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The tug-of-war between resource depletion and technological change in the global oil industry 1981–2009

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ABSTRACT

We perform an empirical analysis of the extent to which ongoing technological change through research and development activity has offset the effect of ongoing depletion on the cost of finding and developing additional reserves of oil in eight global regions. We introduce a finding cost function which, among other factors, depends on the cumulative number of past R&D expenses and cumulative past production, measuring technological change and depletion, respectively. For all our regions we find significant effects of both depletion and technological change on oil finding costs from 1981 to 2009, while we take into consideration cyclical variations in finding costs that could come from changes in factor prices. For almost all regions, technology more than mitigated depletion until around the mid-nineties. However, we find that depletion generally outweighed technological progress over the last decade.

1. Introduction

Finding petroleum is characterized by both increasing knowledge as well as diminishing resources. Increasing knowledge through R&D (research and development) activity leads to advances in technology that improve the productivity of the finding process (i.e., E&D (exploration and development)). Technological advances such as e.g. three-dimensional (3D) seismology and horizontal drilling are widely acknowledged to have had significant impacts on productivity in the E&D process, reducing finding costs over time. At the same time, ongoing production depletes the resource base. Investments first target the most profitable oil reserves, leaving remaining resources in remote or expensive regions. Extracting oil from fewer and poorer prospects diminishes the returns to E&D and increases finding costs [1].

This paper studies the impact of depletion and the offsetting technological change to finding costs for oil worldwide. Findings costs are the exploration and development costs that accrue until the oil field is ready for extraction. We focus on the E&D activity where the effects of depletion and technological growth first exert an impact on the cost of getting petroleum products to the customers [11]. The issue of scarcity is better understood within the context of exploration and development costs rather than within the often-used extraction costs [26].

Many regions experienced a decline in finding costs from around 1980 until the end of the 1990s. In the early 1980s high oil and gas prices supported relatively expensive E&D projects. The price decline in the following years forced producers to reduce finding costs in order to stay competitive [16]. Technological breakthroughs such as bright-spot analysis of oil reservoirs done in the early 1980s were conducted predominantly on 2D seismic data. Acquisition of 3D surface seismic imaging in the late 1980s significantly improved the success rate of oil drilling [10]. In addition, the development of measurement-while-drilling allowed operators to steer the well in directions other than straight down, which led to increased exploration of horizontal wells.

From around 2000, finding costs started to increase in most regions, particularly after 2004. This increase in finding costs was accompanied by a surge in factor prices. Costs of raw materials grew in line with increased demand from emerging economies [7]. In addition, the cost of, for example, renting rigs rocketed along with increased activity following the surge in oil prices. However, new technologies such as 4D seismic exploration further increased the success rate of finding oil.

We apply R&D activity as a proxy for technological growth. Although the relationship between R&D and major technological breakthroughs often may be complex and nonlinear, it is clear that advances in technology cannot occur without R&D work being

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conducted on a systematic basis. Even accidental discoveries tend to develop in such a context [12].

A technological breakthrough is usually not the finished product. However, it has an impact on future technical content. We will frequently see a corresponding stream of normal, incremental inventions, i.e. R&D activity leading to a chain of improvements of new technology [28]. R&D led to increased knowledge in, for example, computer technology and geophysics that gradually improved the importance of both 3D and 4D seismic imaging over the years.

Rouvinen (2002) [28] rightfully criticizes many studies for ignoring the lag structure in analyzing the effects of R&D. We follow up on this issue and test for various lag lengths with respect to the effect of R&D activity on oil finding costs. Furthermore, many analyses implicitly assume that the potency of R&D is essentially constant over time. As opposed to these studies, we analyze whether the effects of R&D on costs have changed over time.

To sum up, while cyclical variations in oil finding costs that may come from variations in factor prices are controlled for, our research questions are:

- What portion of the cost variations can be attributed to technological progress?
- What has been the magnitude of the countervailing effect of depletion?

Various studies have described the race between resource depletion and technological change in the petroleum industry. However, they differ above all in what proxies they apply to measure these two opposing effects. Fagan (1997) [16] applies data for 27 large US oil producers from 1974 to 1994. Depletion is measured as cumulative wells drilled, and a time trend captures technological change. She finds that an accelerating rate of technological growth reduced average finding costs by 15 percent (onshore) and 18 percent (offshore) per year by 1994. Resource depletion increased costs by an average annual rate of 7 percent onshore and 12 percent offshore. Thus, the effect of technological progress outweighed that of depletion over the period.

