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: $R_{t+1}^i = \Pi_{t+1}^i$.

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

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

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

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

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

or, in logs,

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

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

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

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

We approximate the log of total supply as

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

Innovations in supply are then

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

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

Then final good sector return innovations can be approximated as

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

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

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

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

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

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

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

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

Therefore innovations in market return can be defined as

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

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

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

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

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

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

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

Appendix 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

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

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

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

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

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

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

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

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

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

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

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

Consider next the Shale Announcement characteristic portfolio; the loadings solve

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

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

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 Shale Indices

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

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

Table 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

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 4 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.

Appendix 5 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))

Table A-2: Industry Announcement Returns, Betas, and Portfolio Weights

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

- 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 6 Explaining Market Return with Characteristic Portfolios using Rolling Betas

Here as a robustness exercise we perform a similar analysis to that in Table 4, 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 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.

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

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:

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

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

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 4 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	

(A-3) and (A-4) were exactly the same we would have $R^D_{t+1} = \gamma_t^{ShaleDisc} R^{ShaleDisc}_{t+1}$. Therefore, the average return on this portfolio is the analog to the last row of Table 4. 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).