no significant impact on the cross-section of industry returns. In Panel B, we construct new sets of mimicking portfolios using the slopes from these regressions, and repeat our analysis of the time-series performance of the total stock market. Panel B of the table shows that the monetary policy beta portfolios are quite strongly correlated with the market return over the shale period. However, the inclusion of these controls if anything strengthens the effect of the Shale Discovery portfolio on the market return. Additionally, the last line of the table shows the change in intercept when the monetary policy portfolio is removed from the regression. In no period are any of the three portfolios able to explain a significant portion of the market return.

These results show that the covariation between the aggregate stock returns and the shale innovations that we identify using the Shale Discovery Portfolio are not driven by monetary policy shocks. In addition, the fact that market betas on FOMC announcements days in the Shale Period have little impact suggest that our results are unlikely driven by shocks 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. To illustrate this, Figure 5 provides plots of the relations between FOMC announcement day betas, market betas, and industry returns on the shale announcement day. Panel A plots the industry market beta calculated on the 12 FOMC meeting days in the Shale Period against the industry returns on the shale announcement day. As the plot shows, there is very little relation, again suggesting a distinction between the industries' response to the two type of shocks. Panel B then plots industry market beta calculated over the full shale period against the return on the shale announcement day. As the plot shows, there is a slight positive relation here,

Table 7: Robustness Check: Effect of Monetary Policy Announcements

Panel A shows the results of Fama-Macbeth regressions of industry average returns. Each set of four columns shows regressions of sub-period average returns on the industry return on the Shale Discovery day (8/1/2013), the industry return on the OPEC Announcement day (11/28/2014), the industry market beta calculated in the pre-crisis and crisis periods, and the market beta calculated on a set of monetary policy announcement days. The first set is 22 days with announcements regarding the Federal Reserve's Quantitative Easing program. The second set is all 95 FOMC announcement days in the sample. The third is the beta calculated using the 12 FOMC announcement days during the Shale Period. Panel B shows the results of time-series regressions the market return on the characteristic portfolio returns constructed as the weekly cross-sectional slopes from the cross-sectional regression in Panel A. The last two rows of Panel B shows the change in intercept in the time-series regression when the Shale Discovery characteristic portfolio is excluded, and the change in intercept when the monetary policy announcement betas is excluded.

Panel A: Fama-Macbeth Regressions of Industry Returns

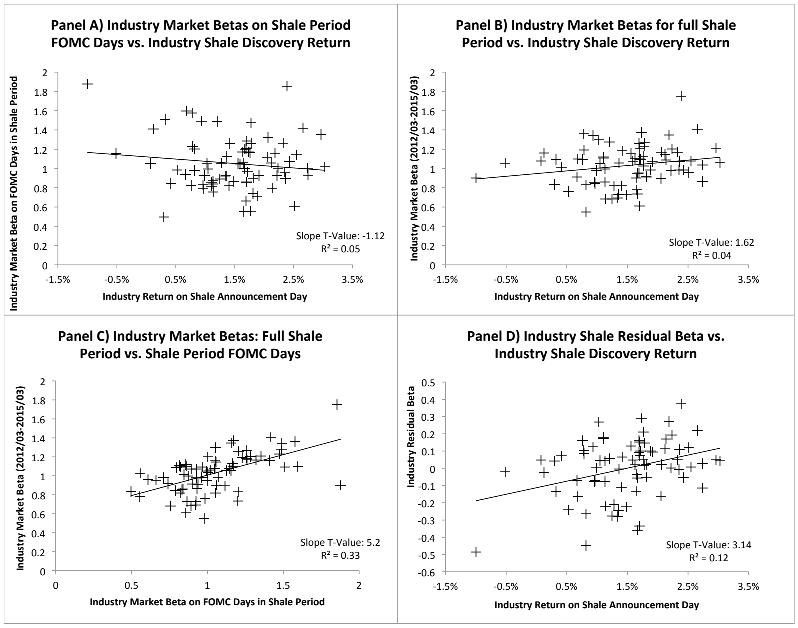
	Industry Average Returns				Industry Average Returns				Industry Average Returns			
	Pre-Crisis	Crisis	Post-Crisis	Shale Period	Pre-Crisis	Crisis	Post-Crisis	Shale Period	Pre-Crisis	Crisis	Post-Crisis	Shale Period
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Shale Discovery Returns	-0.049**	-0.006	0.042	0.094***	-0.042*	-0.022	0.043	0.093***	-0.051**	0.004	0.040	0.097***
	[-1.993]	[-0.033]	[1.180]	[3.081]	[-1.770]	[-0.136]	[1.210]	[3.094]	[-2.114]	[0.025]	[1.136]	[3.191]
OPEC Announc. Returns	-0.159***	0.144	-0.009	0.140***	-0.146***	0.114	-0.008	0.139***	-0.175***	0.202	-0.020	0.151***
	[-3.405]	[0.483]	[-0.153]	[2.881]	[-3.218]	[0.413]	[-0.137]	[2.923]	[-3.523]	[0.613]	[-0.297]	[2.891]
Pre-Crisis Beta	0.259	-0.203	-0.037	-0.053	0.373**	-0.474	-0.046	-0.120	0.264*	-0.244	-0.027	-0.084
	[1.616]	[-0.326]	[-0.215]	[-0.492]	[2.168]	[-0.551]	[-0.235]	[-1.037]	[1.661]	[-0.368]	[-0.153]	[-0.766]
Crisis Beta	0.073	-0.382	0.024	0.027	0.150	-0.569	-0.002	-0.091	0.014	-0.274	0.014	-0.046
	[0.775]	[-0.353]	[0.125]	[0.252]	[1.569]	[-0.529]	[-0.011]	[-0.927]	[0.201]	[-0.262]	[0.080]	[-0.590]
QE Announc. Day Beta	-0.134	0.309	-0.039	-0.099								
	[-1.320]	[0.507]	[-0.275]	[-0.924]								
FOMC Day Beta					-0.368**	0.869	0.003	0.129				
					[-2.580]	[0.862]	[0.014]	[1.013]				
Shale Period FOMC Beta									-0.129	0.427	-0.075	0.055
									[-1.298]	[0.860]	[-0.523]	[0.532]
Constant	0.144	-0.116	0.394***	0.277**	0.173*	-0.187	0.386***	0.239**	0.193*	-0.304	0.430**	0.227*
	[1.620]	[-0.194]	[2.909]	[2.277]	[1.882]	[-0.312]	[2.842]	[1.994]	[1.784]	[-0.483]	[2.570]	[1.743]
Observations	20,976	3,496	9,956	12,388	20,976	3,496	9,956	12,388	20,976	3,496	9,956	12,388
Number of Weeks	276	46	131	189	276	46	131	189	276	46	131	189