Forbes and Zampelli (2000) [17] examine success rates in exploratory drilling in the Gulf of Mexico from 1978 to 1995 using data from 13 large producers. They find that the small increases in the success rate from the early 1980s to 1995 were largely due to a substantial decline in the price of petroleum, discouraging firms from pursuing less promising prospects. Prior to 1985, the net effect of technological progress on depletion was very small. However, after 1985 technological progress resulted in an annual 8.3 percent growth in the success rate of finding petroleum.

In empirical analysis, a linear time trend has been widely used as a proxy for technological progress, since it is usually difficult to construct variables capturing the dynamics of technological change. A linear time trend signifies the same relative change in costs in each period. There are exceptions, though. Cuddington and Moss (2001) [11] introduce a measure of the cumulative number of technological innovations in the petroleum sector. They find that technological progress played a major role in allaying what would otherwise have been a sharp rise in the average cost of finding additional petroleum reserves in the USA over the 1967–1990 period, and that this effect was stronger for gas than for oil. Managi et al. (2004) [22] apply a micro-level data set from the Gulf of Mexico over the 1947–1998 period. They suggest different proxies for technological change in the exploration stage, and find that the rapid pace of technological change outpaced depletion and that productivity increased rapidly, particularly in the most recent five years of their study.

The above mentioned studies have all discussed the opposing effects of technological change and depletion in North America. To our knowledge, our study provides the first empirical evidence of this issue on a global scale. Second, we have not found other studies that cover the past decade. In addition, in line with [16] but contrary to many other studies, we take changing factor prices into consideration. The cost increase in drilling seen worldwide in recent years has likely been one of the major factors behind the increase in gas and oil prices over the last decade [24]. In addition, there has been a huge price increase for many important raw materials, such as steel. According to Cambridge Energy Research Associates 2008 [7] it was above all increasing metal prices and rig rates that led to rocketing costs in the petroleum industry after 2004. Finally, as already mentioned, we apply R&D as a proxy for technological change as opposed to the above mentioned studies. We apply cumulative output as a proxy for depletion. The reason is that oil companies first produce from the most profitable reserves, leaving remaining resources in more expensive regions. Extracting oil from poorer prospects increases costs.

Section 2 derives the model and Section 3 presents the data. Section 4 provides the estimation results and a subsequent discussion. Section 5 concludes.

2. The model

The first step in supplying petroleum to the market is E&D to locate and develop additions to the stock of proved reserves.[1] The amount of new reserves in period t, Q_t, might be thought of as dependent on the traditional input factors; land, labor and capital. Due to lack of data for these variables covering the oil sector in eight regions worldwide, we have instead identified two important input factors; rig activity and steel. Drilling costs can represent more than half of the development cost of an offshore petroleum field [25]. In addition, steel is an important raw material in the oil sector. The share of steel in total exploration and development costs is on average 30 percent of a new oil project [13]. We let the amount of new reserves Q_t be generated using a Cobb–Douglas type of production technology, which relates new reserves to the product of the relevant inputs.

$$Q_t = R_t^{\alpha_1} S_t^{\alpha_2} F\left(\sum_{s=0}^{t-j} RD_s, \sum_{s=0}^{t-1} Q_s\right) \tag{1}$$

where R and S are inputs of rig activity and steel, respectively. F is a function of both cumulative past expenses on R&D activity (RD_{t-j}), where j counts the lag in years, and cumulative past additions to new reserves (Q_{t-1}). We let $F'_{RD} > 0$, as increased technological progress through past R&D activity leads to increased current reserve additions. Romer (1990) [27] describes innovations and new technology as designed and produced by a profit-maximizing research and development sector. Innovations refer to ways to transform an idea into a new, improved process or product, leading to increased profit and/or reduced costs. In economics innovation is therefore modeled as a "production process" in which R&D effort is a crucial input.

In our modeling of technological advances we disregard depreciation with respect to the level of technology, which means that we disregard that the value of the technology in the oil industry may decline and become obsolete over time, for example due to rapid innovation and/or staff turnover. However, Bureau of Economic Analysis (2007) [5] indicates that R&D capital may

[1] BP (2012) [3] defines proved reserves as: "those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions."