Employment Booms and Busts Stemming from Nonrenewable Resource Extraction

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ABSTRACT

A non-renewable resource extraction model is embedded within a lake model of industry-specific employment, where flows to (from) employment from (to) unemployment depend on the attachment (separation) rate. The attachment and separation rates vary with resource extraction, and the results, driven by the rate of extraction and the remaining resource stock, indicate that changes in the stationary employment level can be positive, negative, or zero. There is a range where the separation rate is decreasing (increasing) and the attachment rate is increasing (decreasing), and the change in employment is determined by the combined effect of these changes. Using data on coal production and employment in the US as a guide, simple calculations provide a range of years beyond 2013 when it is expected that peak employment will be reached in the Marcellus Shale, and the results suggest that employment gains will likely continue for at least a decade.

Keywords: Marcellus Shale, Shale Gas, Nonrenewable Resource, Employment, Lake Model

JEL Classifications: Q32, Q33, Q47

1. INTRODUCTION

The economics of non-renewable resource extraction can be traced back to Gray’s (1914) model of a price-taking firm faced with an increasing marginal cost of extraction. Most research on non-renewable resource extraction, however, begins with Hotelling’s (1931) classic model of a firm deciding how to use its resource stock to maximize profits, where profits depend on a rising resource price and a constant unit-cost of extraction. Various versions of Hotelling’s model have since been developed and analyzed under different theoretical and empirical assumptions.¹ In most versions, the price and extraction paths of the resource are easily derived and demonstrate two basic outcomes. First, as the price of the resource grows, firms will have an incentive to save some of the resource for future periods. This is known as profit-based conservation. Second, in equilibrium, the discounted resource rent will be equal across time which leads to the derivation of Hotelling’s rule: The net price of the natural resource will grow at the market rate of interest.

¹ According to Google Scholar, Hotelling (1931) has since been cited over 4000 times, whereas Gray (1914) has been cited slightly more than 300 times.

The basic Hotelling model also predicts that the resource will eventually be depleted, but model extensions have shown that the nature of depletion and Hotelling’s rule can depend on, for example, the market structure (Stiglitz, 1976; Dasgupta and Heal, 1979); tax instruments imposed on the extracting firm (Burness, 1976; Heaps, 1985); aspects of demand and reserve uncertainty (Pindyck, 1980); quality variations in the resource deposit (Hartwick and Olewiler, 1998); the price and availability of substitutes (Herfindahl, 1967); the existence of backstop technologies (Nordhaus et al., 1973; Hartwick and Olewiler, 1998); discovery and exploration costs (Pindyck, 1978; Hartwick, 1991; Cairns, 1990); and changes in extraction costs (Herfindahl, 1974).² Despite these various extensions, there is an important sometimes overlooked theoretical consideration of non-renewable resource extraction: How does employment in the extractive industry

² For excellent overviews of these and many other extensions of Gray (1914) and Hotelling (1931), see the following texts: The Economics of Natural Resource Use (Hartwick and Olewiler, 1988); Economic Theory of Natural Resources (Herfindahl and Kneese, 1974); Economic Theory and Exhaustible Resources (Dasgupta and Heal, 1979); and Resource Economics (Conrad, 2010).
change as the resource is depleted? This question is particularly
important in light of the (Shale) natural gas boom in the US of the
late 20th century and throughout the 21st century.4

Before focusing closely upon employment issues associated
with the shale gas boom, and the Marcellus Shale region in
particular, it should be noted that the large increase in shale gas
production in the US has impacted many energy markets and
raised numerous environmental considerations. Sovacool (2014)
provides a wide ranging review of many of the environmental
issues while Kim and Lee (2015) focus upon how shale gas
developments are impacting the US Regional Greenhouse Gas
Initiative. The US Environmental Protection Agency recently
completed a comprehensive review of the impacts of hydraulic
fracturing (“fracking”) upon drinking water. Their draft
assessment concludes that fracking has “not lead to widespread,
systemic impacts on drinking water resources,” but identifies
specific instances where fracking has impacted drinking water
(Environmental Protection Agency, 2015).