Panel B: Explaining Aggregate Market with Characteristic Portfolios

	Aggregate Market Returns				Aggregate Market Returns				Aggregate Market Returns			
	Pre-Crisis	Crisis	Post-Crisis	Shale Period	Pre-Crisis	Crisis	Post-Crisis	Shale Period	Pre-Crisis	Crisis	Post-Crisis	Shale Period
Portfolio:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Shale Discovery	0.087	-0.732	0.509	1.707***	0.092	-0.618	0.569	1.727***	0.144	-0.835	0.605*	1.722***
	[0.309]	[-0.938]	[1.404]	[5.814]	[0.334]	[-0.847]	[1.540]	[5.834]	[0.513]	[-1.104]	[1.654]	[5.710]
OPEC Announc.	0.239**	0.340	0.022	-0.401**	0.155	0.536	-0.122	-0.406*	0.198*	0.586	-0.080	-0.399*
	[2.163]	[0.866]	[0.105]	[-2.049]	[1.388]	[1.192]	[-0.596]	[-1.825]	[1.874]	[1.419]	[-0.387]	[-1.883]
Pre-crisis Beta	0.608***	0.202*	0.659***	0.483***	0.600***	0.166	0.676***	0.470***	0.598***	0.188*	0.664***	0.478***
	[14.173]	[1.912]	[9.782]	[6.652]	[13.266]	[1.369]	[9.833]	[6.559]	[13.440]	[1.666]	[9.483]	[6.736]
Crisis Beta	0.518***	0.828***	0.839***	0.495***	0.516***	0.828***	0.840***	0.522***	0.515***	0.839***	0.832***	0.515***
	[5.297]	[11.720]	[12.272]	[5.483]	[5.140]	[11.827]	[11.706]	[6.010]	[5.180]	[12.280]	[11.052]	[6.029]
QE Announc. Day Beta	0.555***	0.403***	0.851***	0.270***								
	[6.658]	[3.178]	[10.318]	[2.658]								
FOMC Day Beta					0.516***	0.294**	0.719***	0.417***				
					[5.724]	[2.486]	[12.102]	[5.716]				
Shale Period FOMC Beta									0.500***	0.164	0.694***	0.364***
									[6.406]	[1.337]	[11.419]	[4.814]
Constant	0.083	-0.373	0.375***	0.215*	0.077	-0.333	0.363***	0.226**	0.078	-0.319	0.354***	0.226**
	[1.125]	[-0.989]	[3.125]	[1.937]	[1.017]	[-0.887]	[3.018]	[2.074]	[1.023]	[-0.862]	[2.970]	[2.068]
Weeks	276	46	131	189	276	46	131	189	276	46	131	189
R-squared	0.61	0.80	0.73	0.45	0.61	0.80	0.73	0.45	0.61	0.80	0.73	0.45
	Market Return Explained by Shale Portfolio				Market Return Explained by Shale Portfolio				Market Return Explained by Shale Portfolio			
Change in Intercept	-0.000	0.057	0.023	0.113**	-0.000	0.050	0.025	0.113**	-0.000	0.086	0.026	0.115**
	[-0.092]	[0.681]	[1.089]	[2.184]	[-0.010]	[0.707]	[1.103]	[2.174]	[-0.085]	[0.760]	[1.108]	[2.210]
	Market Return Explained by QE Announcement Day Beta Portfolio				Market Return Explained by FOMC Day Beta Portfolio				Market Return Explained by Shale Period FOMC Day Beta Portfolio			
Change in Intercept	-0.026	0.067	-0.057	-0.015	-0.035	0.112	-0.032	0.007	0.001	-0.001	-0.006	-0.009
	[-0.627]	[0.285]	[-0.498]	[-0.652]	[-0.676]	[0.642]	[-0.266]	[0.170]	[0.063]	[-0.079]	[-0.237]	[-0.327]

T-Statistics in Brackets
*** p<0.01, ** p<0.05, * p<0.1

Figure 5: Shale Announcement Returns, Market Betas, and FOMC Days



but it is not strong. Perhaps the most interesting plot is in Panel C, which shows that the FOMC announcement day beta is strongly related to the overall industry market beta over this period, with the former explaining 33 percent of the variation in the latter.

