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Industry Evolution: Applications to the U.S. Shale Gas Industry

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Industry Evolution: Applications to the U.S. Shale Gas Industry

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Abstract

Industry Evolution: Applications to the U.S. Shale Gas Industry

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The present study applies evolutionary and resource-based firm theories to three of the most prominent U.S. shale gas basins – the Barnett, Fayetteville, and Haynesville plays. Rather than broadly considering a host of factors that enabled what has often been labelled a shale gas revolution, an evolutionary approach recognizes the internal agents that have long been in place, but were triggered by technical and economic developments. As geologic understanding, along with innovation and competitive environment, evolves in each play so too does the entire shale gas industry. Building upon the Bureau of Economic Geology shale gas study funded by the Sloan Foundation, this study offers data-driven analyses to test theories of industrial evolution as applied to shale gas plays. Each of the three focus plays has undergone introductory and growth phases as well as a maturation phase in which there is an evident shakeout of operators. Industries are theorized to enter decline phases, yet none of the plays here have definitively declined. Certain economic signals, however, indicate that a decline is imminent, albeit variable in timing and pace. Conceptualizing the entire shale gas

industry as an amalgamation of individual and evolving plays correctly describes how the industry is able to rejuvenate its growth trajectory through investment in emerging plays. Although heterogeneous geology, engineering capabilities, and economic environment, particularly natural gas prices, complicate the economics of shale gas extraction, an evolutionary approach proves to be a useful tool in describing the historical development of individual plays as well as the entire shale industry. Importantly, this application sheds light on the future development of valuable shale resources.

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INTRODUCTION

According to U.S. Energy Information Administration (EIA) data, the contribution of shale gas resources to total U.S. natural gas production has grown from below 2% in 2000 to 34% in 2012. With abundant shale resources in place, the EIA anticipates the U.S. will produce over 12 tcf of shale gas annually, accounting for 45% of total natural gas production by 2025. Such rapid production growth has been possible primarily due to the advancement of drilling technology, ideas, and persistence. Specifically, horizontal drilling and hydraulic fracturing techniques now allow operators to extract natural gas from shale reservoirs which had previously been considered incapable of producing commercial quantities of gas. In that light, EIA data show U.S. shale gas reserves increasing 465% from 2007-2011.

Estimating reserves, production capacity, and ultimately production volumes from U.S. shale basins, however, is a vastly complex task. A Bureau of Economic Geology (BEG) study at the University of Texas at Austin addresses production potential in four major U.S. plays – the Barnett, Fayetteville, Haynesville, and Marcellus shales. Funded by the Alfred P. Sloan Foundation, the project integrates geologic, engineering, and economic inputs into a model capable of predicting field-wide production volumes under various scenarios. Using actual well-production histories and geologic data each field's analysis estimates production volumes from undrilled portions of the reservoir taking into account the economic factors that dictate the viability of drilling new wells. For instance, with inflation-adjusted gas prices at $4.00/MmBtu, and reasonable assumptions for many other input variables, Barnett production is expected to decline from 2 tcf per year in 2012 to 900 bcf by 2030 (Browning et. al., 2013). As a significant contributor to U.S. natural gas over that time, Barnett production will be supported through the drilling of roughly 10,000 additional wells.

The BEG assessment provides a bottom-up approach to resource and reserve analysis allowing for a long-term forecast of shale gas production. Yet, many questions remain concerning the future of the shale gas industry and its development. Industry optimists and natural gas bulls say marginal price levels will support the expansion of the shale gas industry. On the other hand, pessimists and natural gas bears cite expensive drilling costs, rapid individual-well production decline rates, and public environmental objections as significant impediments to continued expansion in the shale gas sector.

The advancement of shale gas has enormous implications for oil and gas operators, utility producers, energy consumers, policy makers, U.S. energy security, and global LNG markets. Unsurprisingly, many papers have attempted to outline the historic development of the industry with the goal to understand the key drivers of its development, and therewith analyze the potential obstacles impeding its current growth. For instance, Wang et. al. (2013) synopsize recent advancements in the shale gas industry, describe the potential for climate change mitigation, and argue that environmental best practices are far from ubiquitous, which may hamper shale gas development in the face of costly regulation. Various approaches suggest different views on how to predict the future of the shale gas industry including top-down and bottom-up numerical estimates as well as qualitative approximations. Wang and Krupnick (2013) theorize upon the factors that gave way to the U.S. shale gas boom, yet their work lacks the general framework and data-driven evidence to establish the relative importance of the contributing factors. Beyond establishing these influences, the analysis ends with the conclusion that future shale gas development can only occur if policy and market environments incentivize profitable shale investments.

Given the uncertainties and multi-dimensionality that riddles forward-looking assessments, it is essential to understand the conditionality and directionality of future developments, which extend beyond the raw data and singular industry examples. Accordingly, this analysis will take an alternative approach and consider the shale gas industry's development in the framework of an evolutionary theory. More specifically, applying the advancement of shale gas up to its current state to well-established theories of industrial organization and evolution offers an underutilized mechanism for determining the future of the nascent shale gas sector. Building upon the BEG assessment of shale gas, this research aims to test whether theories describing such industries as the technology, manufacturing, and conventional oil and gas sectors can be applied and used to explain the observed development of the U.S. shale gas industry, and therewith inform its future.

Evolutionary economics concentrates on the internal agents of change within an industry and their future implications for firms and industries. The focus herein is therefore on how innovation and industry structure have evolved over time to bring the shale gas industry to its current state and what sort of implications that evolution has for its future. Utilizing empirical as well as qualitative evidence, the present study identifies the developmental path of shale gas plays, the unique aspects of the shale gas business, and by what avenues the industry may facilitate growth. Accordingly, industry participants and policy makers seeking to exploit domestic and global shale resources can better align their goals with the industry's growth trajectory.

CHAPTER ONE: THEORIES OF INDUSTRIAL EVOLUTION

1.1 Industry Theory Defined

1.1.1 THE ADVANTAGE OF AN EVOLUTIONARY FRAMEWORK

Evolutionary economics sheds light on industrial and economic change by permitting a more flexible framework in terms of how and why an economic system is structured. Rather than a technological breakthrough causing a one-time shock or boost to an industry, for example, that breakthrough can be more gradual. Of course, technology is only one of many potential catalysts to an industry, as will be explained in the following section. On the other hand, "orthodox" economics postulates that exogenous "shocks" rather than gradual, internal, and systematic developments serve as the primary agents of change within an industry. The present work demonstrates how an evolutionary approach can be a powerful tool to describe the development and future of the multi-faceted shale gas industry.

Beyond allowing for gradual and internal change within an industry, an evolutionary approach recognizes that the economic impacts of certain variables on an industry change over time. More specifically, a change in one variable may have a significant impact on an industry in its early phases, but as the industry matures a change in the same variable may prove less significant. Thus, depending on the phase or condition of the industry, changes to underlying drivers may result in different states of the industry. In simple terms, the forces governing an industry's development evolve overtime. Examining an economic system through such a flexible lens undoubtedly has its challenges. Namely, empirical analysis of an ever changing system is enormously complicated and the focus of modern applied evolutionary economics research. Because an evolutionary approach acknowledges the fundamental complexity and internal relationships of a system, computationally defining the influences at work within an industry is a challenge. Yet, there exist a wide range of factors driving the U.S. shale gas boom. As such, it is imperative to recognize theoretical connections between these factors and how they evolve over time in order to describe the historical path, current state, and future of the shale gas industry.

1.1.2 Principles of Evolutionary Economics and the Industrial Life Cycle

Evolutionary economics traces its roots to the work and theory of Joseph Schumpeter. In a review of Schumpeterian economics, Esben Andersen explains Schumpeter's research as it relates to this school of economic thought. Namely, Schumpeter envisaged that economic systems in equilibrium are changed by innovation after which the system reaches a new equilibrium or "routine".

The focus of evolutionary economics is on how variables change and result in a new economic state. This mode of thought – contrary to the classical view of establishing an equilibrium given a set of conditions – is therefore focused on changing variables and outcomes. Accordingly, historical analysis of various industries is a powerful tool for evolutionary economists. Such historical analyses have been undertaken to describe the evolution of a range of industries. The present work will build upon those principles to establish an evolutionary framework for the U.S. shale gas industry. That being said, a singular evolutionary outlook is far from defined as economists utilize various methods to theorize upon and apply evolutionary economics.

Many variables can be used to describe the evolutionary path of an industry. For instance, growth variables, output volume, firm entries and exits, firm size, competitive landscapes, and firm strategy are common components of an evolutionary supposition. Recognizing the multi-faceted nature of an evolutionary industrial philosophy, Merascarenhans (1995) explores three questions through 35 international industry surveys: how and where are industry's firm sizes and strategy changing, what factors drive those changes, and how can managers align their firm's strategy within an evolving industry? Merascarenhans unveils that 60 percent of the industries in question have undergone a shift toward fewer, larger firms with smaller firms operating on the fringes of the industry to fill niche roles. The author then cites examples of this consolidation in the investment banking, hotel, tire, and advertising industries. Moreover, increased competition compels this effect as firms compete for sales by either expanding geographically or into other markets (these become the large consolidated firms), or by filling a niche role with secure sales volumes (these become the small specialized firms). For practical purposes managers must be able to navigate such a transition, or else be swallowed up by the competition.

Another popular outlook for industry evolution follows that of the S-shaped product life cycle [Figure 1-1]. Well-known to the technology industry, the product life cycle stipulates that a product undergoes stages in its economic life. Typically, there are introductory, growth, maturity, and decline stages. For instance, a new consumer electronics product may generate enormous sales growth, but eventually the market will become saturated with the product. Increasing competition may then lead to a decline stage. This concept is described in Theodore Levitt's 1965 article in the *Harvard Business Review*, "Exploit the Product Life Cycle." Unsurprisingly, this pattern and its stages are often mimicked in the field of industrial evolution.

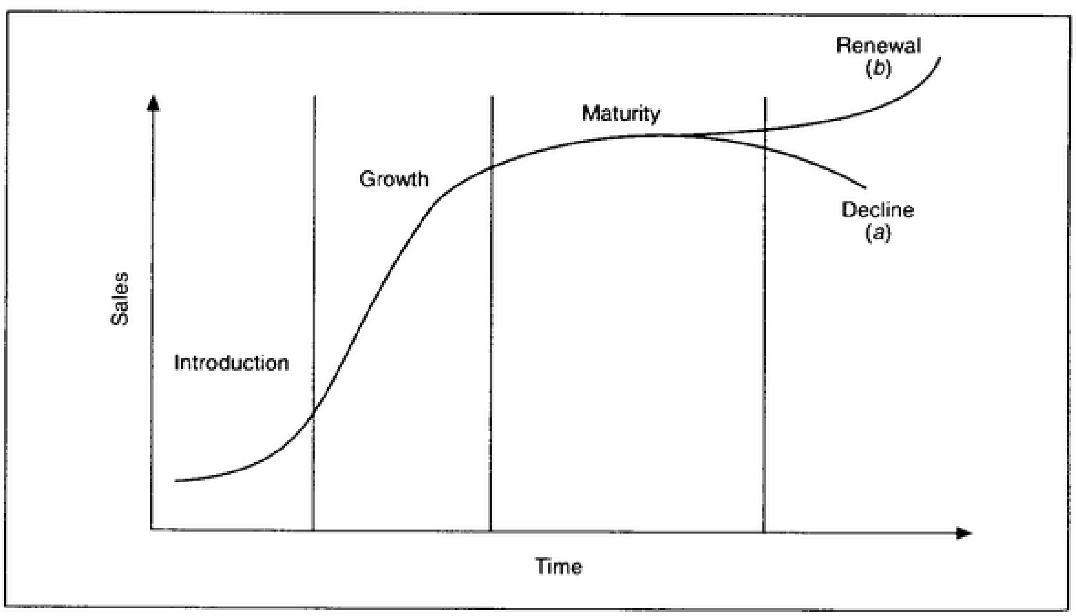

Figure 1-1 The Product Life-cycle curve Showing (a) Decline, and (b) Renewal (Karbhari, Burns, and Wilkins, 1994)

Klepper (1997) sets forth the product life cycle as a prominent model for examining the evolution of new industries. In his paper, Klepper empirically demonstrates the applicability of the product life cycle to the evolution of the US automobile industry. Moreover, Klepper goes on to demonstrate the product life cycle as a suitable model for other industries, especially in "technologically progressive industries with rich opportunities for product and process innovation" (Klepper p. 145). Although the standard, S-shaped product life cycle cannot describe every industry and product, it has been analogous to the experience of the shale gas industry thus far.

To that end, Levitt's seminal article on the product life-cycle explains that the nature and magnitude of an industry's competition change as the product progresses through "stages" in its life. Similarly, Porter (1980) explains that determining an industry's stage is dependent on a long list of factors whose relative importance is never known. Thus, grasping the nature of these variables and recognizing them as evolutionary forces may shed light on what stage the industry or product is in at a given moment. Although no single group of stages can explain every industry, introductory, growth, maturity, and decline stages are commonly cited. This generic set of stages is akin to those observed in the shale gas industry. Each stage is discussed in greater depth below, and chapter two presents a more detailed discussion of how these phases are manifested in shale gas plays.

1.1.2.1 Introductory Stage

The introductory phase of an industry refers to its most nascent and exploratory stages. Industries in this stage can be thought of as "embryonic" and typically form from a technological breakthrough or innovation (Drew, 1987). The nature of that Schumpeterian innovation is the focus of much research. Naturally, the motive to innovate is driven by the potential for high profits. The associated time horizon can vary over a range of factors, however (Kamien and Schwartz, 1972). In their model, Kamien and Schwartz show that fear of rival competitors innovating and the possibilities for high profits as well as substantial losses each have positive impacts on the speed of innovation. Yet, variables concerning an industry's competitive landscape tell only part of the story. Schoonhoven et. al. (1990) utilize a historical analysis of young firms to establish a positive relationship between development time spans and the magnitude of technological innovation.

Mueller and Tilton (1969) offer one of the first accounts of the emergence of new industries and innovation (Klepper, 1997). Within their focus on the Schumpeterian process and technological growth in young industries, the authors discuss the relative sizes of innovating firms. At the time of their writing, conventional Schumpeterian and neo-Schumpeterian theory posited that larger firms were responsible for a relatively greater amount of innovation than smaller firms. Larger corporations possess greater capital access and the ability to achieve economies of scale through a diversified research and development portfolio. Logically, larger companies should therefore have greater capacity to successfully undertake costly innovative activity. Yet, Mueller and Tilton cite two important empirical evidences on the contrary. First, Hamburg (1963) reviews numerous case studies in which smaller entities are responsible for a greater majority of major innovations. Likewise, individuals rather than large oil corporations were responsible for major innovations to the cracking process in the petroleum refining industry (Enos, 1962). More recently, Dinlersoz and Macdonald (2007) statistically analyzes the distribution of firm size for 322 manufacturing industries from 1963-1997. Although the distributions vary, when both firm output and firm employment are used as size measures, smaller firms tend to dominate the industries in their early innovative years.

Beyond attempting to explain the forces underlying innovative motivation, characterizing uncertainty levels is paramount. Mueller and Tilton, for instance, postulate that decisions to initiate R&D programs in larger corporations are undertaken high up the corporate hierarchy where managers are likely to overestimate the riskiness of a project, and therefore fail to pursue it. Whatever the source, uncertainty is implicit in the innovative process (Nelson and Winter, 1977). Thus, Nelson and Winter explain that R&D capital is allocated differently by different individuals and organizations. As with any gamble or risky game, some R&D capital generates great return while a great portion results in loss. In terms of natural resource extraction, firms face substantial uncertainty pertaining to the producible quantity of the resource and the expected value of associated revenues. Hence, the firms operating at the forefront of a new natural resource industry face markedly high price, product, and process risk. It follows that these firms in all likelihood have risk-neutral utility functions (Luchsinger and Mueller, 2003).

Mueller and Tilton define uncertainty in this introductory phase to be primarily grounded in technical capacity as well as the ability to market the product. Accordingly, experimental methods are used to bring products to market (Williamson, 1975). Further, the existence of market uncertainty is grounded in the nature of the products being new. In that light, Gort and Klepper (1982) specify that the onset of a new industry is characterized by *product* rather than *process* innovation which becomes prominent in later industry stages. Innovation also occurs swiftly in new industries requiring early production processes to be adaptable (Clark, 1985).

Surveying the literature, there remains questions and different explanations for the processes governing innovation and the emergence of new industries. Yet, it is generally well accepted that a small number of firms comprise burgeoning industries profuse with innovation and uncertainty. Another school of research advances the notion that smaller firms and individuals with capital access are better equipped to navigate that uncertainty and therefore, are responsible for the lion's share of major industrial innovations. As will be shown in the following chapter, we have observed many of the same qualities in the formative stages of development in shale gas plays.

1.1.2.2 Growth Stage

Following their introductory phases, industries adhering to the S-shaped evolutionary trend enter into a rapid growth stage (see Figure 1). As its name suggests, this phase of the industry life cycle is characterized primarily by industrial expansion in terms of number of competing firms, productive output, technological capacity, and sales.

Whatever the growth variable of focus, firm entries and process innovation are commonly cited as defining forces underlying this stage in the industry life cycle.

Following the major innovations in an industry's introductory phase, the risk environment facing active and potential firms becomes less harsh due to now confirmed technical and market capacities. In other words, once the major innovators and incumbents of a new industry demonstrate technical wherewithal and market potential to prospective firms, the relative uncertainty of entering the industry declines (Mueller and Tilton, 1969). In response to waning risk, a wave of new firms –often referred to as "imitators"- commonly enters the industry.

Upsurges in new firm entries following the exploratory stage have been established empirically in a number of industries. Analyzing manufacturing data for 25 new products, Agarwal and Gort (1996) found that the average annual number of firm entries began a sharp increase and eventual peak in the second phase of a product's commercial life cycle. Gort and Klepper (1982) also define a second stage in which firm entries rise. Using data for 46 new product industries, the authors demonstrate that for all but 3 industries, an introductory phase of at least one year preceded a phase in which average annual net entry rose more than 1,000 percent. Likewise, Klepper (1997) identifies a similar trend in the early years following the emergence of the automobile. In just 12 years following the industry's inception in 1895, the number of manufacturers entering the industry had risen and peaked at 84 firms annually. Importantly, however, in each of the preceding analyses, the number and rate of entries decelerates by the end of this growth stage.

As previously stated, decreased risk perception and industry uncertainty can provide the necessary impetus to entice a wave of entries as imitator firms recognize greater certainty in future profits. Specifically, an industry may experience its growth phase once non-active firms acknowledge the economic rents being captured by incumbent firms. Luchsinger and Mueller (2003) define natural resource extraction rents as the price of production less the production costs; and, with prices given exogenously more efficient firms capture greater rents. Further, the authors posit that "resource" rents

– those that arise due to unsatisfied demand and/or differential production sites – cannot be competed away. Outside firms, therefore, may enter a natural resource industry once incumbent firm rents and the potential for future rents make the value of entry sufficiently high and certain. Simply put, the existence of resource rents and innovation adoption make the risk *and* reward of entry attractive to new firms during the growth stage.

Ample uncertainty exists in the growth stage, however. Williamson (1975) notes that industry uncertainty is still considerable during this stage, albeit lower than in its earliest years. To reflect part of that uncertainty, Jovanovic (1982) develops a model in which potential entrants are unaware of their individual production costs. Although entering firms do know equilibrium prices, their entry decisions and initial investments are still inherently risky. Moreover, the entering firms are essentially price-takers until the industry becomes substantially large for them to become price setters. Lastly, a key takeaway from this model is that a firm discovers its efficiency not upon entry, but instead over time as it produces within the industry.

In addition to declining uncertainty and a rise in firm entries which Horvath et. al. (2001) attributes to the accumulation of information about the success of incumbent firms, a transition from product to process innovation typifies an industry in its growth stage (Klepper, 1997). K.B. Clark (1985) notes that after the fundamental innovations of an industry's earliest stages, a dominant product design emerges and production volumes rise markedly during the growth stage. Along with increased competition (Klepper, 1997), these forces result in problem solving and process improvements to reduce costs. Through process innovations, Clark recognizes that the technological capabilities in bringing product to market become better understood.

The combination of heightened entry into a growing industry and process innovation unsurprisingly results in rapidly growing output volumes to satisfy market demand (Williamson, 1975). But perhaps most importantly for firms operating in the growth stage of an industry, the competitive landscape is markedly different than in the earlier introductory stage. Namely, heightened competition requires imitating firms to successfully replicate the strategies of the most lucrative firms (Grant, 1991). Moreover, the imitation problem is one of transparency in terms of both resource accumulation and the emulation of productive processes.

As follows from the preceding paragraph, firms must necessarily replicate successful strategies in order to sustain a competitive advantage. As the growth stage progresses, competitive advantages become harder and harder to come by. As such, the latter part of the growth stage may include the beginnings of what is frequently referred to as a "shakeout" process which will be discussed in detail as part of the maturation phase of an industry's evolution. Nevertheless, declining but still relevant uncertainty, increasing entries and competition, and process innovation are all fundamental facets of a rapidly growing industry. These features along with their relevance and presence in the shale gas industry will be discussed in the following chapter.

1.1.2.3 Maturity Stage

The previous section briefly alluded to what is known as an industry "shakeout." As its name suggests, an industry experiences a shakeout when a substantial portion of its participants indeed exit or cease operations. In an analysis of 25 manufactured product industries, Agarwal and Gort (1996) observes a steep rise in exit rates in what they label the fourth stage of an industry. Importantly, the author's fourth stage is congruent with what we refer to as the "maturity" phase. Graphically, the maturity stage and its associated shakeout are depicted by the shallowing slope in the typical product life cycle S-curve (see Figure 1-1).

Mass exits from an industry, however, are almost always preceded by a decline in the rate of entry caused by the emergence of a dominant design. Once a dominant design is developed, competition occurs on an efficiency of process basis (see previous section), and the industry's shakeout begins (Utterback and Suarez, 1991). In each of the eight industries Utterback and Suarez considered, the development of a dominant design immediately precedes a decline in the total number of firms in the industry. Although a fall in the number of active firms in an industry is in part due to exiting firms, it is also important to note that the rate of industry entry declines in the shakeout process.

Before firms are seen exiting an industry, it is common that the rate of entry slows down due to increased competition (Agarwal and Gort, 1996; Horvath et. al., 2001). Hence, the shakeout process often begins with a deceleration of entry due to increased competition and the deterioration prospective rents for entering firms. More specifically, Luchsinger and Mueller (2003) defines quasi-rents to be those that are achieved via exceptional investment and strategic decisions at the managerial level. Because those strategies can be imitated, those rents tend to be competed away which weakens industry-wide entry incentives.

Exacerbating the effects of a deceleration in entry, increased competition and declining profit margins may entice less efficient firms to exit (Mueller and Tilton, 1969). In their decomposition of industry stages Gort and Klepper (1982) found that 36 out of 46 industries experienced a period of negative net entry when more firms exited the industry than entered. The average number of firm reductions were 40, but up to 70 percent of peak numbers. Moreover, this net exiting or shakeout phase occurs in roughly half the amount of time as the second stage or what the present work considers the growth stage.

Empirical explanations for shakeouts and negative net entry in maturing industries can be found in the literature. Klepper and Miller (1995), for instance, posit that industries experience a shakeout if the number of operating firms falls below 70 percent of the peak number, and does not return above 90 percent. They then explore the existence of an "overshooting" problem in which the number of entries into an industry exceeds the number of firms the market can support. Shakeouts, therefore, occur as a consequence of firms coordinating their entries and exits poorly.

Other hypotheses of the shakeout process hinge upon the nature of competition and innovation. The preceding growth phase's influx of competition drives down prices, defines the market in terms of demand capacity, establishes supplier-buyer connections which limits larger changes in market shares, and delivers increasing returns to the R&D efforts of incumbent firms. Entry, therefore, becomes progressively unprofitable and inefficient firms even exit the industry (Williamson, 1975; Klepper, 1996a). It follows that innovation remains important during a shakeout insofar that firms must make efficiency improvements to remain profitable in the face of falling prices. Consequently, Abernathy and Utterback (1978) characterize innovation as gradual and incremental during this stage given that the market is well established, competition is largely on a price-basis, and innovations can be quite costly. With these process innovations being harder to imitate, more firms fail and exit the industry (Agarwal and Gort, 1996).

With firms acting as price takers and competing in a mature industry (Jovanovic. 1982), the relationship of price and demand becomes an important determinant in the shakeout phase. Hopenhayn (1993)'s shakeout model considers the price elasticity of demand. Inelastic demand curves allow significant downward price pressure for a given level of demand; therefore, firms must strive for greater efficiency gains and cost-cutting innovations to effectively compete. Consequently, more demand-inelastic industries experience larger shakeouts. In this environment, firms most capable of implementing technological innovations survive, while more idol firms can't keep up efficiently, and exit the industry (Gort and Klepper, 1982).