Investigations of the impact of the shale gas boom on other
energy markets includes its impact on oil prices (Obadi et al.,
2013) and electricity production (Yuan and Zhang, 2014). In
terms of employment impacts, the direct impact of the shale gas
boom upon employment in the oil and natural gas industry has
been substantial. In particular, the Marcellus Shale gas boom has
transformed the state of Pennsylvania’s oil and natural gas industry. From 2007 to 2012, Pennsylvania rose from the 10th to 6th largest
state in terms of oil and gas industry employment, and was second
to Texas in the increase in oil and gas employment over this
period (BLS, 2014).

Going from direct counts of related industry employment to
estimates of the overall employment impact from shale gas drilling,
however, is challenging for reasons including the potential for
“resource curse” related job displacement in non-oil and gas
sectors and the difficulty of accurately estimating employment
linkages across both geographic regions and industries. Using
national data Corden and Neary (1982) use the term “resource
curse” to characterize findings that resource abundant nations grow
more slowly than resource scarce countries, findings extended by
analyzes a set of European nations and finds that while more
oil production has a negative impact upon per capita real gross
domestic product (GDP) growth, greater natural gas production
has a positive impact upon per capital real GDP growth. At the
county level within the US, results are mixed with some studies
finding that counties more dependent upon natural resources
grow more slowly (James and Aadland, 2011) while others find
a positive employment impact from oil and natural gas resources

Early estimates of the employment impact from shale gas
development came from studies utilizing input-output models.

3 A notable but indirectly related exception is the seminal research of Corden
   and Neary (1982).
4 This is also a relevant question for the extraction of any non-renewable
   resource.

Considine et al. (2009) estimate that Marcellus shale gas
extraction created nearly 30,000 jobs in Pennsylvania in 2008,
and follow-up studies raised the employment estimate to over
44,000 jobs in 2009 and 139,000 in 2010 (Considine et al., 2010;
2011). Similar methodologies generated estimated employment
gains for Arkansas from Fayetteville shale gas extraction of
approximately 9500 jobs over 2008-2012 (Center for Business
and Economic Research at the University of Arkansas, 2008;
2012). These estimation methodologies were reviewed by
Kinnaman (2011) who noted they may well be overstating
the employment gains from shale gas development due to a
variety of assumptions embedded in the input-output models.
Econometrically based estimates of the employment effects from
shale gas development have been varied, but largely positive.
Analyzing county-level panel data from Colorado, Texas, and
Wyoming, Weber (2012) finds moderate positive changes in
employment, wage and salary income, and median household
income. Each $1 million spent on natural gas production, for
example, would generate roughly 2.35 local jobs.

Using county-level panel data from Pennsylvania, Perides et al.
(2015) also find modest statistically significant employment
effects from Marcellus Shale gas extraction over the 2004-2011
extraction period. Evaluated at the average number of wells in a
Marcellus Shale Pennsylvania county (10.8 wells), they estimate
an average employment effect of 71-181 total county jobs or 6.5-
16.8 jobs per well. These employment estimates are larger than
those of DeLeire et al. (2014) whose Pennsylvania county-level
analysis finds a mean impact upon county total employment of
4.2 jobs per Marcellus shale well in the county. They estimate
that by 2012, Marcellus Shale drilling accounted for on average
only 2% of job growth (not total jobs) in Pennsylvania counties
with Marcellus shale drilling. Similarly modest employment
effects are found by Mauro et al. (2013) and Kelsey et al. (2011; 2012; Jaenicke et al. (2015) utilize Pennsylvania state tax data
to more precisely estimate the jobs for residents within the
county where Marcellus shale gas drilling occurs. They find a
statistically significant positive impact on county employment
only for counties with 90 or more wells drilled in a single year.
Aggregating their results to the state level, they estimate total
employment gains of 18,000-20,000 for Pennsylvania from
Marcellus shale drilling, but only 7300-9600 of those jobs went
to residents of the county in which the drilling occurred. Lastly,
in contrast to the previous research Munasib and Rickman (2015)
utilize a synthetic control methodology and fail to find any
significant impact upon total employment through 2011 for any
of their tested aggregations of Pennsylvania Marcellus shale gas
counties.