Finally, panel D shows that the shale announcement returns are able to explain a substantial of the variation in market betas not captured by the FOMC announcements (the plot shows the regression of residuals from panel C plotted against shale announcement returns). What is crucial for the validity of our identification 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.

5.2 Alternative Measure of Shale Exposure

In this section we examine whether a simple and robust measure of shale industry exposure can yield similar explanatory power to our Shale Discovery Portfolio for the increase in the aggregate market value during the shale period. This test provides a verification that our results are not being driven by industries which are only tangentially related to shale oil (but happen to experience a high return on the Shale Announcement day).

In this exercise, we first identify four groups of firms as the major shale-related industries. These groups are the Shale Oil Index, consisting of firms which own and operate shale oil leases; Drilling firms, which provide contract services to the primary oil firms; Oil Pipelines; and Railroads, both of which provide transportation of extracted shale oil from fields to refineries. We construct a Shale Dummy variable, which takes a value of one for these four industries, and zero for all others. We then repeat the primary analysis using this dummy as our metric for shale exposure. Table 8 shows the results.

The first four columns of Panel A show the results from cross-sectional Fama-Macbeth as in Panel A of Table 7, with the Shale Dummy used in place of the shale announcement return. What we see here is that the Shale Dummy firms outperformed the rest of the market in both the post-crisis and shale periods, after controlling for the OPEC Announcement returns, market beta in each of the first two periods, and the market beta on FOMC day in the shale period. In Panel B we repeat the exercise of Table 3 by constructing characteristic portfolios and examining their explanatory power for market returns. As the first four columns show, the shale dummy characteristic portfolio has a strong positive correlation with the market, but only in the Shale Period. The last two rows of Panel B show the estimate of the change in intercept in the regression explaining the market return when the shale dummy characteristic portfolio is removed. Again we see that this estimate is positive and significant, suggesting that this portfolio has the ability to explain some of the positive market return but only in the shale period, with the point estimate being 8.4 basis points per week. This weekly impact correspond to a 17.2% change in overall market cap, or a value of $2.7 trillion.

The last four columns of Panels A and B repeat this exercise, but this time include the shale announcement day return as a control the cross-sectional regression, and the corresponding characteristic portfolio is the time series regressions. While the shale dummy still exhibits significant explanatory power for the cross-section during the shale period, and the shale dummy characteristic portfolio is still positively correlated with the market over this period, the magnitude of both these coefficients is reduced. Most strikingly, the 0.084% per week explained by the shale dummy portfolio in column (4) is reduced to 0.025% per week in column (8). This suggests that the effect of the Shale Dummy is largely captured by the shale announcement return. These findings together imply that the two methods yield a similar result, and provide further evidence that the effects documented previously are in fact driven by the impacts of shale oil.

6 Conclusion

In a matter of a few years the technological innovations associated with fracking have revolutionized the U.S. oil market. We document that fracking innovations have had large effects on the aggregate stock market and the real economy. However, we caution that our estimates do not include or reflect the impact of potential costs or adverse consequences of shale development that are yet to be understood. Additionally, welfare consequences that are not linked with job growth or the stock market are not reflected in our estimates. Existing research has documented that shale oil and gas extraction has had localized negative impacts on the home values of houses dependent on ground water (Muehlenbachs, Spiller and Timmins (2015)). There have been additional unanticipated effects of shale development, such

Table 8: An Alternative Proxy for Shale Oil Exposure

Panel A shows the results of Fama-Macbeth regressions of industry average returns. The first four columns shows regressions of sub-period average returns on a Shale Dummy variable, the industry return on the OPEC Announcement day (11/28/2014), the industry market beta calculated in the pre-crisis and crisis periods, and the market beta calculated on the 12 FOMC days during the shale period. The Shale Dummy variable takes a value of one for industries directly involved in the Shale Oil supply chain (Shale Oil Firms, Oil Pipeline firms, Drilling Service firms, and Railroads), and zero otherwise. Panel B shows the results of time-series regressions the market return on the characteristic portfolio returns constructed as the weekly cross-sectional slopes from the cross-sectional regression in Panel A. The final row shows the change in intercept in the time-series regression when the Shale Discovery characteristic portfolio is excluded.

Panel A: Fama-Macbeth Regressions of Industry Returns

	Industry Average Returns				Industry Average Returns			
	Pre-Crisis	Crisis	Post-Crisis	Shale Period	Pre-Crisis	Crisis	Post-Crisis	Shale Period
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Shale Industry Dummy	-0.129*	0.138	0.215**	0.321***	-0.097	0.238	0.167*	0.189**
	[-1.675]	[0.259]	[2.275]	[3.651]	[-1.310]	[0.533]	[1.773]	[2.326]
OPEC Announc. Returns	-0.192***	0.227	0.005	0.188***	-0.189***	0.237	0.000	0.175***
	[-3.415]	[0.608]	[0.074]	[3.340]	[-3.389]	[0.658]	[0.005]	[3.115]
Pre-Crisis Beta	0.210	-0.169	-0.007	-0.036	0.208	-0.174	-0.005	-0.030
	[1.316]	[-0.276]	[-0.038]	[-0.328]	[1.307]	[-0.286]	[-0.026]	[-0.270]
Crisis Beta	0.025	-0.291	0.022	-0.038	0.030	-0.275	0.015	-0.059
	[0.362]	[-0.279]	[0.124]	[-0.491]	[0.426]	[-0.264]	[0.082]	[-0.758]
Shale Years FOMC Day Beta	-0.104	0.372	-0.063	0.065	-0.099	0.389	-0.071	0.043
	[-1.115]	[0.854]	[-0.471]	[0.693]	[-1.048]	[0.898]	[-0.526]	[0.450]
Shale Discovery Return					-0.015	-0.047	0.022	0.062**
					[-0.785]	[-0.534]	[0.751]	[2.451]
Constant	0.139	-0.307	0.444***	0.298**	0.097	-0.055	0.386***	0.269**
	[1.317]	[-0.515]	[2.693]	[2.221]	[1.095]	[-0.099]	[2.862]	[2.264]
Observations	21,804	3,555	10,349	14,931	21,804	3,555	10,349	14,931
Number of Weeks	276	45	131	189	276	45	131	189