Naturally, much research has been dedicated to what sort of attributes and exogenous factors contribute to a firm's ability to survive the shakeout process. As alluded to above, mature industries are highly competitive. Necessarily, firms strive for efficiency and must effectively initiate or replicate successful process innovations. Furthermore, much of the existing literature establishes incumbent firms to be the most capable survivors. In other words, an industry's earliest entrants enjoy the benefits of being first-movers and are most able to sustain a competitive advantage (Klepper, 1996a; Klepper, 1997; Klepper, 1996b; Grant, 1991). Early entrants also tend to capture a larger and larger portion of market share while the later entrants who do survive fill niche roles in the market (Klepper, 1997; Klepper, 1996b; Green et. al. 1995). That being said, firm survival can be highly improbable even for incumbents who must succeed in what is initially a highly uncertain operational environment (Utterback and Suarez, 1993).

As John Sutton (1998) simply puts, “a natural model is one where the average size of plant shifts upwards and current industry production is reallocated to a smaller number of surviving plants.” In such a model, it is the incumbent entrants growing and capturing greater market shares. Accordingly, many industries display a positive correlation between firm age and survival (Samuelson, 1989). The tire, television, penicillin, and typewriter industries all display a first mover advantage (Klepper and Simons, 1996; Klepper 1996b). Klepper affirms that the firms that seize the greatest share of the market and achieve the greatest returns tend to be those that entered earliest (Klepper, 1997). Jovanovic (1982) offers an explanation of this correlation in that older firms have had more time to understand their individual operating costs and efficiencies which gives them a better chance at survival during a shakeout.

Success in “learning by doing” represents only one survival mechanism, and when taken alone, fails to account for individual firm attributes that impact survival outcomes (Agarwal and Gort, 1996). Grant (1991) proposes different variables that better enable incumbents to sustain competitive advantage. First, Grant describes that competitive advantages arise not only from capabilities (*e.g.* efficiency of process), but also from the firms resources - human, financial, physical, or technological variety. In the context of a shakeout, surviving firms are those able to maintain competitive advantage by utilizing their capabilities *and* resources effectually. Further, Grant outlines three factors which allow incumbent firms to sustain competitive advantage over imitators: transparency, transferability, and replicability. Taken together each of these factors challenge imitators in that it is difficult to amass the appropriate resources, establish the proper market connections, and replicate a profitable operation. Finally, Grant asserts that hurried resource accumulations are less productive and more costly than those made over a longer time period. Unsurprisingly, it is the imitating rather than incumbent firms who most often partake in such aggressive strategies. With respect to natural resources, accumulating resources may require auction participation which poses huge price uncertainties (Luchsinger and Mueller, 2003). If an entering firm finds itself on the wrong side of that uncertainty during a blitzkrieg of amassing resources, this effect may be more pronounced and in turn weaken its chances of survival.

The previous paragraphs point to the plethora of literature and theory surrounding the shakeout process, what mechanisms trigger a shakeout, and what sort of firms are able to survive them. Importantly, not all industries experience a shakeout. For this very reason, models attempting to describe shakeouts in data must have a clear rule as to what the process entails (see Klepper and Miller, 1985). That being said, the shakeout serves as a useful tool to describe the maturation stage of industries adhering to the product life cycle and S-shaped development curve. In turn, the most common attributes of shakeouts will be shown to fit the next chapter's description of maturity in the shale gas industry: declining uncertainty, increased completion, decelerating rate of entry followed by accelerating exits, gradual process and efficiency innovations, and market concentration with incumbents becoming dominant while smaller surviving firms operate on the industry fringe.

1.1.2.4 Decline Stage

Having undergone a shakeout, mature industries as described above are competitive with relatively stable market shares and therefore profits. Many industries, however, enter a decline stage following maturity. While its name is explanatory, the decline phase is widely defined in literature. That being said, a declining industry is generally one whose sales and demand are in decline or whose net entry rates have transitioned to zero from a negative phase (Porter, 1980; Gort and Klepper, 1982). For instance, Levy (1981) defined a decline stage in the television industry in which production growth slowed to negative rates. Similarly, Koponen and Arbelius (2009) define industry decline to occur once the market size or number of firms wanes.

Much research has focused on reduced demand as the source of declining profits in an industry. For instance, Hamermesh and Silk (1979) tie declining GNP growth and mediocre disposable income growth to the likelihood that more industries will experience decline. Declining demand in an industry may be caused by technological supremacy of substitutes, consumer behavior changes, or consumer financial woes (Harrigan and Porter, 1983). On the other hand, supply constraints may restrict growth due to the finiteness of natural resources. Further, McGahan (2004) explains two sources of decline. First, an industry's primary profit making activities may be threatened, perhaps due to supply or demand alternatives. Second, an industry's assets may become less valuable. Whatever the source of decline, McGahan asserts that the scope of these factors determines whether or not an industry will experience radical, creative, intermediating, or progressive change. McGahan depicts a 2x2 matrix describing these trajectories based on whether or not the industries core assets or core activities are threatened. In similar respects, McGahan, Harrigan, and Porter (1983) explains that steeper declines yield greater competition.

Decline rates, however, are variable among industries, and may prove difficult to determine. In his analysis of firm size consequences during the decline stage, Lieberman (1990) uses the rate of capacity reduction and the rate of industry divestment as indicative measures. Harrigan (1980) conjectures that industries with slow price and consumption declines may maintain attractiveness to certain firms, yet more rapidly declining industries may warrant immediate exit. Given the variability of industry declines, it is therefore paramount for firms seeking to restore profitability to understand their own environment when formulating a competitive strategy in burgeoning industries.

Much research has focused on strategic management and strategic options in declining industries. As mentioned, divesting incrementally or altogether exiting the industry may prove optimal in rapidly declining industries (Harrigan, 1980). Mass divestment and exit then raises question as to what sort of firms will be first in the sequence. By many accounts, larger firms with their lower marginal revenue and voluminous output reduce capacity first (Ghemawat and Nalebuff, 1990; Reynolds, 1988). Alternatively, Lieberman (1990) concluded that larger firms have strong economies of scale, but larger strategic liabilities given their higher output volumes. In rapidly devolving industries, Lieberman found an even distribution of early divestment between large and small firms.

Conversely, divestment strategies may be infeasible if a firm's assets turn out to be costly to retire, thereby creating an exit barrier (Harrigan, 1980). Firms in slower declining industries may actually choose to reinvest in the industry either to become the dominant producer or to focus on a niche segment of the industry where profits are still attainable (Harrigan and Porter, 1983). Such strategies may include marketing efforts or acquiring competitor product lines. To reflect this possibility Filson and Songsamphant (2005) incorporate mergers and acquisitions into their industry exit model. Additionally, firms may strategize to cut prices and facilitate shrinking demand (Lamont et al 1993).

A price cutting strategy, however, may not be useful for our purposes where prices are more exogenous. For the purposes of the present work the growth strategy laid out in Koponen and Arbelius (2009) is of most relevance. To pursue a growth strategy, firms in declining industries must identify and focus their efforts and investment in subsegments which may be defined on the basis of customer group, geography, service, technology, etc. (Hamermesh and Silk, 1979). This sort strategy is especially relevant to natural resource producers who deplete their most economic inventories. Turning to new "submarkets" or resource plays may be an effective method to sustain profitability even as those supply inventories diminish.

1.1.3 Industry Reiterations

The existence of S-shaped product and industry life cycles has been well-defined in literature, yet decline phases are not ubiquitous. In other words, an industry may reach maturity without entering a decline in terms of production volumes or demand. Moreover, in many cases a mature sector may reinvent itself in which case another growth stage and oscillation of the S-curve may occur. Commonly, a reinvention may stem from reinvestment into submarkets or growth segments within an industry (Hamermesh and Silk, 1979). Although the present work's theory of individual basin evolution adheres to an S-shaped lifecycle, its view of the overall shale gas industry follows a growth and reiterating path.

Strategically, firms with either limited resources, replicable operations, or both face two fundamental options: invest in new resources to retain competitive advantage, or accept a short term strategy of profit reaping (Grant, 1991). For purposes of industrial renewal, firms who reinvest fuel industrial expansions, whereas the latter may become victims of the shakeout process. Firms that successfully reinvest in growth areas with the purpose of maintaining their resource base and extending competitive advantage may accordingly reignite an industry, and garner the benefits often afforded to first-movers (Grant, 1991).

