Sources of innovation in the upstream oil and gas industry: Demand pull and technology push

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ABSTRACT

An annual count of the number of technical diffusions in the exploration and development industry from 1947 to 1990 shows a pattern that ebbs and flows, notably with peaks centered around 1962, 1974, and 1984. I present an analysis to determine, in the aggregate, if these periods of prolific innovative activity were driven by the typical engines of technological development: at least one of demand-pull or technology push. This analysis suggests: in 1962 innovation responded to demand pull, the 1972 innovation boom is attributable to technology push, and the 1984 cycle was driven by both. Current conditions favor an increased rate of diffusions due to both technology push and demand pull.

INTRODUCTION

"What laws govern the growth of man's mastery over nature?" So begins the late economist Jacob Schmookler's 1966 landmark book *Invention and Economic Growth*, and with it renewed realization that technological progress and economic phenomena are inextricably linked. Schmookler's answer to this important question, and the ensuing debate, provides a framework for understanding the forces that act on technological progress within an industry.

The June 2000 edition of *The Leading Edge* features a special section dedicated to innovation and its importance to the economics of the energy business. This volume contains remarkably insightful analysis regarding the state of affairs in the upstream industry, and prospects for the future. A recurring theme concerns identifying ongoing sources of new innovations. Forecasts such as these may benefit from an understanding of the industry's historical innovation drivers.

I begin with a cursory review of (Schmookler's) demand-pull, and the distinct technology-push, models for driving technological progress. The subsequent analysis applies Schmookler's methodology to the exploration and development (E&D) industry in an attempt to determine, in the aggregate, if observed periods of increased rates of diffusion of innovations are attributable to demand pull or technology push. Schmookler compared time series representing economic activity and technology diffusions within an industry. Thus, I present metrics for these two phenomena. Additionally, to evaluate the importance of technology-push as a driver, I also present a time-series measuring the relative supply of technological capability. Comparison of these three records is the basis for the discussion in the following section.

TECHNOLOGY DIFFUSION: DEMAND PULL VERSUS TECHNOLOGY PUSH

Schmookler introduced the notion that inventive activity responds to investment activity. Previously, technological change, and the body of scientific and engineering knowledge underlying it, was thought to evolve independently of, rather than according to, economic forces. Schmookler's analysis included more than a thousand inventions spanning four industries. At the time, the longest running (over a century) and most exhaustive record came from the railroad industry which revealed a recurring pattern of increases in the purchase of railroad equipment and components, followed by slightly lagged increases in new patents on such goods. The significance of the lag, Schmookler argued, is that it indicates that variations in equipment sales induce variations in inventive effort. That is, inventors perceive that increasing equipment purchases signal increased profitability for inventions in that industry, and allocate resources accordingly.

Although Schmookler differentiates an invention ("a prescription for a producible product or operable process so new as not to have been obvious to one skilled in the art at the time the idea was put forward") from an innovation ("the act of being the first to produce a new good or service or the first to use a new method or input"), his demand-pull theory applies equally to both. In any event, this characterization makes the process of invention and innovation largely indistinguishable for many E&D technologies.

An important response to Schmookler's influential conclusions (that demand-pull exclusively drives innovation) is the contention that the state of scientific and technological capability also plays an important role (see e.g. Rosenberg, 1974). When improvements in such capability make possible something that was previously unattainable, diffusion of an innovation is said to occur by technology push. This perspective allows that advances may also be driven by the supply of science or technology.

Subsequently, it has been recognized that, in many industries, both market factors and new scientific or technological advances are engines of technological change. A comprehensive study (Utterback, 1974) attributed between 60 and 80 percent to the former, and the remainder to the latter. Recognizing the influence of both drivers suggests that polarization of the debate into opposing demand-pull and technology-push camps is "crude" (Walsh, 1984). An oft-cited review (Mowery and Rosenberg, 1979) reveals no unambiguous evidence for either as the dominant driver. Recent research in the energy industry (Popp, 2002) analyzes patenting activity of energy-efficient innovations, and concludes that energy prices (demand pull) and scientific advancements (technology push) both influence innovative activity.