While most of the empirical studies show a positive relationship
between natural gas extraction and job creation, there is
clearly a lack of consensus about how many jobs are created.
Moreover, the Marcellus Shale related empirical research to
date also has been focused upon job creation during this early
phase of resource extraction for this formation. Over time jobs
can also be lost, however, and this is especially the case as the
stock of the natural resource is depleted. Rather than directly
contribute to the empirical literature, we develop a simple
“lake” model of employment that helps to explain the empirical
variations in employment gains and also captures the possibility
of employment declines. The lake model thus captures flows
from employment in the extractive sector to the unemployed
pool, and flows from the unemployed pool to the extractive
sector, where the separation and attachment rates depend on
remaining stock of the non-renewable resource available for
extraction.

The remainder of the paper is organized as follows: Section 2
presents the resource extraction and lake model; Section 3 presents
the stationary employment level and subsequent employment
changes based on resource extraction; Section 4 first reviews
the historical employment and extraction patterns for coal in the
Appalachian Basin using the model’s analytic perspective, and
then constructs potential scenarios for peak employment related
to Marcellus shale gas extraction given the findings for coal; and,
Section 5 concludes.

2. MODEL

The stock of the natural gas, $X_t$, evolves according to the following
law of motion,

$$X_{t+1} = f(X_t, Q_t)$$  (1)

Where, $X_t$ is the initial stock of natural gas, and $Q_t$ is the total
amount of natural gas extracted in period $t$. We assume a fixed
initial stock such that $X_0 = A$, and also that,

$$\frac{\partial f(X_t, Q_t)}{\partial Q_t} < 0,$$  (2)

Which implies extraction of natural gas today reduces the stock
available for extraction tomorrow.

Employment in period $t+1$ in sector $i$ takes the following form,

$$E_{i,t+1} = [1 - \delta_i(X_t)]E_i + \beta_i(X_t)[N_u - E_u]$$  (3)

Where, $\delta_i(X_t)$ is the separation rate from employment in sector $i$;
$\beta_i(X_t)$ is the attachment rate or the rate at which the unemployed
find a job in sector $i$; and $N_u$ is the size of the labor force qualified
for jobs in sector $i$ in period $t$. $N_u$ is further defined as the sum of
the existing labor force in sector $i$, $N$, and also those employees
who were separated from their jobs in sector $i$ in period $t$, $\delta_i(X_t)$
$E_u$. Equation (3) is augmented in the following way,

$$E_u = [1 - \delta_i(X_t)]E_u + \beta_i(X_t)[N_i + \delta_i(X_t)E_u]$$  (4)

Because the stock of natural gas is either fixed or diminishing,
depending on extraction rates, we make the following assumptions
about the separation rate,

$$\frac{\partial \delta_i(X_t)}{\partial X_t} < 0, \text{ for } A > X_i > X_t > 0$$  (5)

Where, $X_t$ is a critical threshold value of the natural gas stock
where the likelihood of losing a job in sector $i$ starts to increase.
We also make the following assumptions about the attachment rate,

$$\frac{\partial \beta_i(X_t)}{\partial X_t} > 0, \text{ for } A > X_i > X_t > 0$$  (6)

Which implies that the likelihood of finding a job in sector $i$
increases as natural gas is extracted, but only up to the threshold
value of the natural gas stock. Once the threshold is reached, the
likelihood of attachment decreases.

3. CHANGES IN STATIONARY
EMPLOYMENT

Given (4), (5), and (6), it is straightforward to determine the
potential effects of natural gas extraction/depletion on equilibrium
employment in sector $i$. Imposing the typical stationary
employment condition that $E_{i,t} = E_i \forall t$, yields the following
stationary employment rate,

$$E_i = \frac{N_i \beta_i(X_t)}{\delta_i(X_t) + \beta_i(X_t) - \delta_i(X_t)\beta_i(X_t)}$$  (7)

To determine the net effect of resource extraction and depletion
on employment in sector $i$, differentiate (7) with respect to $X_t$ to
find the following,

$$\frac{\partial E_i}{\partial X_t} = \frac{N_i[\delta_i(X_t)\beta_i(X_t) - \delta_i(X_t)\beta_i(X_t)^2]}{\delta_i(X_t) + \beta_i(X_t) - \delta_i(X_t)\beta_i(X_t)}$$  (8)

By signing the numerator of expression (8), it is easy to see that the
net effect on employment of resource extraction and depletion can
be positive, negative, or zero depending on the relative changes in
the separation and attachment rates as extraction increases (i.e. as
the resource is depleted). Figure 1 illustrates a relatively simple
way to view this relationship.