Submarkets arise within industries due to differences in technology, customer groups, or geographic scope. The creation and destruction of submarkets can serve as a major impetus for industrial expansion or decline, respectively; and underlay the future trajectory of an industry's growth [Figure 1-2]. Klepper and Thompson (2006) develop a model in which the emergence of submarkets offers exploitation opportunities for an industrial expansion. Applying their model to the laser industry, the authors show that the number of producers increases over time with periods of revamped entry corresponding to the emergence of a new submarket. Furthermore, there is a positive correlation between firm age and the number of submarkets in which they operate indicating that surviving firms often invest in subsectors within an industry to maintain competitive positions.

The emergence of new submarkets comes about through technological advancement or a rise in that submarket's demand base. Hence, innovation can be a principal factor that spurs a new period of growth and entry in an industry (Buenstorf and Klepper, 2010). As the Schumpeterian growth model predicts, rent-seeking firms bring forth industry altering innovation internally (Dinopaulos, 2006). Importantly, the magnitude of innovation or demand increases may positively affect the trajectory of the next growth phase [Figure 1-2]. Hence, the oscillations of the industry wide growth curve, determined by the emergence or destruction of submarkets, are not expected to follow wholly regular patterns. Nonetheless, the present work finds utility in conceptualizing individual plays as submarkets whose growth and decline determine outcomes in the entire shale gas industry.

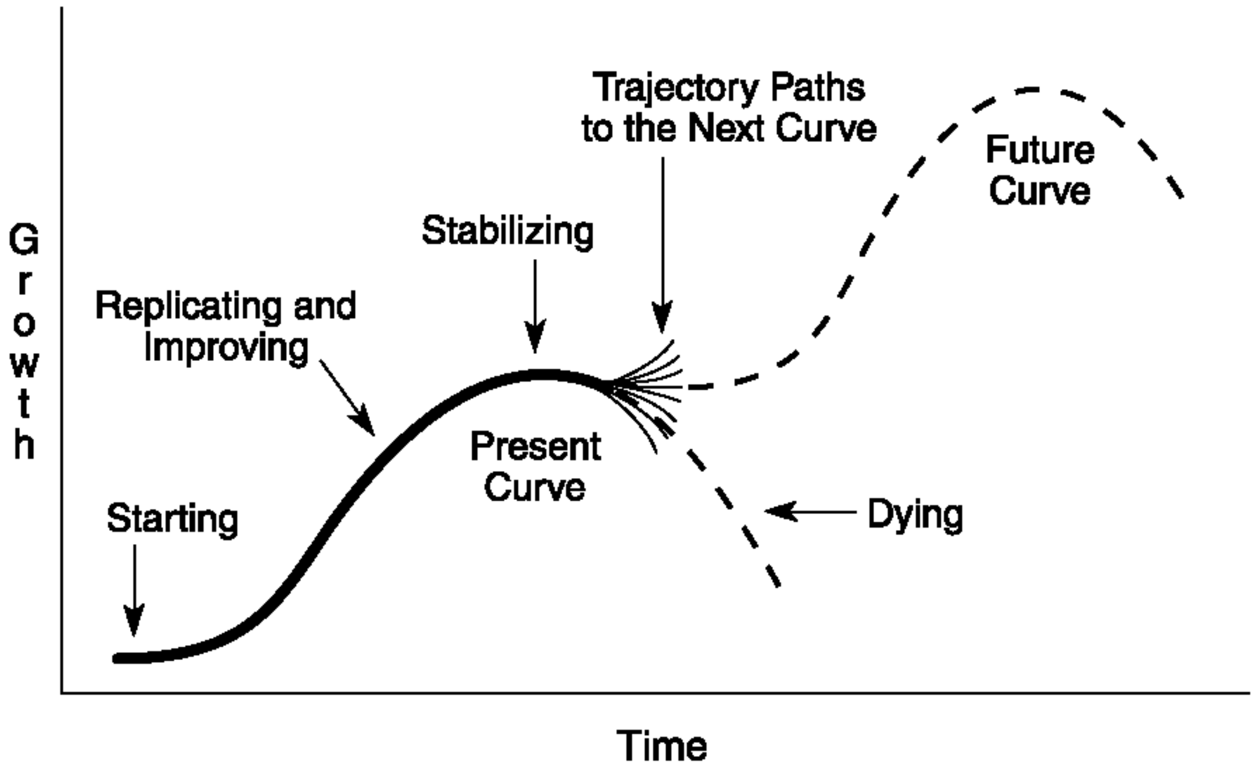

Figure 1-2 The S-curve model (Abraham and Knight, 2001)

1.2 Theory of industrial evolution: conclusions and implications

The basis of an evolutionary vision of industry development is that industries pass through stages in which a certain set of conditions persist. Varying conditions yield an evolving competitive environment; as such, internal forces govern an industry's advancement. Contrary to a more classical approach in which exogenous variables dictate an equilibrium status, an evolutionary approach allows outside observers and industry players greater insight into what factors have the greatest impact during different phases of the industry's life cycle. Hence, the governing forces as well as the various stages of industry evolution are integral for strategy formulation. Practical implications will be discussed in the conclusion following the analyses.

A convenient and powerful approach to describing stages is that of the S-shaped life cycle. Not only have numerous industries been proven to follow an S-shaped evolution, but the S-curve also lends itself to well-defined segments each characterized by its own set of prevailing conditions. Although no generic set of circumstances can define each stage in every industry, those described in this literature review are commonly cited and applicable to an analysis of the shale gas industry. As internal influences drive the evolution of an industry, identifying the key variables therein, predicting their transformations, and anticipating industrial reiterations are necessary exercises to any forward-looking speculations.

CHAPTER TWO: EVIDENCE FROM THE U.S. SHALE GAS INDUSTRY

2.1 Evidence from the shale gas industry to support evolution theory

The rise in shale gas production seen in recent years is often labeled a "revolution." The present work discounts that moniker in favor of a more evolutionary description – the foundations of which are described in the preceding chapter. Branding the shale gas industry's recent growth as a "revolution" promotes the notion that the emergence of a shale gas sector arose unexpectedly. Yet, shale formations have long been known to hold hydrocarbons with shale wells being drilled as far back as the early 20th century (Wang et. al. 2014). Further, the National Petroleum Council had predicted shale gas to be a significant portion of total U.S. natural gas output as early as 2003 when only the Barnett shale had ever produced considerable volumes of shale gas [Figure 2-1]. Likewise, the U.S. Energy Information Administration had predicted significant growth in unconventional gas production in the *Annual Energy Outlook* 1999 [Figure 2-2]. Comparing those forecasts to the most recent projection from the *Annual Energy Outlook 2013 Early Release* [Figure 2-3], however, indicates that early projections of nonconventional gas production – including from shale, coal seam, and tight sand reservoirs – often fall shy of current and projected shale gas production output.

While some forecasts have proven too low, others anticipated an evolution rather than revolution. A 2004 presentation to the IPAA (Independent Producers of America Association) in Austin, Texas titled *The Future is Unconventional: Impact on Independent Producers* showed probable 15 tcf of annual natural gas production from unconventional reservoirs (tight gas, coalbed methane and shale gas) by 2015 (Tinker, 2004b). Further, many of the drivers for the unconventional gas reservoir industry, such as demand growth and technological advancement, had been identified as early as 2004 (Tinker, 2004c).

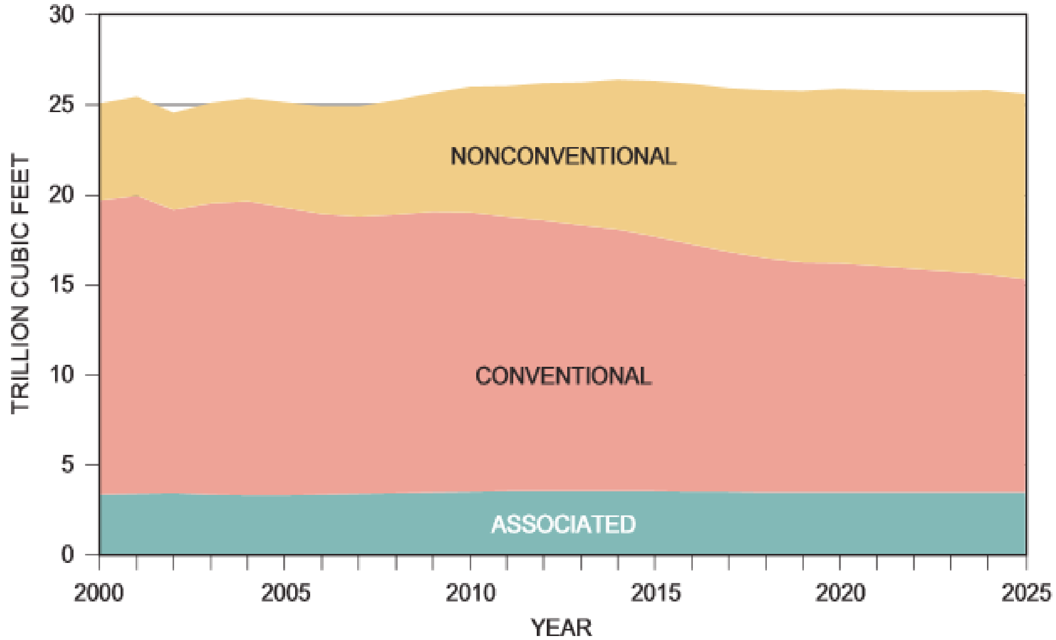

Figure 2-1 U.S. Lower 48 and Non-Arctic Canadian Natural Gas Production (NPC, 2003)

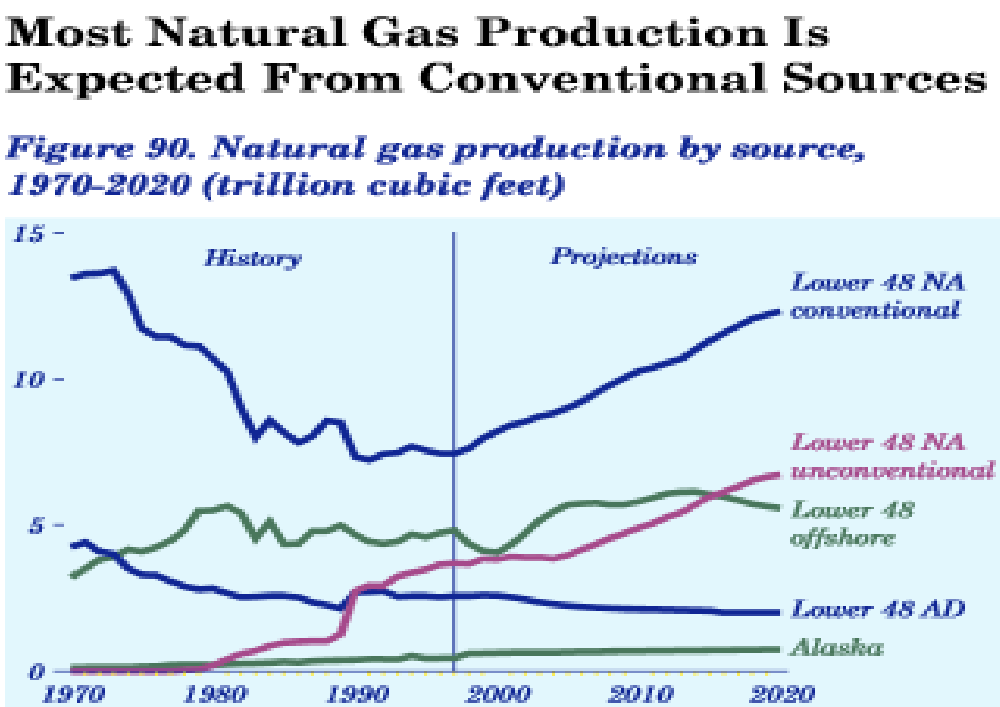

Figure 2-2 U.S. Natural Gas Production (U.S. EIA, 1999)

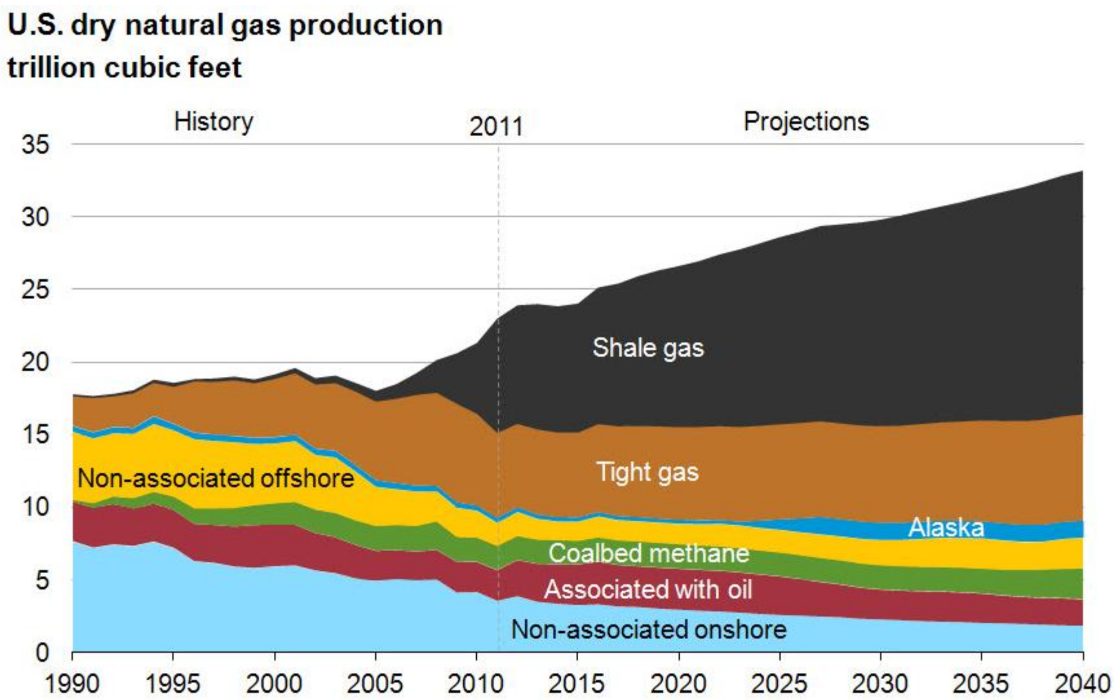

Figure 2-3 U.S. Natural Gas Production by Source (U.S. EIA, 2013)

The fact that shale plays have long been included in reserve and production forecasts indicates that the shale industry did not emerge suddenly. Rather, the shale industry experienced a long introductory period in which government programs and entrepreneurial incentives provided the necessary environment to gradually substantiate shale resources. In the 1970s the U.S. natural gas market experienced shortages due to price ceilings and interstate pipeline restrictions. Part of the federal government's response was to initiate research and development programs under the newly formed Department of Energy in 1977 to unlock supplies from unconventional gas sources (Wang et. al. 2014; Wang and Krupnick, 2013). In addition, the government provided producers with tax credits for Devonian shale gas of $0.52/mcf-$0.94 mcf, and deregulated wellhead prices allowing them to exceed regulated natural gas prices. While research programs propagated technology such as massive hydraulic fractures into the industry, tax credits and price incentives helped derisk investment in shale gas resources.

In conjunction with favorable energy policy, entrepreneurial efforts and private investment in research and development as well as exploration and production identified new unconventional natural gas resources (Tinker and Kim, 2001; Tinker 2004a). Consequently, the technical barriers and uncertainty that characterized shale gas reservoirs declined (Wang and Krupnick, 2013). Early on, certain scholars recognized this developmental period, driven by public and private investments, as part of the industries "anticipated evolution" (Tinker, 2013). For this reason, along with the evidence and analyses in this chapter, we believe the shale gas industry aptly follows the sort of evolutionary path described in the preceding chapter.

2.1.2 Evolutionary Cycles as applied to individual shale gas plays

Before any analysis or data-driven empirical evidence is brought forth, the following sub-sections will outline the variables and ways in which industry evolution may be manifested in shale gas plays. A shale gas basin's development demonstrates four main stages: introductory, growth, maturation, and decline. Each phase along with itskey characteristics and materialization is defined. Importantly, each basin or play is considered to be its own industry. The next section will then form an aggregated view of the entire shale gas industry as a collection of plays or sub-industries.

2.1.2.1 Introduction and Delineation

Competition motivates large scale innovation and scientific delineation.

At the onset of a new shale play, the commercial potential of production volumes is unknown. The process of proving economic viability, therefore, requires a great deal of innovation in terms of both product (natural gas from a previously un-exploited formation) and process (new techniques used to produce the gas). As firms seek to capitalize on the profits such innovations may reward, they must amass mineral rights and scientifically delineate the play. In that light, geology is one of the most significant controlling factors to shale gas development. A "lack of understanding of the [geologic setting]" (Steward 2007) often leads to unsuccessful wells in shale plays. Thus, in the early innovative years of a shale play we expect operators to not only initiate substantial land positions, but also to drill a high, yet declining number of vertical test wells used to demarcate formation geology and resource in place.