Panel B: Explaining Aggregate Market with Characteristic Portfolios

	Aggregate Market Returns				Aggregate Market Returns			
	Pre-Crisis	Crisis	Post-Crisis	Shale Period	Pre-Crisis	Crisis	Post-Crisis	Shale Period
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Shale Industry Dummy Portfolio	-0.278***	-0.163	-0.164	0.479***	-0.382***	-0.185	-0.247*	0.268**
	[-3.464]	[-0.696]	[-1.130]	[4.451]	[-4.636]	[-0.784]	[-1.657]	[2.371]
OPEC Announc. Portfolio	0.319***	0.075	0.061	-0.477***	0.365***	-0.024	0.074	-0.395**
	[2.789]	[0.214]	[0.264]	[-2.671]	[3.261]	[-0.064]	[0.326]	[-2.307]
Pre-crisis Beta Portfolio	0.591***	0.132	0.677***	0.460***	0.615***	0.163	0.697***	0.451***
	[19.769]	[1.086]	[10.039]	[6.296]	[20.711]	[1.278]	[10.349]	[6.465]
Crisis Beta Portfolio	0.527***	0.826***	0.893***	0.434***	0.585***	0.829***	0.883***	0.459***
	[7.814]	[13.627]	[13.004]	[3.963]	[8.708]	[13.596]	[12.991]	[4.395]
Shale FOMC Day Beta Portfolio	0.148***	0.046	0.193*	0.402***	0.164***	0.072	0.207**	0.374***
	[2.905]	[0.206]	[1.903]	[4.353]	[3.285]	[0.318]	[2.063]	[4.243]
Shale Discovery Portfolio					0.424*	0.740	0.582	2.194***
					[1.701]	[0.687]	[1.382]	[7.059]
Constant	0.065	-0.302	0.390***	0.224**	0.073	-0.290	0.389***	0.188*
	[0.895]	[-0.718]	[3.058]	[1.990]	[1.039]	[-0.685]	[3.082]	[1.749]
Weeks	276	46	131	189	276	46	131	189
R-squared	0.591	0.826	0.768	0.347	0.615	0.829	0.776	0.411
	Market Return Explained by Shale Industry Dummy Portfolio							
Change in Intercept	-0.009	-0.011	-0.029	0.084**	-0.013	-0.015	-0.040	0.029
	[-0.589]	[-0.309]	[-1.088]	[2.124]	[-0.665]	[-0.399]	[-1.445]	[1.329]

T-Statistics in Brackets
*** p<0.01, ** p<0.05, * p<0.1

as an increases in seismic activity in shale producing states, such as Oklahoma. However, to the extent the negative environmental impacts are well understood already, our estimates document that these effects are offset by positive employment and value effects in the stock market. The long run impact of shale technology on 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. In doing so we provide a novel framework for how to estimate the effect of technological innovations on the economy.

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Internet Appendix

Appendix 1 Model of Oil Supply, Demand, and Industry Returns

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: $R^i_{t+1} = \Pi^i_{t+1}$.

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

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

or, in logs,

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

where the risk premium

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

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

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

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

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

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

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

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

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

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

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

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

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

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 2 Characteristic Portfolios

We have three "characteristics":

1. $R^j_{OPECAnn}$: The return of industry j on the OPEC Announcement day

2. $R^j_{ShaleDisc}$: 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

$$X = [\iota \ \bar{r}_{ShaleDisc} \ \bar{r}_{OPECAnn} \ \bar{\beta}_{PreShale}],$$

where the overbar indicates an N x 1 vector of the industry characteristics. The goal is to construct maximally diversified portfolios with industry weights $\bar{w}_{ShaleDisc}$, $\bar{w}_{OPECAnn}$, $\bar{w}_{MarkeBeta}$ 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:

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

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

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

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

Likewise for the Shale Announcement Portfolio the weights solve:

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

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

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

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

And finally for the OPEC Announcement Portfolio:

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

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

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

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

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

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

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.

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

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

$$\Gamma_a^k = \sum_{j=1}^{N} w_k^j \beta_{Other}^j$$
$$\Gamma_{Other}^k = \sum_{j=1}^{N} w_k^j \beta_{Shale}^j$$
$$\Gamma_{Shale}^k = \sum_{j=1}^{N} w_k^j \beta_a^j$$
$$\nu_t = \sum_{j=1}^{N} w_k^j \epsilon_t^j$$

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:

$$\begin{aligned}
&\sum_{j=1}^{N} w_k^j \beta_{Mkt,PreShale}^j \\
&= \sum_{j=1}^{N} w_k^j \left[\frac{\beta_a^j \sigma_a^2 + \beta_{Other}^j \beta_{Other}^{Mkt} \sigma_{Other}^2}{\sigma_a^2 + (\beta_{Mkt}^{Other})^2 \sigma_{Other}^2} \right] \\
&= \frac{\left(\sum_{j=1}^{N} w_k^j \beta_a^j \right) \sigma_a^2 + \left(\sum_{j=1}^{N} w_k^j \beta_{Other}^j \right) \beta_{Other}^{Mkt} \sigma_{Other}^2}{\sigma_a^2 + (\beta_{Mkt}^{Other})^2 \sigma_{Other}^2} \\
&= \frac{\Gamma_a^k \sigma_a^2 + \Gamma_{Other}^k \beta_{Other}^{Mkt} \sigma_{Other}^2}{\sigma_a^2 + (\beta_{Mkt}^{Other})^2 \sigma_{Other}^2}
\end{aligned}$$

Next consider the Shale announcement day return, recall that $r_{ShaleDisc}^j = \beta_{Shale}^j z_{ShaleDisc}^{Shale}$ by our identifying assumption, and that for simplicity it is assumed that $z_{ShaleDisc}^{Shale} = 1$:

$$\sum_{j=1}^{N} w_k^j r_{ShaleDisc}^j = \sum_{j=1}^{N} w_k^j \beta_{Shale}^j = \Gamma_{Shale}^k.$$

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

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

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:

$$\begin{aligned}
1 &= \frac{\Gamma^{MarketBeta}_a \sigma^2_a + \Gamma^{MarketBeta}_{Other} \beta^{Mkt}_{Other} \sigma^2_{Other}}{\sigma^2_a + (\beta^{Other}_{Mkt})^2 \sigma^2_{Other}} \\
0 &= \Gamma^{MarketBeta}_{Shale} \\
0 &= \Gamma^{MarketBeta}_{Other} + \Gamma^{MarketBeta}_{Shale} z^{Shale}_{OPECAnn}
\end{aligned}$$

The solutions to this are $\Gamma^{MarketBeta}_{Shale} = \Gamma^{MarketBeta}_{Other} = 0$ and $\Gamma^{MarketBeta}_a = 1 + \frac{(\beta^{Other}_{Mkt})^2 \sigma^2_{Other}}{\sigma^2_a}$

Consider next the Shale Announcement characteristic portfolio; the loadings solve

$$\begin{aligned}
0 &= \frac{\Gamma^{ShaleDisc}_a \sigma^2_a + \Gamma^{ShaleDisc}_{Other} \beta^{Mkt}_{Other} \sigma^2_{Other}}{\sigma^2_a + (\beta^{Other}_{Mkt})^2 \sigma^2_{Other}} \\
1 &= \Gamma^{ShaleDisc}_{Shale} \\
0 &= \Gamma^{ShaleDisc}_{Other} + \Gamma^{ShaleDisc}_{Shale} z^{Shale}_{OPECAnn}
\end{aligned}$$

The solutions to this are $\Gamma^{ShaleDisc}_{Shale} = 1$, $\Gamma^{ShaleDisc}_{Other} = -z^{Shale}_{OPECAnn}$, and $\Gamma^{ShaleDisc}_a = \frac{z^{Shale}_{OPECAnn} \beta^{Mkt}_{Other} \sigma^2_{Other}}{\sigma^2_a}$.

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

$$0 = \frac{\Gamma_a^{OPECAnn}\sigma_a^2 + \Gamma_{Other}^{OPECAnn}\beta_{Other}^{Mkt}\sigma_{Other}^2}{\sigma_a^2 + (\beta_{Mkt}^{Other})^2\sigma_{Other}^2}$$

$$0 = \Gamma_{Shale}^{OPECAnn}$$

$$1 = \Gamma_{Other}^{OPECAnn} + \Gamma_{Shale}^{OPECAnn} z_{OPECAnn}^{Shale}$$

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 3 Data

Data for this project come from several sources. All data for oil production and forecasts are from the Energy Information Administration (EIA). WTI futures returns are constructed using data from Bloomberg. Stock market data is from CRSP and Datastream. We use NAICS code descriptions to construct 76 industry portfolios of all CRSP stocks. We construct our own industries to generate greater variation in exposure to oil industry shocks than standard portfolios can provide. For instance, in the 49 Fama-French industries available from Ken French's website, "Airlines" are a subset of transportation industries, and separate aspects of oil and gas extraction, including drilling, pipelines, and refineries, are all gathered in a single oil industry, despite the fact that they may be very differently exposed to oil supply and/or demand shocks.

We treat stocks of primary oil and gas producers 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, which is included in our main set of 76 industry portfolios.

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.

Table A-1: 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

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 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 Announcement Returns, Betas, and Portfolio Weights

Table A-2 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 01/2003-06/2008 (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 A-2: Industry Announcement Returns, Betas, and Portfolio Weights

		Announcement Returns and Market Betas				Characteristic Portfolio Weights			
		Shale	OPEC	Pre-Crisis	Crisis	Shale	OPEC	Pre-Crisis	Crisis
	Industry	Discovery	Announc.	Beta	Beta	Discovery	Announc.	Beta	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

Appendix 6 Shale Announcement Market Observations

Below are several quotations from market observers discussing the size and importance of the Wolfcamp A DL Hutt C #2H well result that Pioneer Natural Resources disclosed after close on July 31, 2013. The Wolfcamp A is a part of the Permian Basin, and successful extraction with fracking technology increased the quantity of recoverable reserves in the Permian from 37 Billion Barrels of Oil Equivalent (BBOE) to 50 BBOE, based on estimates from Pioneer Natural Resources. The well results announced for Q2 2013 earnings were from wells in Midland County, TX.