As seen in Figure 1, as extraction approaches the threshold
level, employment in sector is increasing, and as extraction is

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5 See Chapter 6 in Ljungqvist and Sargent (2004) for more on basic lake
models of employment/unemployment.
pushed beyond the threshold level, employment in sector begins to decline.

The above analysis assumes that the inflection point and hence the threshold level of non-renewable reserves are the same across the separation and attachment rate functions, but it is possible that the inflection points occur at different threshold levels. The turning point of the stationary employment function will be determined by the net effects of attachment and separation. Suppose, as depicted below in Figure 2, the threshold value for the inflection point of the separation rate function is smaller than it is for the attachment rate. Over the range \((X_T^a, X_T^b)\), employment could be increasing or decreasing. Although there is diminished hiring as a result of \(\beta_i' < 0\), there is less separation as a result of \(\delta_i' < 0\), and one effect could dominate the other. If instead the range were reversed to \((X_T^b, X_T^a)\), then it would be the case that \(\beta_i < 0\) while \(\delta_i < 0\) with hiring gains and increased separation.

4. APPALACHIAN BASIN: HISTORICAL AND PROJECTED DEPLETION PATHS FOR COAL AND SHALE GAS

The large multi-state Appalachian coal basin region has been one of the world’s largest historical sources of coal, and extraction of the resource has been underway for more than 200 years. As such, the pattern of coal employment and remaining recoverable reserves across US. states in the basin can be compared against the stylized predictions of this paper’s model. Figures 3 and 4 contain indexes of coal mining employment by Appalachian basin state from 1969 to 2013. Coal mining employment data for 1969-2000 is from the bureau of economic analysis (BEA) data files (BEA, 2015), and the 2000 onward data is from the (BLS, 2015). Each of the seven states reach peak coal mining employment within the 5 years from 1976 to 1981. The declines in employment from peak have been substantial for each of the states. West Virginia and Alabama have had the smallest relative declines, but their current employment is only about 1-3rd of peak employment. The other states’ current employment levels are only 1-5th or less of their peak employment levels.

Of course many factors beyond simply the remaining stock of recoverable reserves has impacted the employment patterns and the timing of peak employment across these states. These factors include the severity of the early 1980s recession in the US, the collapse of oil prices in 1984-85, and the passage of environmental regulations restricting sulphur emissions from coal-fired power plants. While these market forces compressed the time range for peak employment across the states, the depletion of these reserves had been ongoing for many decades and declining employment would have begun somewhat later even in the absence of these adverse Appalachian coal demand shocks. Relevant to the insights from our model, we next examine the remaining recoverable coal reserves at the time of peak employment by state shown in Table 1.
The peak employment year data in Table 1 is as reported in Figures 3 and 4. The estimates for the original recoverable reserves are from Milicini and Dennen (2009), and the cumulative production through peak employment year estimates are from Milicini (1997). The estimated percentage of original reserves remaining relates to the range of and in Figure 2 or $X_i$ in Figure 1. For Appalachian coal reserves, peak employment by state is associated with between one-quarter and one-half of the originally recoverable reserves having been extracted.

Unlike the coal reserves, extraction of the Marcellus formation shale gas is in its early years. Marcellus shale original recoverable reserves are estimated as 210 trillion cubic feet, which is the sum of: (1) Approximately 7 trillion cubic feet in production through 2013 from Pennsylvania and West Virginia Marcellus shale gas (Energy Information Administration [EIA], 2015a), (2) 62 trillion cubic feet of proved recoverable reserves (EIA, 2015b), and (3) 141 Trillion cubic feet of unproved technologically recoverable reserves (EIA, 2012). While it is impossible to know with any certainty the future extraction path for this resource, it is somewhat informative to consider when peak employment might occur under a variety of assumed threshold percentages of remaining recoverable reserves and average annual rates of extraction. Based on the remaining coal reserves at peak employment, Table 2 presents a few scenarios for prospective peak Marcellus Shale employment dates measured in years from 2013.

With these assumptions, if production is maintained at the 2013 level of 3600 billion cubic feet per year (BCF/year) and peak employment occurs once 80% of original recoverable reserves remain, then the peak employment date will be 11.67 years from 2013 or about 2025. If instead employment does not peak until 40% of original reserves remain while production remains at 3600 BCF/year, then the peak employment date will be 35 years or around 2048. While gas production from the Marcellus shale continues to rise, the explosive growth phase is likely over, suggesting that the assumed annual extraction rates that are 25% (4500 BCF/year) or 50% (5400 BCF/year) higher may be plausible upper bounds on production. If so, then peak employment would be 8-28 years beyond 2013 if $X_i$ lies in the 40-80% range. Table 2 highlights the large uncertainty surrounding the employment path for Marcellus shale gas development, but it seems likely that the peak employment date is at least a decade into the future.

### Table 1: Remaining recoverable Appalachian coal reserves at peak employment

<table>
<thead>
<tr>
<th>State</th>
<th>Peak employment year</th>
<th>Original reserves (billions tons)</th>
<th>Cumulative production through peak employment year</th>
<th>% original reserves remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>1980</td>
<td>4.6</td>
<td>1.33</td>
<td>71</td>
</tr>
<tr>
<td>Kentucky</td>
<td>1979</td>
<td>11.7</td>
<td>3.16</td>
<td>73</td>
</tr>
<tr>
<td>Ohio</td>
<td>1979</td>
<td>15.2</td>
<td>2.93</td>
<td>81</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>1979</td>
<td>22.6</td>
<td>9.83</td>
<td>57</td>
</tr>
<tr>
<td>Tennessee</td>
<td>1978</td>
<td>1.14</td>
<td>0.53</td>
<td>54</td>
</tr>
<tr>
<td>Virginia</td>
<td>1981</td>
<td>3.4</td>
<td>1.52</td>
<td>55</td>
</tr>
<tr>
<td>West Virginia</td>
<td>1976</td>
<td>30.6</td>
<td>8.54</td>
<td>72</td>
</tr>
</tbody>
</table>

### Table 2: Years from 2013 to reach prospective peak Marcellus shale gas employment

<table>
<thead>
<tr>
<th>Average annual production (bcf)</th>
<th>Remaining original reserves at peak employment (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td>2,700</td>
<td>15.56</td>
</tr>
<tr>
<td>3,600</td>
<td>11.67</td>
</tr>
<tr>
<td>4,500</td>
<td>9.33</td>
</tr>
<tr>
<td>5,400</td>
<td>7.78</td>
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<tr>
<td>6,300</td>
<td>6.67</td>
</tr>
<tr>
<td>7,200</td>
<td>5.83</td>
</tr>
</tbody>
</table>

### 5. CONCLUSION

The simple model presented above captures sector-specific employment gains and losses associated with the extraction or depletion of a non-renewable resource. Although the model was motivated with a discussion of and applied to coal production and shale gas extraction in the US, the model is applicable to the extraction of any non-renewable resource. Empirical deviations in shale gas employment gains (losses) stemming from resource extraction are easily explained by considering the rate of extraction and the remaining size of the resource stock as each relates to increased (decreased) labor demand. To a certain extent, a relatively large stock reduces the need to fire employees, for example, and also allows for an expansion in sector-specific employment from the existing unemployed pool. Then as the resource is depleted, however, the need for firms to maintain a relatively large workforce falls while there is a decreased need to hire workers from the unemployed pool. As noted above, these inflection points in attachment and separation can be different, thereby leading to increased uncertainty in both the time path of employment gains (losses) and the employment peak.

Although the primary theoretical results are driven purely by assumptions about the attachment and separation rates as each relates to the remaining stock of the resource, it is straightforward to consider complicated yet realistic extensions similar to the development of the basic Hotelling model. Additional caveats include, but are not limited to, the lack of ancillary employment gains (losses) in other sectors; extraction costs; the lack of labor force differentiation; the role of prices in determining the feasibility of extraction; and uncertainty about the threshold resource stock.

Using data on coal production and employment in the US as a guide, simple calculations based on the results of the theoretical model offer a range of years beyond 2013 when peak employment is expected in the Marcellus Shale. Based on an arguably strong assumption that employment depends wholly on the remaining resource stock, the results suggest that employment gains will perhaps continue for at least a decade.

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