A common approach (see e.g. the Popp and Walsh papers) analyzes time series similar to Schmookler's methodology. When an economic boom does not lead an inventive cycle, demand pull is ruled out and the search begins for an alternative driver. This is the approach that I mimic. Other studies (many of the prominent ones are reviewed by Mowery and Rosenberg, 1979) rely on qualitative data, for instance tapping the memory of key participants credited with contributing to a technological advance. A weakness inherent in this approach, as noted by Mowery and Rosenberg, is a predisposal to lay claim to *a priori* knowledge of demand, as to do so otherwise might suggest the project lacked sound management. Thus, these qualitative studies may be biased in favor of the demand-pull case. No qualitative analysis is undertaken in this study.

TIME SERIES

I present data for a Schmooklerian analysis of the E&D industry and also include a parameter to measure the supply of technology to assess the influence of technology push. In the following I discuss and present the metrics I use for innovative activity, investment activity, and level of technology supply. Note, that all these data are extracted from companies and activity in the U.S.

Technology Diffusions

A common measurement of the varying level of innovation over time (including the metric used in Schmookler's original analysis) is patenting activity. Apart from the fact that a comprehensive database encompassing all patents contributing to E&D technological innovations would be difficult and expensive to create, this measure also is problematic because on the one hand, not all patents are commercially successful, and on the other hand many successful innovations are never protected by patents. Further, many patented technologies that find their way into a new technology often originate outside of the industry. Fortunately, an alternative record, documenting technology diffusions in the E&D industry is available.

Cuddington and Moss (2001) have presented an historical account of the annual number of E&D industry diffusions between 1947 and 1990. This time series was constructed by counting onsets of widespread commercial use of new technologies. They extracted data for the period spanning 1947 to 1965 from a 1968 study by the National Petroleum Council (NPC). This time series is accompanied by a review of the NPC study that notes E&D technologies typically evolve in three stages: experimental testing; gaining acceptance; and general acceptance. A technology is considered diffused when it enters the first year of the third stage. From the NPC study, the timing of 89 diffusions were recorded. Cuddington and Moss also extended the time series extracted from the NPC study to include the period from 1966 to 1990. This entailed compiling a year-by-year chronology of technology diffusions, primarily from surveying technical articles, interviews with industry experts and general reporting in the *Oil and Gas Journal* and *Petroleum Engineer*. This produced a record documenting an additional 116 technology diffusions between 1966 and 1990, so that the period from 1947 to 1990 comprises 205 diffusions. The time series of technology diffusion counts is shown in Figure 1.

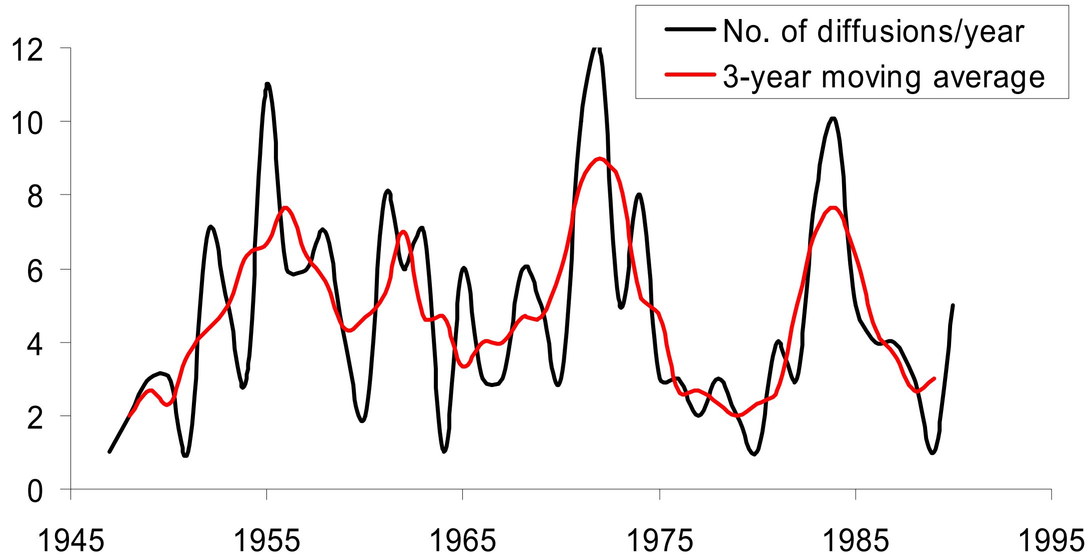

FIG. 1. Technology diffusions per year for the period from 1947 to 1990. Source: Cuddington and Moss (2001).

It is important to stress that it is the jump from the prototypical to the typical that is represented on Figure 1. No doubt some technologies were languishing in laboratories prior to being drawn into the commercial world, whereas others were fast tracked into production. Thus, analysis that reveals whatever it is at work carving out these peaks and valleys implicitly assumes that it is the marketplace that passes judgment as to what constitutes a technological advance in the E&D industry.

It is interesting to note that research and development expenditures by major US-based energy companies, according to the Energy Information Administration, reached its all time high in 1985, only one year after the peak in diffusion counts (Figure 1). Inasmuch as research and development spending is also considered a good measure of innovative activity, the corresponding peaks in R&D spending and diffusion counts lends credence to the notion that the time series of diffusion counts suits my purpose well.

Investment Activity

As noted previously, Schmookler concluded that an upswing in equipment purchases is the stimulus for inventive activity. Ideally, a comparable metric in the E&D industry would be geophysical and geological expenditures by energy producers, as significant portions of such spending is made early in the exploration cycle, and increased activity would likely portend an industry-wide peak in E&D spending. The record of geological and geophysical spending is readily accessible after 1977, but difficult to find before that. Thus, as a proxy I use seismic crew counts as the measure of spending rates prior to 1977. This is justified by the similar pattern exhibited by crew counts and geological and geophysical expenditures (Figure 2). Note, the peak in activity in the early eighties coincided with several industry-wide all-time highs, including employment levels.

Technology Supply

According to the NPC study, computer-aided interpretation of Bouguer gravity measurements in 1961 marks the onset of the computer age in the E&D industry. Since that time, it seems likely that Information Technology (IT) has been the most important impetus for E&D diffusions driven by technology-push. Frequently used indicators of IT supply are: IT spending as a percentage of revenue; IT spending per employee; and IT assets as a percentage of total assets (see e.g. Rubin, 2003). Here, I use the ratio of IT spending growth to non-IT spending growth. Note, this ratio includes all industrial spending in the U.S. Thus, periods with a relatively abundant IT supply in the economy as a whole occur when this ratio is high. These are likely times for technology push to play an important role in driving diffusions. Shown on Figure 2 are periods in which this ratio exceeded two.

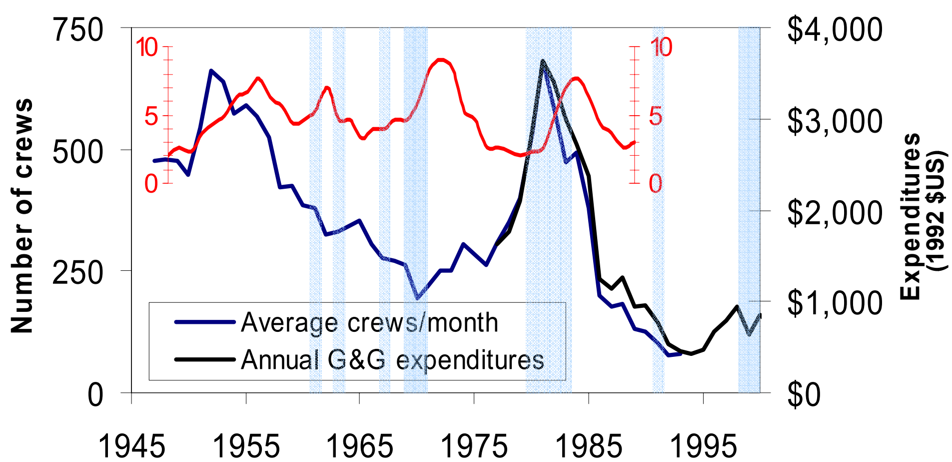

FIG. 2. Smoothed technology diffusions per year (from Figure 1) shown in red and superimposed on activity levels (geology and geophysics expenditures and average crew counts). Additionally, areas shaded blue correspond to periods in which IT spending growth was more than double non-IT capital spending growth. Note, all data are U.S. based. Sources: Average crew counts are from the SEG; IT and non-IT capital spending are from the Bureau of Economic Research; and geological and geophysical expenditures are from the Energy Information Administration (http://www.eia.doe.gov).

DISCUSSION

Figure 2 can be used to detect innovation drivers in a particular era by identifying Schmooklerian lags between investment and innovative activity, or alternatively by identifying upswings in the technology diffusion rate that are instead accompanied by a period of relatively elevated growth in IT spending. In the former case the innovative cycle is attributed to demand pull. In the latter case it is assumed that coincident periods of high growth rates in IT spending (shaded blue) and an increasing diffusion rate indicate an innovative cycle driven by technology-push.

Starting from the beginning, 1956 marks the first peak in diffusion counts. This seems to be a demand-pull diffusion peak, as it lags a peak in average crew counts by four years. Next is a relatively minor peak in 1962 that may have been induced by a nearly coincident minor boom in IT spending. Alternatively, this could be a protracted demand-pull cycle. Following this is the second large cycle of increased diffusion rate, peaking in 1972. This onset of this peak coincides with a multi-year IT spending spree, and thus is interpreted to have been driven by technology push. Finally, in 1984 there is a peak in diffusion rates that seems to be driven by both demand pull and technology push.

To summarize then, the time series in Figure 2 shows a fluctuating rate of technology diffusions that apparently responds first to demand pull, next to technology push, and finally to both.

What Happened in the 1990's?

During the first half of the 1990's finding and development costs fell at an accelerating rate, providing good circumstantial evidence that the pace of technology development quickened (Fagin, 2000). However, from Figure 2 it is apparent that neither of the drivers of previous upswings in the rate of technology diffusions were prevalent during that time.

The reason for this is not clear, but I will discuss two possibilities. First, it is quite likely that as the industry deployed increasingly complex technology, relatively low growth rates in IT spending does not alone imply there was a scarcity of technological capability. That is, increasingly complex technology typically combines a number of innovations, drawn from a variety of sources. Thus, innovations in a technologically mature industry may indeed be driven by technology push; however, circumstances for this technology push will not be evident in a metric that captures only one dimension (abundant IT) of the technology supply. The second possibility is that there was a counter cyclical era of technologic development. That is, Gerhard Mensch proposed a model whereby firms innovate in response to economic downturns. This model has fallen out of favor (for a summary of the criticisms of Mensch's conclusions see Kleinknecht, 1990). In spite of the fact that this mechanism for spurring innovative activity is no longer widely accepted, it may offer an explanation as to what occurred in the E&D industry in the first half of the 1990's.

CONCLUSION

Returning to the June 2000 edition of *The Leading Edge*, in the article entitled *Business Models for Future E&P Technology Generation*, it is noted that "many key advances are being driven from outside the traditional energy industry". This suggests an era featuring renewed importance of technology push as an innovation driver. Furthermore, sustained high energy prices leading to increased expenditures could simultaneously lead to a proliferation of diffusions driven by demand pull. If there is something to be learned from the past, such a confluence of technology-push and demand-pull drivers may well result in a sustained period featuring a high innovation diffusion rate. So, an answer to the question as to where innovations will originate is quite likely they will come from the same place as always: curious and driven innovators.

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