- ISI Group: Wolfcamp A results "biggest surprise," Wolfcamp B also better than expected; appears co. has established "giant" resource play (Shapira (2013))
- Capital One Southcoast: "Fantastic" result for Wolfcamp A (Shapira (2013))
- Howard Weil: Midland Basin horizontal wells likely to "steal most headlines" (Shapira (2013))
- Johnson Rice: "Very strong" rate from Wolfcamp A test and narrowing of growth forecast makes for "strong" release, likely increasing confidence in L-T prospects (Shapira (2013))
- Barclays: We believe that PXDs Wolfcamp position is one of the most exciting emerging oil assets in the US. (Barclays (2013))
- Credit Suisse: Great Scott–Wolfcamp A Delivers in Spades. PXDs initial A Bench well in Northern Midland is another resounding success. (Credit Suisse (2013))
- RBC: First Wolfcamp "A" well comes on at outstanding rate (RBC (2013))

- SunTrust: Very strong Wolfcamp A result. Pioneer announced its first Central Midland Basin Wolfcamp A averaged ∼1,100 Boepd (∼75% oil) the first 30 days. To put the initial 30-day rate in context, it is the second highest in Midland County to our knowledge. Big estimated ultimate recoveries. The Wolfcamp A result is all the more impressive when one considers the Wolfcamp B well has produced in six months what a vertical well produces in its entire 40-year lifetime (140 Mboe). Pioneer is pegging recoveries at 800-1,000 Mboe for its first three Central Midland Basin wells, suggesting development costs could be below $10/Boe. (SunTrust (2013))

- Topeka Capital Markets: We believe PXDs in line quarter 2Q13 is overshadowed by its first Wolfcamp A well in Midland County, which had a 24-hour IP of 1,712 boe/d and a 30-day rate of 1,107 boe/d (74% oil) and appears to tracking well north of a 900 Mboe type well. This is a significant well, as it opens up as much as 580,000 net acres for the Wolfcamp A in the northern Midland Basin. (Topeka Capital Markets (2013))

Shale Announcement References

Barclays, "Pioneer Natural Resources", August 5, 2013, via Thomson One, accessed September 12, 2016

Credit Suisse, "Pioneer Natural Resources", August 2, 2013, via Thomson One, accessed September 12, 2016

RBC, "Pioneer Natural Resources", August 2, 2013, via Thomson One, accessed September 12, 2016

Shapira, Arie "PXD STREET WRAP: Wolfcamp Likely Trumps 2Q, Positive for FANG," August 1, 2013, Bloomberg, via Bloomberg, accessed September 12, 2016

SunTrust, "Pioneer Natural Resources", August 2, 2013, via Thomson One, accessed September 12, 2016

Topeka Capital Markets, "Pioneer Natural Resources", August 1, 2013, via Thomson One, accessed September 12, 2016

Appendix 7 Placebo Test

In this section we consider how unusual the Shale Discovery Announcement day is in generating the results we highlight in our main identification strategy. Given that the total stock market return is positive on this day, it is possible that the cross-section that we identify is really driven by market beta exposures (which are hard to measure). So we proceed by asking the question: How likely is it that a randomly picked trading day could produce a similar result?

To answer this, we repeat our analysis using all of the trading days in our post-crisis and shale oil period samples in place of the Shale Discovery Announcement day. We use the results to construct a "placebo" distribution of the key test statistics of interest. This distribution then allows us to assess how likely it is that a randomly-picked day would generate a portfolio that performs at least as well as the Shale Discovery Portfolio on the key economic dimensions that are most relevant to our study: the ability of the portfolio to explain the time-series of the U.S. aggregate stock market return during the shale period, as well as the relationship to the shale oil development itself. Specifically, we consider five statistics of interest. The first statistic measures the overall return on the total market portfolio during the shale oil period which is attributable to the shale discovery portfolio. (From Table 5, the relevant number is Change in Intercept, $\Delta\gamma_0^{Mkt} = 0.116\%$ in the last row of Panel B Column (8)). The second is the increase in the ability of the portfolio to explain variation in the market return, which is measured as the difference in the t-statistics of the slope coefficient of the shale discovery portfolio in explaining the market return γ_1^{Mkt} during the shale oil period relative to the t-statistic on this coefficient over the post-crisis period. (Table 5, first row Panel B, the difference in the t-statistics between columns (8) and (6) is 4.00). The third measures the ability of the portfolio to explain specifically Shale Oil Index returns in the shale period. To create the relevant statistic we take the difference in the t-statistics associated with $\gamma_1^{ShaleOil}$ and $\gamma_1^{S\&PInt}$. (Table 4, the t-statistic of the first row in column (8) of Panel D less the corresponding t-ratio in Panel B). The fourth statistic measures the ability of the portfolio to explain real shale drilling growth, and is the t-statistic in the regression of monthly growth in the shale oil rig count on the Shale Discovery Portfolio return δ_2, as shown in Table 3. The fifth is the t-statistic of the cross-section of industry returns in explaining employment growth, λ_E^1 (Table 6, first row of column (8)).

