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

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Abstract

We use evidence from asset price data to quantify the contribution of shale oil to the U.S. economy. Equity market valuations of firms engaged in shale oil extraction reflect the market's expectations about the future growth in shale oil supply and its potential for raising aggregate productivity in the U.S. economy. We use returns on an index of shale oil producers orthogonalized with respect to oil prices and industry-wide return controls to extract an empirical measure of shale-specific productivity innovations. This hedged strategy explains roughly 10% of the increase in aggregate U.S. equity market capitalization since 2010.

Keywords: cash-flow news, long-run growth, oil prices, shale oil, fracking, horizontal drilling

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1 Introduction

Asset pricing theory is typically agnostic about the nature of technology shocks that underpin the variation in asset values.[1] At the same time, much of the debate in empirical research 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 (e.g., Bansal and Yaron (2004), Campbell and Vuolteenaho (2004), Hansen, Heaton and Li (2008), Cochrane (2011), Greenwald, Lettau and Ludvigson (2014)). 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, suggesting falling discount rates as the main driver of rising valuations. However, over the same time period U.S. oil production increased dramatically, from less than 5 MBD (million of barrels per day) in 2010 to over 8 MBD in 2014, with total U.S. oil production forecast to nearly double by 2015 relative to the pre-crisis levels. Almost all of this increase can be attributed to technological innovations that allow oil to be extracted from shale rock formations. These innovations involve the combination of hydraulic fracturing ("fracking") and horizontal drilling, and in the matter of a few years have fundamentally changed the global energy supply-demand balance. Their success was also largely unexpected, as evidenced by the published forecasts of the Energy Information agency (EIA). Given the importance of oil to the U.S. economy, how much of the recent rise in the equity market can be attributed to the unexpected development of U.S. shale oil? Might this suggest a greater role for cash-flow news in explaining asset price fluctuations?

Our approach centers on using covariation between returns on a portfolio of companies concentrated in shale oil extraction that we construct – the Shale Oil Index – and the aggregate market portfolio to estimate the contribution of the technological innovations in the shale sector to the broad equity market. We construct our index by identifying firms that have significant exposure to shale oil discoveries, as indicated by asset holdings listed in the firms' 10-K filings. Given the focus that our index firms have on shale oil, changes in the index value should reflect the market's assessment of shale oil development.

The main challenge is to identify the component of stock returns that is attributable to

[1] Recent work by Kogan, Papanikolaou, Seru and Stoffman (2012) linking news on patented technologies to equity returns is a notable and important exception.

technology shocks in the shale oil sector. There are several sources of shocks that contribute to both the aggregate stock market returns and the Shale Oil Index returns. Aggregate shocks to productivity in sectors that rely on petroleum as an input or increase household demand for oil through complementarities or income effects are generally good news both for the aggregate stock market and for oil prices, and, therefore, for oil producers, and can thus confound the effect of innovation in oil production. Shocks to other oil producers domestic and foreign - as well as demand shocks abroad - have an opposite impact on the shale producers relative to the aggregate economy. Decreasing (net) supply to the U.S. market has a negative effect on the aggregate market but is a boon to domestic producers that are not themselves affected by the shock directly (a prominent example is the explosion on the Deepwater Horizon offshore rig and the subsequent oil spill in the Gulf of Mexico, which affected supply by BP, but was also potentially bad news for other offshore oil producers in light of the heightened safety concerns).

We address this challenge by orthogonalizing the Shale Oil Index returns with respect to both oil prices and the returns to an index of non-shale oil producers (North-American Integrated Index). We also orthogonalize the with respect to an index of shale gas producers, given the fact that some of the shale oil producers are also active in natural gas extraction and that could bias our inference about the contribution of the oil-extraction technology. The unexplained component representing innovations unique to shale oil firms we refer to as the "Shale Shock". Finally, we estimate covariances between the Shale shock and the aggregate stock market portfolio. We find that roughly 10% of the increase in aggregate stock market returns since 2010 can be explained by our Shale shock, suggesting a gain of roughly \$1.5 trillion based on the stock market appreciation over the period.

Increased shale production has two potentially positive effects for the U.S. Economy, one is the direct effect of increased employment and production in the Shale Oil sector, and the second is the indirect effect on oil prices, potentially lowering both their levels and long-run uncertainty about oil. Though we control for oil prices in our identification strategy, we find evidence of lower levels of oil price uncertainty, with increasing valuations of shale oil firms coinciding with reductions in oil price volatility. We also examine the cross-section of industry returns, and find strong positive effects of shale oil in a a broad set of industries, ranging from car manufacturers and consumer goods producers to mining services and steel firms, suggesting that our shock is capturing both direct and indirect benefits of shale oil production.

To further shed light on the sources of benefits, we examine industry returns around a large exogenous shock to oil prices around the OPEC announcement of 11/28/2014. On this day OPEC announced that the member countries would not cut production in response to increased world production and falling prices, leading to a one day drop in oil prices of roughly 10% and a one day drop in our shale index of roughly 7%. This decision by OPEC casts doubt on the long-run viability of relatively high cost shale production, and therefore may have lasting impacts on this industry.

Given the exogenous nature of this shock one would expect that it would positively impact firms which are exposed to shale through their dependence on oil prices, while negatively impacting those which stand to benefit by their participation in shale production. We find that roughly 25% of the cross-sectional variation of industry returns in around this announcement can be explained by pre-announcement exposure to our shale shock, with industries, such as mining services, which stand to directly benefit from increased shale production having very negative returns. However, we also find that there are outliers to this pattern, particularly among consumer goods firms, which seem to have relatively high returns on this day despite high exposure to the shale shock. We show that including pre-announcement exposure to oil prices along with exposure to shale shocks can explain these outliers, and that jointly the two exposures are both highly significant, and can explain over 60% of the cross-sectional industry variation of returns around this announcement. These findings suggest that our shock, though constructed by controlling for price changes, is still effective in capturing some of the indirect benefits of lower oil prices.

This paper proceeds as follows. First we develop a simple reduced-form asset pricing model with an explicit role for oil demand and production in Section 2. We then describe the data construction and our empirical approach in Section 3. Section 4 presents the results of our empirical analysis. Section 5 concludes.

2 Model

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

2.1 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).

2.2 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, etc., net of foreign demand) , 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 implications.

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

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

2.3 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 no depreciation between periods ($V_t^i = K_t^i$) implies that the returns to an average firm are

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

or, in logs,

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

where the aggregate market equity risk premium

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

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

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

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

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

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

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

We approximate innovations to the log of total supply as

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

where $\xi^{Shale}=E\left[\frac{S^{Shale}_t}{O_t}\right]$, and we assume that Σ is a constant variance-covariance matrix of S^{Shale}_t and S^{Other}_t 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 aggregate market return innovations can be approximated as

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

Therefore, since the market return innovation in equation (2) is a linear combination of the sector-specific oil productivity shocks and innovations to oil prices, the long-run average share of shale oil in total oil supply, ξ^{Shale} can be identified by regressing the market excess return on the shale sector return, controlling for the other sector returns (given by (1)) as well as oil price innovations.

3 Data

Data for this project come from several sources. All data for oil production and forecasts are from the Energy Information Assocation (EIA). WTI futures returns are constructed using data from Bloomberg. Stock market data is from CRSP and Datastream. Reported revenue and analyst projections of revenue are from Thomson Reuters' IBES database. The analysis will rely heavily 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 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

3.1 Shale Index Construction

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.

4 Empirical evidence

4.1 The Shale Revolution: a Primer

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

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

The second important feature of the boom is its magnitude. While clearly increased productivity is a benefit for shale oil producers, its importance for the rest of the economy hinges on the fact that this production increase is significant relative to total world supply. Panel C of Figure 1 illustrates that the increase in U.S. oil production driven by shale deposits amounts to roughly 5% of total world oil production. While this may not seem large, given the highly inelastic nature of oil demand it has a potential to have a large long-run impact on price levels. Typical estimates of long-run demand elasticity (see for instance Kilian and Murphy (2014)) are near -0.25, suggesting that a 5% increase in world supply may yield up to a 20% drop in price. While the price does not drop dramatically over the sample we consider, this period coincides with unrest in the Middle East and consequently volatile supply from the region. The recent increases in Libyan production combined with the greatly increased

U.S. production have combined to depress global prices by roughly 20% in the three months since the end of our sample. Without U.S. oil production increases, it is very likely that the recent reductions in Middle East supply would have translated into significantly higher prices than those observed.

The final feature that makes this shock somewhat unique is that it originated in a small number of easily identifiable firms, which allows us to isolate innovations using stock return data.[2]. Panel D illustrates the cumulative returns to several stock price indices. The most important is the "Shale Oil Index" described in Section 3, which is designed to isolate firms which are primarily engaged in oil production in the shale oil plays. The returns to this index are plotted with several other energy producer stock indices. The first is the"Shale Gas Index", described in Section 3, the second is a "Non U.S. E&P Index", which consists of E&P firms outside of the United States. The third is an index of the four large integrated oil and gas producers on the S&P 500. The cumulative returns to the aggregate CRSP market index are also included for comparison. As Panel D shows, the shale oil firms exhibit no abnormal returns relative to other industry producers prior to the sharp rise in production. However, following that rise, they experience a period of extraordinary growth, rising roughly 200% in a two year time. The fact that this return was unique to these firms allows us to isolate market expectations of the value of the shock, which we do in the following section.