Significant uncertainty from price, product, and process risk.

The risks surrounding an exploratory shale gas basin arise from three principal uncertainties. First, natural gas prices are historically volatile subjecting future cash flows to commodity price swings [Figure 2-4]. However, the Sloan Study's model suggests that price sensitivity is not extraordinary in a play's early years due to the large inventory of drilling locations in high quality areas (Browning et. al., 2013). Second, reserve volumes are unknown in unproved basins adding uncertainty to producible quantities and future cash flows. In the sense that the industry's product is natural gas, young plays are prone to product risk. Finally, the processes necessary to efficiently extract gas from shale formations are not only complex, but to some extent unique to each play. Whether or not economical techniques can be implemented remains to be fully recognized in the early years of a play resulting in experimentation by operators with well lengths, hydraulic fracturing designs, and well spacings.

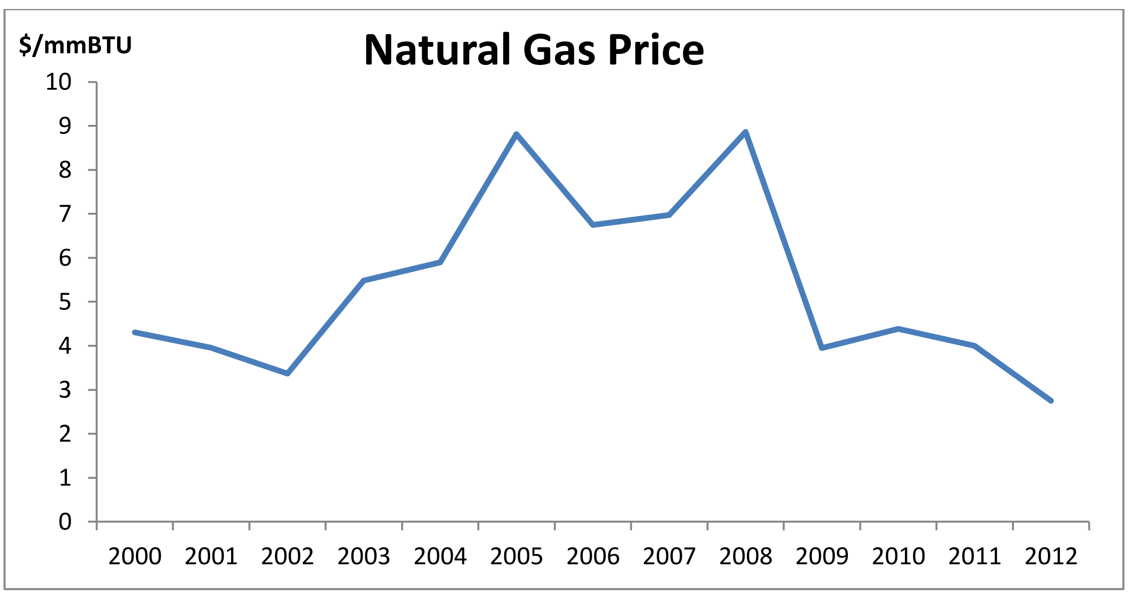

Figure 2-4 Average Annual Natural Gas Price at Henry Hub, LA (U.S. EIA)

A small number of smaller firms dominate the industry

Shale gas plays have historically been found and delineated by risk-tolerant independent operators. While some of these firms are by no means small companies, their size relative to major oil producers who are perhaps more risk-averse and have higher cost structures is considerably less. That being said, some are, or have grown large enough to have substantial access to capital. Because shale development is heavily capital intensive, independent operators are therefore uniquely situated with enough capital to undertake exploratory shale projects, but nimble enough to navigate these risky environments. This study, therefore, anticipates that the introductory phase of a shale play will be dominated by a small number of independent operators who can tolerate the risk and initial losses of developing the play. On the other hand, it stands to reason that major oil corporations are best able to tolerate risk and loss in capital intensive emerging plays in deep offshore and unconventional resource plays.

The magnitude of innovation positively impacts the time horizon of this stage

The amount of time it takes a play to progress through its introductory phase is affected by the magnitude of the innovations necessary to unlock its potential. In the earliest years of shale gas production, innovations were drastic. Thus, the earliest plays demonstrate relatively longer introductory phases. More recent plays, on the other hand, have shorter introductory stages as incumbent firms tend to have prior shale experience and therefore accumulated geologic understanding and engineering capabilities. Shorter time periods of vertical drilling and experimentation in later plays represent steeper learning curves as the innovations necessary to prove a shale play’s potential become more of an exercise in applying previous experience to new formations. In addition, as more plays are successfully developed the risk perception of new plays trends downward, and the amount of time necessary to de-risk them will contract.

2.1.2.2 Growth

Wave of new firm entries

The initial success of the few operators delineating new shale plays has the effect of alleviating some of the uncertainty facing potential entrants to the basin. While natural gas price risk cannot be relieved outside of individual firm hedging strategies, press releases and reports from incumbent operators proliferate information about favorable geology and successful drilling. Given the declining risk environment and the perception that prospective rents are more certain, a wave of new firms begin leasing mineral rights and replicating the drilling techniques of incumbent firms. Although uncertainties remain concerning replication and reserve volumes, a shale play experiencing a growth phase demonstrates a sharp increase in the number of active firms in the play. Entrants during this stage are of all sizes ranging from small, private companies to major oil corporations and their subsidiaries.

Expansion of productive output, drilling activity, and technological capacity

With more firms pursuing strategies to develop a growing field's reserves and drilling wells, productive output naturally accelerates. Hence, alongside a sharp rise in a play's operator count, the play's total production volumes and number of wells drilled increases rapidly in the growth stage. In combination with ever increasing technological advancement which increases average well productivity, competition in the play rises perhaps resulting in price pressure, infrastructure constraints, or lease price hikes.

Resource rents arise due to differential production sites

Once the growth stage of a play commences, geologic features such as natural fractures and engineering techniques are better understood and well-defined, yet entering firms still face uncertainty pertaining to their acreage's geology and technical ability to imitate the success of earlier firms, which may not be fully transparent. Shale plays have heterogeneous geology and reserves; accordingly, a portion the growth phase's surge of new firms lease and drill non-core areas of the play. The Bureau of Economic Geology Shale Gas Study assigns each square mile (block) of a play a productivity "tier" value with lower tiers signifying greater production potential, vice-versa[1]. Productivity is determined by the anticipated EUR of wells drilled in that block taking into account historical well performance and geologic parameters[2]. Drilling in low-productivity tiers of the play increases during the growth stage. Obviously, firms in favorable areas with better technical capacity may possess competitive advantages giving them better chances of survival during the shakeout process that characterizes the maturity stage.

2.1.2.3 Maturation and Saturation

Decelerating Entry Rate

Ensuing from the growth stage's surge in firm entries, increased competition within a shale play contributes to the degradation of prospective rents for new firms. Rents may deteriorate due to increasing lease prices or declining availability of quality acreage. Regardless of the reason, anticipating lower net present values, prospective entrants may refrain from establishing a stake in the play. Hence, the maturation phase begins with a deceleration in the number of entering firms.

Shakeout occurs through steep rise in exit rate

Just as potential entrants come to expect lower profitability in a maturing shale play, a portion of firms actively drilling the basin will struggle to capture rents and may exit the basin, or even the industry. These firms' inability to drill commercial wells may be a result of poor-quality reserves, failure to competitively replicate completion techniques, poor economics related to cost of entry, or some combination of these factors. Further, even firms with positive economics may be acquired by another operator for a price that is favorable compared to their expected future cash flows from continued drilling. In such cases, individual wells and leases change ownership. No matter the reason, a number of firms will cease drilling activities effectively exiting the basin.

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[1] Productivity tiers are assigned according to average horizontal well productivity and estimated future recovery according to the Sloan Foundation shale gas study methodology with lower tiers representing higher productivity, vice-versa (Browning et. al., 2013)

[2] EUR refers to Estimated Ultimate Recovery of natural gas over a 25 year well-life

Combined with decelerating entries, exits will drive net entry at least close to negative as the shale play matures.