Figure 6 plots the histograms of these test statistics simulated using all of the trading days in both the post-crisis and shale oil periods (07/2009 - 09/2015). Panel A shows that the distribution of the market return explanatory coefficients is centered around zero but with a long right tail. Still, the Shale Discovery Announcement day is in the 95.0th percentile of this distribution. Panel B shows that the distribution of differences in the market explanatory power as measured as the difference t-statistics between the post-crisis (pre-shale) and the shale period is also centered near zero, but with a larger left tail. Consequently, there are fewer days that are “as good” or better at explaining this difference, so that the Shale Discovery Announcement is at the 98.6 percentile of this distribution. Panel C displays the distribution of the difference in t-statistics between the Shale Oil Index and the S&P Integrated Producer Index regression coefficient on the Shale Discovery Portfolio. These are also centered around zero, with the 3.9 value for the actual Shale Discovery Announcement day is at the 98.9 percentile of this distribution. Panel D plots the histogram of the t-statistics in the regression of monthly shale rig count growth on the lagged Shale Discovery Portfolio return. This distribution is centered around zero and quite dispersed. The Shale announcement day's ability to link stock return to actual activity falls in the 96.3 percentile of all days. Panel E shows that the ability of the Shale Discovery day to explain employment growth is in the 95th percentile of all days. Finally, panel F summarizes the joint distribution of the test statistics described above by plotting the histogram of the lowest percentile of the five statistics corresponding to each day in the sample. Thus, it evaluates every day on its ability to explain the stock market returns jointly with the shale index returns, the shale drilling activity, and employment growth. By this measure, there is no other day in the sample that is as good as the Shale Discovery Announcement day that we use, whose minimum percentile (among the five values above) of 95.0 is the 100th percentile (highest of 1565 days) of the distribution. In fact, the second closest day has the minimum percentile of 87, which means that there is no other day in our sample that would fall in the 95th (or even 90th) percentile on all five measures.

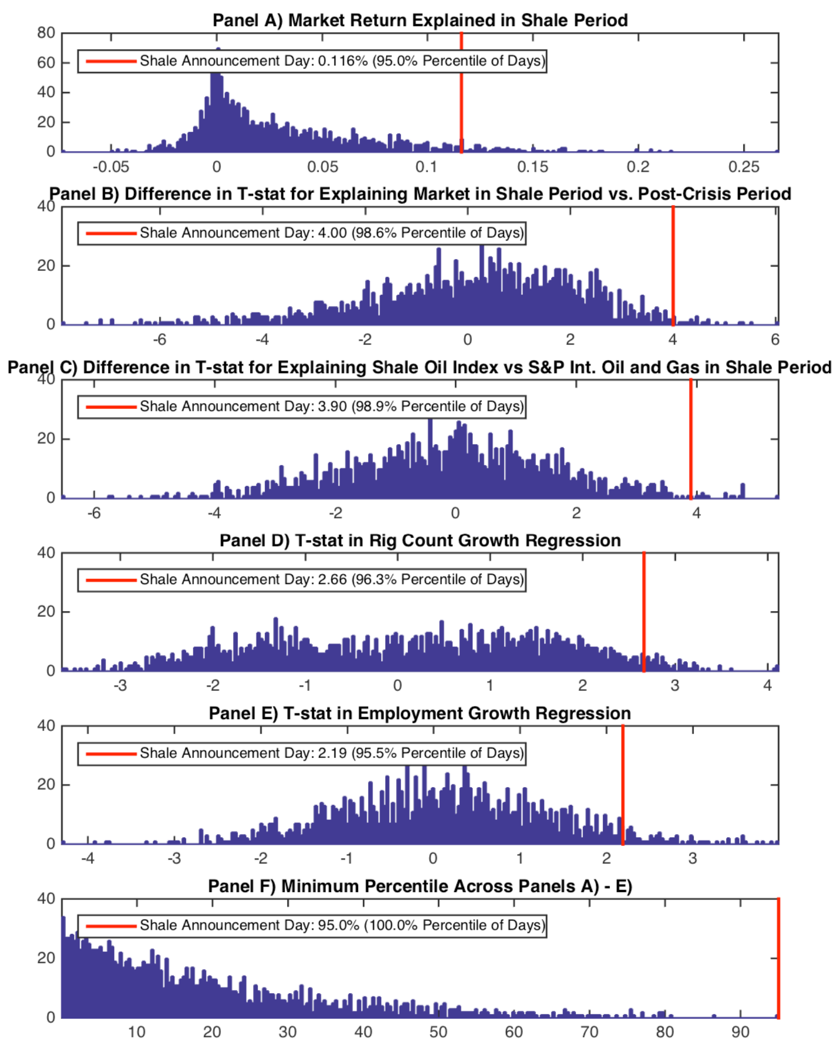
This placebo evidence confirms that the shale discovery announcement is indeed a unique event, in that the industry stock returns on the day following this announcement have an unmatched ability to explain both the aggregate stock market return and employment growth during the shale period and to capture shale oil related news, both in the returns on shale stocks and in the real drilling activity.