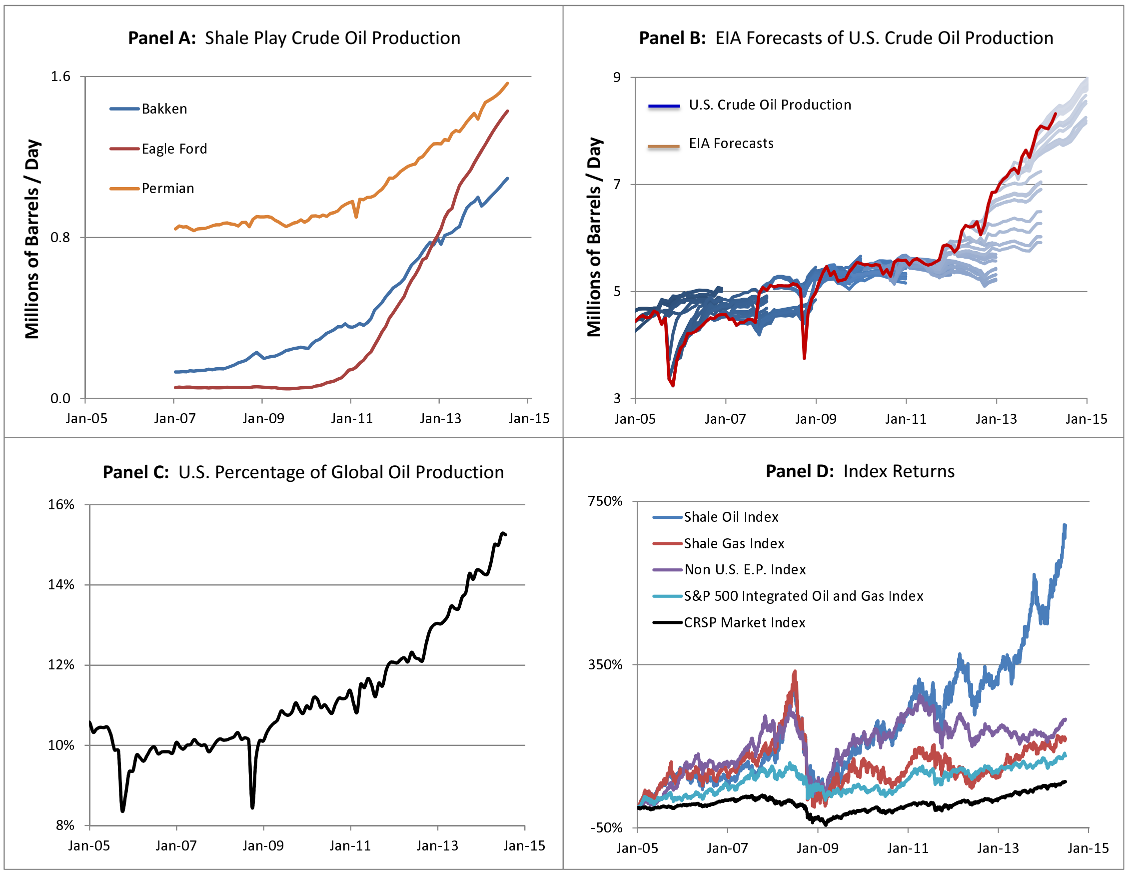
4.2 Constructing the Shale Shock

To isolate the impact of shale oil production we first construct daily returns on a tradable shale oil strategy by orthogonalizing the return to the shale oil index, $R^{ShaleOil}$, with respect the returns of a set of control assets. These assets are the shale gas index, $R^{ShaleGas}$; an international index of non-U.S. Exploration and Production (E&P) firms, $R^{E\&P}$; the S&P 500 index of integrated oil and natural gas producers, R^{Int}; and the return to the near month NYMEX WTI oil future, R^{WTI}. Therefore, the resulting Shale Shock is given by

$$S_t = R_t^{ShaleOil} - \beta_{t-1}^{ShaleGas} R_t^{ShaleGas} - \beta_{t-1}^{E\&P} R_t^{E\&P} - \beta_{t-1}^{Int} R_t^{Int} - \beta_{t-1}^{WTI} R_t^{WTI} \quad (3)$$

[2]This is similar to the approach used by Ward (2014) to study the impact of IT innovation on aggregate stock prices

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



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The regression loadings are calculated using a rolling 1-year regression of the daily returns to $R_t^{ShaleOil}$ regressed on the set of control variables. R_t^{WTI} controls for changes in the price of oil, while $R^{E\&P}$ and R^{Int} control for general changes in the prospects for oil producers, by controling for conventional non-shale producers. To ensure that we are identifying the technological breakthroughs linked to shale oil, and not overall shale oil and natural gas, we also include $R^{ShaleGas}$ as a control. While some firms in $R^{ShaleGas}$ and R^{Int} may have some U.S. shale oil exposure, we have gone through the 10-Ks of these firms to make sure that U.S. shale oil does not represent a significant portion of existing or potential earnings for the firms in these indices. As suggested by the analysis of the toy model in 2 above, the hedged return to the shale sector can be interpreted as the pure technology shock to this sector, or more broadly can be seen as the innovation to the market participants' expectations about the ability of the shale sector to supply oil in the future.

Table 2 shows summary statistics for the constructed indices as well as the variables used in the construction. The statistics are split across two periods: Sample 1 is pre-crisis period from January 2003 to June of 2008, and Sample 2 is the post-crisis period from June of 2010 to June of 2014. We remove the crisis period so as to prevent the outlier return observations from driving any of the subsequent analysis. The start of the pre-crisis period is chosen to correspond with the beginning of the pre-crisis run-up in oil prices.

The table shows that the hedged shale strategy earns essentially no return on average over the Sample 1 (Sharpe ratio of -0.05), while subsequently earning very high returns in Sample 2 (with a Sharpe ratio of 0.75). Shale firms performed very well prior to 2008, however their performance was not abnormal given the observed increase in oil prices and the high returns of comparable firms that are used as controls in the construction of the hedged strategy. In Sample 2 the situation is quite different. While the returns to all of the energy indices are once again robust, the shale strategy earns a large abnormal return over this period after controlling for the relevant industry returns. In both periods the shale strategy constructed using the rolling betas has very low correlation with the control variables, suggesting that the strategy is effective in controlling for shocks impacting the energy industry as a whole.

In contrast, the correlation between the aggregate market return and the shale strategy

Table 2: Summary Statistics: Shale Shock and Index Returns

Sample 1 (01/2003 - 06/2008)

Variable	Mean	STD	Sharpe Ratio	Correlation Matrix					
				S_t	R^{Mkt}	$R^{ShaleOil}$	$R^{ShaleGas}$	$R^{E\&P}$	R^{int}
S_t	-0.01	0.12	-0.05						
R^{Mkt}	0.05	0.16	0.33	0.04					
$R^{ShaleOil}$	0.31	0.28	1.12	0.43	0.49				
$R^{ShaleGas}$	0.34	0.29	1.16	0.04	0.50	0.86			
$R^{E\&P}$	0.27	0.22	1.23	0.03	0.36	0.71	0.75		
R^{int}	0.14	0.22	0.65	0.03	0.68	0.74	0.73	0.64	
R^{WTI}	0.30	0.34	0.88	-0.01	0.00	0.42	0.44	0.49	0.32

Sample 2 (06/2010 - 06/2014)

Variable	Mean	STD	Sharpe Ratio	Correlation Matrix					
				S_t	R^{Mkt}	$R^{ShaleOil}$	$R^{ShaleGas}$	$R^{E\&P}$	R^{int}
S_t	0.11	0.15	0.75						
R^{Mkt}	0.17	0.16	1.07	0.13					
$R^{ShaleOil}$	0.27	0.31	0.86	0.47	0.78				
$R^{ShaleGas}$	0.13	0.32	0.40	-0.01	0.69	0.79			
$R^{E\&P}$	0.08	0.20	0.38	0.03	0.72	0.78	0.72		
R^{int}	0.14	0.18	0.78	0.03	0.86	0.78	0.69	0.72	
R^{WTI}	0.08	0.26	0.32	0.04	0.48	0.62	0.50	0.59	0.55

is very different across samples, close to zero in Sample 1 (at 0.04) but noticeably higher in Sample 2, at 0.13. Coincidentally, the average stock market returns are also much higher in the second period, at 16% per annum versus 5% over Sample 1. Discount rate shocks, such as the high but declining equity premium post-crisis, may be the main driver of this difference. However, the changing correlation between the shale strategy and the aggregate stock market suggests the possibility that positive technology shocks in the shale sector have a significant positive effect on the market as a whole. We explore this possibility in more detail below.

4.3 The Shale Shock and the Aggregate Market Returns

Having isolated the Shale Shock as a market-based measure of expectations about shale oil production, we now examine its relation with returns to the aggregate stock market. To do this we regress daily market returns on the contemporaneous value of the shock, S_t:

$$R^{Mkt} = const + \beta_S^{Mkt} S_{t+1} + \epsilon_{t+1}. \tag{4}$$

The first two columns in Panel A of Table 3 report the results over Samples 1 and 2. As the table shows, the market has a negligible loading and zero R^2 on the shock in Sample 1, but a significantly positive coefficient over Sample 2 with a slightly higher R^2. A Chow test for the difference in coefficient on the shale shock across the two samples rejects the null hypothesis that they are the same with p-value of 0.04.

The third and fourth columns of Panel A split Sample 2 into two subsamples, Sample 2a from June of 2010 to June of 2012, and Sample 2b from June of 2012 to June of 2014. Here we see that, while the coefficients are similar across the two subsamples, the last two years of the sample period exhibit much stronger explanatory power in terms of R^2. This increase in explanatory power comes from both a lower market volatility and a higher volatility of the shale shock due to a reduction in the explanatory power of the control variables for returns to the shale oil index. However, Panel B of Table 3 shows that this reduction in variance does not lead to an increase in correlation between S_t and the controls. In all periods the explanatory power of oil prices and the other energy indices for the constructed shocks is essentially zero, confirming that the hedged strategy construction is successful in eliminating these correlations.

The fact that shale oil firms become less correlated with oil prices and the return to other energy firms, while simultaneously becoming more correlated with market returns, is consistent with the emergence of a new – and volatile – shock to shale oil firms, which is also important for aggregate market returns. Additionally, the timing of this behavior is perfectly aligned with the rapid, unexpected, increase in oil output from the shale deposits exploited by these firms. These facts together suggest a causal link between the increase in shale output and aggregate market returns.

The regressions also allow us to quantify the contribution of the Shale Shock to aggregate market returns. From Table 2 we can see that market return earned an annualized 17.3% over the second sample. After controlling for the Shale Shock in the second sample, that constant in the regression reduces to 15.6%, suggesting that roughly 10% of the total market increase over this period can be attributed to shale oil growth. Given the current market capitalization of the U.S. stock market, this 10% growth translates into an approximately $1.5 trillion increase in total market value. While this is obviously an imprecise estimate, it nevertheless speaks to the large economic magnitude of these discoveries.

The interpretation of these regressions relies on the effectiveness of the constructed Shale shock as a proxy for market expectations of shale oil production. In order to address concerns that this correlation is the result of an omitted variable bias, we now provide evidence regarding the behavior of stock returns around earnings announcements by two major shale firms.

4.4 Shale Oil Earnings Announcements and Stock Returns

In order to address the issue of causality, we would like to identify exogenous shocks to shale oil firm values to act as an instrument for returns to the shale oil index. An ideal instrument would be an announcement, or series of announcements which provide information about shale oil production without providing material information about other important economic shocks (e.g., Savor and Wilson (2014) show that announcement dates capture the bulk of priced shocks to firm cash flows). Unfortunately, while there are announcements made by

Table 3: Shale Shock and Aggregate Market Returns

	Sample 1 01/2003-06/2008	**Sample 2 06/2010-06/2014**	**Sample 2a 06/2010-06/2012**	**Sample 2b 06/2012-06/2014**
Panel A: Regressions of Market Return on Shale Oil Strategy				
	R^{Mkt}	R^{Mkt}	R^{Mkt}	R^{Mkt}
S_t	0.029	0.138***	0.118*	0.159***
	(0.032)	(0.034)	(0.070)	(0.040)
Constant	0.107*	0.156*	0.138	0.196**
	(0.0588)	(0.079)	(0.139)	(0.079)
Observations	1,383	1,006	505	522
R-squared	0.001	0.016	0.008	0.042
Panel B: Regressions of Shale Oil Strategy on Control Variables				
	S_t	S_t	S_t	S_t
$R^{E\&P}$	0.017	0.023	0.036	0.047
	(0.028)	(0.040)	(0.061)	(0.081)
R^{Int}	-0.007	0.036	0.055	-0.018
	(0.028)	(0.040)	(0.064)	(0.081)
$R^{ShaleGas}$	0.011	-0.037	-0.072	-0.002
	(0.023)	(0.023)	(0.054)	(0.044)
R^{WTI}	-0.009	0.020	0.029	0.026
	(0.011)	(0.023)	(0.030)	(0.044)
Constant	-0.008	0.107	0.052	0.076
	(0.051)	(0.074)	(0.104)	(0.104)
Observations	1,383	1,006	505	522
R-squared	0.002	0.004	0.015	0.004

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

government agencies regarding oil production, they do not appear to have a material impact on the returns to oil firms, suggesting that they are not a source of new information. Instead we look at information provided by the shale oil companies' themselves as part of their regular earnings announcements, which should be private prior to the announcements as it is material to the value of the companies.

For this exercise we focus on the last two years of the sample, during which the R^2 of the market return on the shale oil strategy is high and we see the largest increase in shale oil production. Though we have many companies in the shale index, the information released for each company reflects the same time period, and therefore may become rapidly redundant. To this end, we focus on the two largest companies (in terms of shale oil assets) in the index, EOG Resources (EOG) and Pioneer Resources (PXD).

To construct a measure of new information in the earnings reports, we focus on a measure of unanticipated revenue surprise, which is simply the log of the ratio of actual reported revenue to the average analyst projected revenue in the Thomson Reuters' IBES database.

We construct 15 observations, which represent announcements related to Q2 2012 to Q1 2014, with the exception of Pioneer's 2014 Q1, which is not in the IBES database. Since the earnings reports are released after market close on the announcement day, we match the revenue surprise measure to returns over the next trading day. The standard method for this analysis is a two stage least squares (2SLS) regression of R^{MKT} on $R^{ShaleOil}$, using the measure of revenue surprise as instrument for returns to the shale oil index. However, due to the well-known poor statistical properties of this procedure (especially acute in our very small sample), it may be preferable to focus on the reduced form specification of the IV regression, as suggested by Chernozhukov and Hansen (2008). Table 4 shows the results for both procedures. The OLS regressions of returns to the shale index, as well as returns to the aggregate market index, against the revenue surprise from the two firms' announcements, can be interpreted as the first stage and the reduced form specifications, respectively. Both variables show a clear positive relation with the revenue surprise of these shale firms. Even with only 15 observations, the relationship between both return variables and the revenue surprise variable is significant at the 5% level, and in fact at 1% level for the shale index return. The reduced form regression has a fairly high R-squared of 19% on the shale firms' revenue

Table 4: Stock Market Returns on Shale Announcement Days

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

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

surprise. Consistent with the reduced form results, the 2SLS regression of the market excess return on the shale index return instrumented with the shale firms' surprise also recovers a strong, statistically significant relationship with an R-squared of 55%.

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

4.5 Oil Price Volatility and the Shale Shock

While the evidence presented above suggests that shale oil is important to the aggregate economy, it does not shed light on the mechanism. One obvious channel would be through increased production yielding decreasing oil prices. However, we find strong evidence of shale technology innovations impacting the broader stock market even after controlling for the level of oil prices, which suggests that there may be additional channels through which shale oil supply affects the real economy. In this section we examine the relation between the Shale Shock and oil price volatility to see if decreasing uncertainty about oil is a potential channel for the impact of shale oil.

Recent work by Ready (2014) and Christoffersen and Pan (2014) emphasizes the importance of uncertainty in oil prices. To examine whether or not the increase in shale oil expectations has reduced uncertainty about oil, we examine the relation between the CBOE's Oil VIX measure (OVX) and the returns to our shale strategy. Rather than using daily data, as we do in Section 4, we use monthly data to capture long run trends in volatility, which are potentially not captured in the day to day changes in short-term option implied volatilities used to construct the OVX.

Table 5 shows regressions of changes the OVX for 1-month periods, as well as for 3- and 12-month overlapping periods. These changes are regressed on changes in the VIX and the innovations to the Shale Strategy over the corresponding periods. Additionally, lagged values of the VIX and the OVX are included as controls. As the table shows, for both the 3-month and 12-month time horizons, innovations to the Shale Shock are strongly correlated with decreases in the OVX, controlling for changes in aggregate stock market value. This reduction in oil price uncertainty associated with rising expectations of shale producer values provides a potential channel for economic benefits from the increases in production even absent a large reduction in price.

4.6 Shale Oil and Industry Returns

We are able to estimate the relative effect of shale oil on individual industries. In Table 6 we report the sensitivities of returns on stocks in different industries to the Shale Shock, as well as to the market returns. We use the 49 industry portfolio constructed as in Fama and French (1997), with daily returns taken from Ken French's website. For each industry we regress industry return on both the aggregate market return and the daily return the shale strategy (S_t) over the sample from June 2010 to June 2014. Inclusion of the market return means

Table 5: Shale Shock and Oil Volatility

	n = 1		n = 3		n = 12	
	$\Delta OVX_{t-n,t}$	$\Delta OVX_{t-n,t}$	$\Delta OVX_{t-n,t}$	$\Delta OVX_{t-n,t}$	$\Delta OVX_{t-n,t}$	$\Delta OVX_{t-n,t}$
$\Delta VIX_{t-n,t}$	0.482***	0.487***	0.586***	0.588***	0.709***	0.700***
	(0.062)	(0.062)	(0.069)	(0.063)	(0.096)	(0.073)
VIX_{t-n}	0.199***	0.198***	0.274**	0.267**	0.827***	0.676***
	(0.076)	(0.075)	(0.121)	(0.110)	(0.188)	(0.148)
OVX_{t-n}	-0.208***	-0.205***	-0.282**	-0.243**	-0.735***	-0.506***
	(0.074)	(0.074)	(0.119)	(0.108)	(0.218)	(0.175)
$S_{t-n,t}$		-0.273		-0.532***		-0.603***
		(0.269)		(0.204)		(0.184)
Constant	0.121	0.117	0.145	0.042	0.043	-0.243
	(0.143)	(0.141)	(0.243)	(0.222)	(0.472)	(0.366)
Observations	48	48	45	45	36	36
R-squared	0.509	0.517	0.646	0.691	0.699	0.775

Newey-West Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

that a negative coefficient on the shock does not imply that an increase in shale production hurts the industry, merely that it helps this industry less than could be explained through its exposure to the market as a whole.

The economic effects we identify at the industry level are consistent with economic intuition. For example, industries for which oil is a key input appear to benefit: transportation (trans), automobiles and trucks (autos), agriculture (agric), chemicals (chems). Industries which benefit from more consumer disposable income also benefit: entertainment (fun), construction materials (bldmt), construction (cnstr), textiles (txtls). Lastly, industries that directly and indirectly support shale development also appear to benefit, for example the fracking process requires a significant amount of sand, so we see non-metallic and industrial metal mining (mines) benefitting. Significant amounts of shale oil is transported by railroads which benefits railroad equipment (ships). Concurrent with shale development there has been a large pipeline infrastructure buildout, so we see fabricated products (fabpr) and machinery (mach - includes oil field machinery) benefit. These results provide further detail and insight into the general effects we identify.

Table 6: Shale Shock and Industry Returns

High Exposure Industries					Low Exposure Industries				
	S_t	R^{mkt}	Constant	R-squared		S_t	R^{mkt}	Constant	R-squared
mines	0.146***	1.512***	-0.001**	0.658	hardw	0.016	0.953***	-0.000	0.520
	(0.038)	(0.035)	(0.000)			(0.032)	(0.029)	(0.000)	
fun	0.143***	1.305***	0.000	0.636	toys	0.014	1.024***	0.000	0.639
	(0.035)	(0.032)	(0.000)			(0.027)	(0.025)	(0.000)	
fabpr	0.131***	1.475***	-0.000	0.669	aero	0.008	1.081***	0.000	0.782
	(0.036)	(0.033)	(0.000)			(0.020)	(0.018)	(0.000)	
txtls	0.099***	1.328***	0.000	0.674	bussv	0.004	1.085***	0.000	0.930
	(0.032)	(0.030)	(0.000)			(0.010)	(0.009)	(0.000)	
ships	0.097***	1.492***	0.000	0.737	gold	0.003	0.741***	-0.001**	0.127
	(0.031)	(0.029)	(0.000)			(0.068)	(0.062)	(0.001)	
bldmt	0.093***	1.387***	-0.000	0.848	hlth	-0.003	0.967***	0.000	0.620
	(0.021)	(0.019)	(0.000)			(0.026)	(0.024)	(0.000)	
mach	0.089***	1.358***	-0.000	0.892	medeq	-0.001	0.967***	-0.000	0.777
	(0.017)	(0.015)	(0.000)			(0.018)	(0.016)	(0.000)	
chems	0.064***	1.236***	0.000	0.868	coal	-0.007	1.716***	-0.002***	0.476
	(0.017)	(0.015)	(0.000)			(0.062)	(0.057)	(0.001)	
agric	0.062*	1.419***	0.033	0.478	paper	-0.007	1.049***	0.000	0.879
	(0.031)	(0.034)	(0.035)			(0.013)	(0.012)	(0.000)	
cnstr	0.062**	1.489***	-0.000	0.760	rtail	-0.007	0.808***	0.000	0.768
	(0.029)	(0.027)	(0.000)			(0.015)	(0.014)	(0.000)	
labeq	0.059***	1.273***	-0.000	0.867	fin	-0.001	1.378***	-0.000*	0.855
	(0.017)	(0.016)	(0.000)			(0.020)	(0.018)	(0.000)	
autos	0.056**	1.388***	-0.000	0.817	books	-0.014	1.156***	0.000	0.670
	(0.023)	(0.021)	(0.000)			(0.028)	(0.026)	(0.000)	
elceq	0.046**	1.284***	-0.000	0.846	food	-0.025	0.645***	0.000*	0.648
	(0.019)	(0.018)	(0.000)			(0.016)	(0.015)	(0.000)	
clths	0.045	1.091***	0.000	0.637	soda	-0.022	0.772***	0.000	0.505
	(0.029)	(0.026)	(0.000)			(0.026)	(0.024)	(0.000)	
trans	0.045**	1.067***	0.000	0.815	insur	-0.026*	1.122***	-0.000	0.870
	(0.018)	(0.016)	(0.000)			(0.015)	(0.014)	(0.000)	
rubbr	0.043**	1.134***	0.000	0.832	hshld	-0.030*	0.647***	0.000	0.605
	(0.018)	(0.016)	(0.000)			(0.018)	(0.017)	(0.000)	
steel	0.042	1.601***	-0.001***	0.822	drugs	-0.035**	0.782***	0.000***	0.713
	(0.026)	(0.024)	(0.000)			(0.017)	(0.016)	(0.000)	
persv	0.041	1.147***	-0.000	0.649	guns	-0.036	0.741***	0.000*	0.479
	(0.029)	(0.027)	(0.000)			(0.027)	(0.025)	(0.000)	
boxes	0.038*	1.041***	-0.000	0.746	telcm	-0.038***	0.872***	0.000**	0.827
	(0.021)	(0.019)	(0.000)			(0.014)	(0.013)	(0.000)	
chips	0.035*	1.102***	-0.000	0.808	beer	-0.048**	0.561***	0.000**	0.501
	(0.019)	(0.017)	(0.000)			(0.019)	(0.018)	(0.000)	
rlest	0.030	1.364***	-0.000	0.789	smoke	-0.048*	0.600***	0.000**	0.418
	(0.025)	(0.023)	(0.000)			(0.024)	(0.022)	(0.000)	
softw	0.029*	1.015***	0.000	0.818	banks	-0.054**	1.340***	-0.000	0.817
	(0.017)	(0.015)	(0.000)			(0.022)	(0.020)	(0.000)	
meals	0.023	0.809***	0.000	0.682	other	-0.050***	1.015***	-0.000	0.831
	(0.019)	(0.018)	(0.000)			(0.016)	(0.014)	(0.000)	
whlsl	0.018	1.014***	0.000	0.905	util	-0.062***	0.655***	0.000*	0.637
	(0.011)	(0.010)	(0.000)			(0.017)	(0.016)	(0.000)	

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

4.7 Case Study: November 2014 OPEC Announcement

The primary period for our analysis ends in June of 2014. Three months after the end of the sample, on November 28, 2014, the OPEC released the results of its Conference meeting and announced that the Organization's members 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.

This announcement provides an interesting case study, as it allows us to cleanly identify an exogenous supply shock to oil prices, unrelated to technological innovation in the shale sector. From the perspective of the U.S. market such a shock would have two opposing effects: a positive effect from a reduction in oil prices and a potentially negative effect from the reduced share of U.S. oil production in total oil supply, as some of the high-cost shale production is rendered unprofitable. As noted in Section 4.6, the way in which the Shale Index as constructed potentially conflates the two effects. Though we orthogonalize the Shale Index return with respect to oil prices in the construction of our Shale Shock variable, if growing shale production reduces long-run oil price uncertainty, this will still be a boon to companies with exposure to oil prices, either through the cost of inputs or consumer demand. In addition, growing shale production in the U.S. is also positive news for companies involved in shale production, and therefore these firms' stock prices should respond negatively to news that signal poor future prospects for U.S. shale oil firms.

Given the two potential sources of correlation with shale oil returns, we would expect industries with high exposure to shale from an indirect oil price channel (i.e., through the demand side) to have relatively high returns on the OPEC announcement day, while companies with high shale exposure due to their involvement in shale production (i.e. through the supply side) to have relatively low returns on this day.

In order to test this hypothesis we estimate two regression specifications. The first one is

$$R_{i,11/28/2014} = \gamma_o + \gamma_1 \beta_i^{shale} + e_i,$$

where $R_{i,11/28/2014}$ is the industry return on the announcement day and β_i^{shale} is the regression coefficient from a time series regression of daily industry returns on the constructed Shale Shock and the market return over the period June 2012 to June 2014 as described in Section 4.6. The first column of Table 7 shows the regression results and the first panel of Figure 2 shows the actual industry returns on this day vis-a-vis those predicted by this regression. The shale beta is a strong significant predictor, with high shale exposure industries experiencing negative returns on the OPEC announcement. The estimated betas from the previous sample explain roughly 23% of the cross-sectional variation on the announcement day. However, as the first graph in Figure 2 shows, there are some outlying industries. In particular, the entertainment industry, the textile and clothing industries, and the auto industry, all experience positive returns despite having relatively high shale exposure, and coal and gold companies have a very low return despite having low shale exposure. The outliers appear to be due to the indirect effect of low oil prices for these industries.

In order to control for price exposure, we then estimate the extended specification

$$R_{i,11/28/2014} = \gamma_o + \gamma_1 \beta_i^{shale} + \gamma_2 \beta_i^{price} + e_i,$$

where β_i^{shale} and β_i^{price} are estimated jointly from a time series regression of daily industry returns on the constructed shale shock, changes in oil prices, and the market return from June 2012 to June 2014. The second column of Table 7 show the regression results and the second panel of Figure 2 show the actual returns vs. the predicted values from this regression. As the regression results show the previous period's estimated price exposure adds a great deal of explanatory power to this regression, increasing the estimated R^2 to 67%, while greatly reducing the observed outliers from the first regression. However, even controlling for price exposure, the shale exposure is strongly significant (t-stat = 3.55), suggesting that the negative impact on the shale industry was a significant driver of the market impact of this announcement.

Table 7: Industry Shale Exposure and 11/28/2014 OPEC Announcement Returns

Table reports regressions of the form

$$R_{i,11/28/2014} = \gamma_o + \gamma_1 \beta_i^{shale} + \gamma_2 \beta_i^{price} + e_i$$

Where $R_{i,11/28/2014}$ is the industry return on the 11/28/2014 opec announcement day, and β_i^{shale} and β_i^{price} are estimated jointly from a time series regression of daily industry returns on the constructed shale shock, changes in oil prices, and the market return from June 2012 to June 2014. OLS standard errors in parentheses.

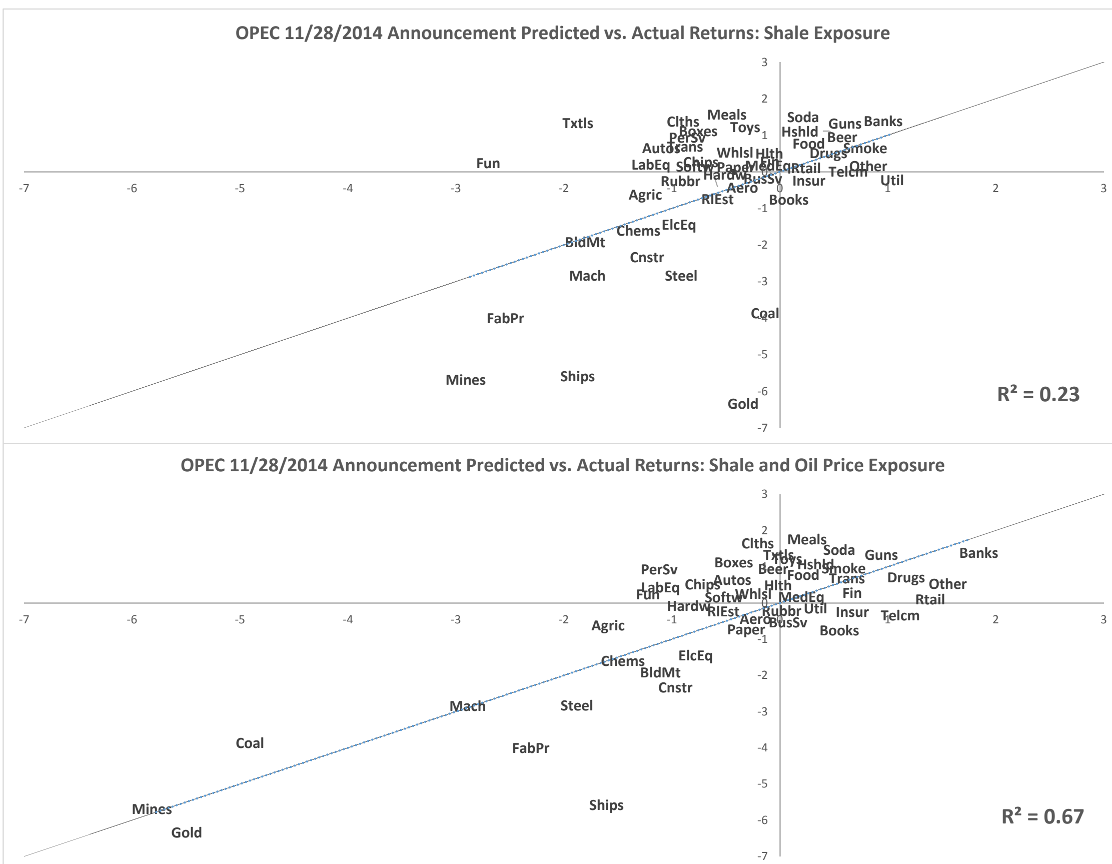
	$R_{i,11/28/2014}$	$R_{i,11/28/2014}$
β_i^{shale}	-0.185**	-0.118**
	(0.049)	(0.033)
β_i^{price}		-0.227**
		(0.029)
Constant	-0.065	-0.438**
	(0.271)	(0.184)
Observations	48	48
R^2	0.237	0.679

Figure 2: Predicted and Actual Industry Returns on 11/28/2014 OPEC Announcement

Figure graphs predicted values from regressions of industry returns on 11/28/2014 OPEC announcement against the predicted value from the following regression

$$R_{i,11/28/2014} = \gamma_o + \gamma_1 \beta_i^{shale} + \gamma_2 \beta_i^{price} + e_i$$

Where $R_{i,11/28/2014}$ is the industry return on the announcement day, and β_i^{shale} and β_i^{price} are estimated jointly from a time series regression of daily industry returns on the constructed shale shock, changes in oil prices, and the market return from June 2012 to June 2014. The first plot shows predicted values from a regression using only β_i^{shale}, while the second shows predicted values using both β_i^{shale} and β_i^{price}. The 45 degree line is plotted for reference.



5 Conclusion

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

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