Appendix 8 Explaining Market Return with Characteristic Portfolios using Rolling Betas

Here as a robustness exercise we perform a similar analysis to that in Table 5, but using rolling betas to calculate market exposure to the characteristic portfolios in place of subsample regressions. Table A-3 reports the average excess returns to four portfolios in each of the

Figure 6: Placebo Tests for the Shale Discovery Announcement day

This figure shows the result of a placebo exercise in which other trading days' returns are used in place of the Shale Discovery Announcement day (8/1/2013). Each panel shows the histogram of a specific test statistic. To generate these histograms, we first obtain the cross-section of industry returns on an alternate trading day, and then repeat the analysis using these returns in the place of the shale discovery returns to recalculate the statistic. This exercise is repeated for each of the 1,595 trading days in the post-crisis and shale oil periods to create the distributions, which are plotted in blue. The red lines show the statistic obtained with the Shale Discovery Announcement day along with its associated percentile in the distribution of trading day statistics. The statistic examined in Panel A is the annualized return to the market portfolio return during the Shale Oil Period explained by the "trading day portfolios", calculated in analogous manner to the Shale Discovery Portfolio (The value for the Shale Discovery Portfolio is shown in Table 5). Panel B examines the difference in the t-statistics on the slope coefficient of the trading day portfolio return in explaining aggregate market returns during the shale period relative to the t-statistic on this coefficient in the post-crisis period (Table 5). Panel C shows the difference in the t-statistics of the slope coefficient on the trading day portfolio in the regressions explaining Shale Index returns and those explaining S&P Integrated Oil and Gas Producers index returns (Table 4). Panel D shows the t-statistic in the regression of monthly growth in the shale oil rig count on the trading day portfolio (Table 3). Panel E shows the t-statistic when using trading day returns to explain the cross-section of industry employment growth (Table 6). Panel F shows the minimum percentile for each trading day's place across the distributions shown in Panels A - E.



subsamples. The first row reports the aggregate market return. The second row reports the average return to a portfolio which goes long the market and short positions in the OPEC Announcement Portfolio as well as the Pre-crisis and Crisis beta characteristic portfolios.

$$R^{B}_{t+1} = R^{Mkt}_{t+1} - \gamma^{OPECAnn}_{t} R^{OPECAnn}_{t+1} - \gamma^{PreCrisisBeta}_{t} R^{PreCrisisBeta}_{t+1} - \gamma^{CrisisBeta}_{t} R^{CrisisBeta}_{t+1}. \qquad \text{(A-3)}$$

Here the values of γ are time-varying and calculated as the slope coefficients from rolling regression of the market return on the three characteristic portfolios over the previous 52 weeks. The third row shows the returns of a portfolio calculated in a similar manner, but with the Shale Discovery Portfolio included:

$$R^{C}_{t+1} = R^{Mkt}_{t+1} - \gamma^{ShaleDisc}_{t} R^{ShaleDisc}_{t+1} - \gamma^{OPECAnn}_{t} R^{OPECAnn}_{t+1} - \gamma^{PreCrisisBeta}_{t} R^{PreCrisisBeta}_{t+1} - \gamma^{CrisisBeta}_{t} R^{CrisisBeta}_{t+1}. \qquad \text{(A-4)}$$

Finally, the fourth row shows the average return on a portfolio calculated as the difference between the second and third portfolio returns: $R^{D}_{t+1} = R^{B}_{t+1} - R^{C}_{t+1}$. The return to this portfolio can be interpreted as the component of the market return that is explained by adding the Shale Discovery portfolio, since if the slopes on non-shale characteristics portfolios in (A-3) and (A-4) were exactly the same we would have $R^{D}_{t+1} = \gamma^{ShaleDisc}_{t} R^{ShaleDisc}_{t+1}$. Therefore, the average return on this portfolio is the analog to the last row of Table 5. As the table shows, the Shale Discovery portfolio explains a significant portion of the positive market returns in the Shale Oil Period, but not in the other periods. The magnitude is similar and slightly larger than the earlier results (13.4 bps per week as opposed to the 11.6 bps per week).

Table A-3: Explaining Market with Characteristic Portfolios using Rolling Betas

This table shows average weekly returns for four portfolios over the various sub periods. The first portfolio (A) is the return to the aggregate market. The second portfolio (B) is the return to a long position aggregate market combined with a short position in the OPEC Announcement, Pre-Crisis Beta, and Crisis Beta characteristic portfolios, where the short positions are calculated using slope coefficients from weekly regressions of the market return on the characteristic portfolios using rolling annual windows. The third portfolio (C) is calculated as a similar manner to portfolio (B), but the Shale Discovery Portfolio is included in addition to the other three characteristic portfolios. The final portfolio (D) is a long position in portfolio (B) and a short position in portfolio (C). See Table 5 for a description of the characteristic portfolios and subsample periods

	Precrisis		Crisis		Postcrisis		Shale Oil Period	
	Return	T-statistic	Return	T-statistic	Return	T-statistic	Return	T-statistic
Portfolio	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
				Market Return, R^{Mkt}				
(A)	0.161	[1.473]	-0.553	[-0.588]	0.358	[1.414]	0.281**	[2.141]
				Market Return Less Position in Non-Shale Characteristic Portfolios, R^B_{t+1}				
(B)	0.060	[0.796]	-0.531	[-0.951]	0.400***	[3.052]	0.335***	[2.802]
				Market Return Less Position in All Characteristic Portfolios, R^C_{t+1}				
(C)	0.079	[1.029]	-0.564	[-0.983]	0.374***	[2.826]	0.201*	[1.869]
				Contribution of the Shale Discovery Portfolio to Market Return, $R^D_t = R^B_{t+1} - R^C_{t+1}$				
(D)	-0.020*	[-1.791]	0.032	[0.975]	0.026	[1.356]	0.134***	[2.725]
Weeks	276		45		131		189	