Market shares are concentrated

Stemming from the shakeout and its negative net entry effect, a mature shale play's production, which may continue to grow albeit at a slower rate, is largely accounted for by a concentrated number of large firms. Moreover, these large firms tend to be incumbents, and together produce a strong majority of the play's total production. That being said, a niche in the play's market may develop. Perhaps comprising only a few firms, this niche portion of the play's production is small. Nonetheless, a limited number of lesser producing firms maintain a portion of market share even during maturation in oligopolistic plays.

Competition drives incremental efficiency and process innovations

Once a play reaches maturity, groundbreaking innovations such as those seen in the introductory and perhaps even growth stages are unlikely. That is not to say, however, that operators cease innovating. Rather, innovation in this phase tends to occur on the basis of increasing efficiency in the face of higher competition. As a result, optimal well lengths become more established and operators transition to pad drilling operations. However, piecewise innovation along with drilling in non-core areas leads to a slowdown in average well productivity growth. Incremental gains in process innovation may drive continued growth in field wide production. Importantly, given that substantial resources are being left behind in parts of the play, the possibility for a major innovation, such as a lucrative secondary recovery technique, to reignite the industry exists, and may be more applicable in the future.

Incumbents are most likely to survive the shakeout

Although incumbent firms to a shale play must bear the cost of innovation (often through trial and error), they also enjoy first mover advantages relative to their imitators and late entrants for a number of reasons including but not limited to: leasing efforts before resources are established and prices are low, greater accumulation of scientific knowledge, and positioning in better areas of the play. Incumbents are better able to survive the shakeout process, and as a shale basin matures its latest entrants demonstrate the worst survival rates. Importantly, firms may exit during the shakeout phase in favor of pursuing development other plays.

2.1.2.4 Decline

The industry's core assets and activities are threatened

Firms in a declining shale play face an operating environment where profits are increasingly hard to come by. As operators' inventory of high quality drilling locations diminishes, their established operational processes become less cost effective. A significant decline in high quality drilling locations and waning average well productivity may serve as a signal of a decline phase and weakening profitability.

Production volumes decline

An obvious manifestation of decline in a shale play is decreasing production. After all, reserves are finite in the absence of technological advancements that enable extraction of residual gas. Lacking that sort of progress, field wide production volumes can be expected to decline in a burgeoning basin.

Degree of decline is variable

The slope and degree of decline is by no means uniform among plays. Technological advancements may enable secondary recovery or more efficient extraction techniques both of which may prop up profits. Further, firms entering from outside the basin may be able to purchase mineral rights at low enough prices to justify development. Such off-cycle investment and enhanced recovery techniques, may result in shallow or even oscillating decline.

2.1.3 THE SHALE GAS INDUSTRY AS A COLLECTION OF INDIVIDUAL PLAYS FOLLOWING EVOLUTIONARY DEVELOPMENT PATHS.

In the last section, evolutionary cycles were explained in the context of an individual shale play. Understanding these cycles is undoubtedly important at the per-play level. Yet taking a broader view of the shale gas industry is especially relevant for policy makers, natural gas traders, and regulators. Collectively, individual plays form the shale gas industry, which is part of the larger natural gas industry. Given that single basins follow an evolutionary pattern it follows that the aggregate industry adheres to a composite and discernible path. It is the hypothesis of this paper that the shale gas industry, composed of numerous basins in unique stages of development, follows an oscillating s-shape growth curve with reiterations occurring as new plays enter their growth stages.

Recognizing that profitable growth and development strategies may be limited in a mature or declining play, firms often seek expansion into exploratory basins. Given that these operators have prior shale experience, debt obligations to satisfy, and the need to grow cash flows; new basins offer appealing growth opportunities. Thus, it often occurs that experienced shale operators are those firms who de-risk a new shale formation's reserves and establish early leaseholds. As information amasses regarding the operator's success in a new play, the play will enter its growth phase. As was described in the previous chapter, this process relies upon firms reinvesting in geographic sub-industries (new plays). Of course, the emergence and growth of a new play adds to the entire shale industry's production output, number of firms, and well counts. As this process repeats itself, the shale industry's enveloping growth profile- underlain by the onset of new plays- rises more or less monotonically over time.

Three important concepts emerge from this developmental path. First, the emergence of new plays and the industry's growth trajectory is brought about internally by operators who are incentivized by long term growth and profit maintenance. Secondly, hydraulic fracturing and horizontal drilling techniques are relatively refined at the time of this writing; therefore, innovations that rejuvenate the industry are of the product (natural gas from a new formation) rather than process variety. That said, major technological advancements could certainly boost recovery factors and rejuvenate production from new and old plays alike. Lastly, the shale industry and its production volumes are rescaled during each renewal. Consequently, the contribution of new plays is relatively lower, and the reiterations of the industry's combined growth curve become less steep.

2.1.4 THE DATA

Given the description of industry evolution above, the next section looks for empirical evidence that the shale gas industry indeed follows such cycles. In an effort to describe development paths, each of the analyses is applied to three major U.S. shale plays: Barnett, Fayetteville, and Haynesville. The data underlying the analyses are courtesy of IHS Inc. and DrillingInfo.

Further, the analyses presented here build upon the geologic, engineering and economic shale gas analyses performed by the Bureau of Economic Geology at The University of Texas at Austin as part of a study funded by the Alfred P. Sloan Foundation. The shale gas assessment integrates engineering, geology, and economics as part of its forecasting model. Moreover, plays are demarcated into productivity tiers based upon geologic and production data. The analyses herein incorporate tiers as a method of distinguishing high and low reserve quality areas within a basin.

Lastly, empirical evaluations are supplemented by qualitative evidence pulled from individual company investor presentations, earnings call transcripts, and industry reports. Although this evidence lacks quantitative rigor, it offers insight into firm-level strategy. In order to protect company interests, companies will be referred to abstractly rather than by corporate names.

2.2 Evidence from three U.S. shale gas basins

2.2.1 Introduction and Delineation

2.2.1.1 Competition motivates large scale innovation and scientific delineation.

Firms operating at the forefront of a shale play are motivated by the financial rewards of innovation, which in its broadest form, is the verification of a play's commerciality. Seeking to appropriate substantial gains from innovation, pioneering firms often undergo extensive and largely secretive leasing efforts in a basin before substantial drilling commences.

The motivation of the pioneering firm in the Barnett shale play is multi-fold. On the one hand, the company sought to shore up natural gas production from its North Texas fields in order to satisfy a contract with a midstream operator. With the Barnett formation underlying existing leaseholds, the play was a natural target. That said, improving returns from completions in the Barnett helped to intensify the company's innovative motivation. Accordingly, management drastically expanded its land position in the late 1980's, and avoided technical and monetary assistance from the Gas Research Institute (Wang and Krupnick, 2013). In essence, the company wanted to avoid any public exposure that could raise awareness of the play's potential and therefore, negatively impact leasing efforts (Steward, 2007).

The producer responsible for discovering the Fayetteville shale play first identified the play's favorable geologic characteristics as early as 2002. Recognizing the potential of the frontier play, the firm pursued extensive geologic mapping and in August 2004, the firm announced its accumulation of a large acreage position in the Arkoma Basin of Arkansas having only drilled four vertical wells. Although it was the first public statement regarding the Fayetteville shale, the 2004 announcement notes that the most recent acreage acquisitions were a continuation of leasing efforts begun in 2003[3].

[3] Information from investor presentations, earnings calls, and press releases for key Fayetteville operators (Southwestern Energy Co., Chesapeake Energy Corporation, BHP Billiton Ltd.) was collected.

Given the success of shale gas production in the Barnett and Fayetteville shales, it is no wonder that more than one company was busy evaluating the play's productive potential in the years leading up to its commercial discovery. Although the firm that announced the Haynesville play in 2008 had already leased or gotten commitments on over 200,000 acres with plans to extend that position, another operator commonly cited as an initial developer of the Haynesville had established leasehold as early as 2005. Commercial production in the Haynesville, however, would not be fully established until 2009[4].

Following land acquisitions, play developers must define reserves, geologic parameters, geographic expanse, etc. Geologic characteristics have been shown to have significant impacts on production results (Browning et al, 2013). Failing to fully understand the geologic setting commonly results in uncommercial wells when drilling shale plays (Steward, 2007). Vertical test wells are often used to advance geologic and engineering knowledge while proving a play's commerciality. Further, operators can drill vertical wells cheaply and quickly in order to "hold" leases or commence production before mineral rights are turned over to the original owner. Thus, drilling efforts are mainly vertical in the early years of a play's existence when innovating firms seeking to scientifically demarcate a play and assure leases as seen in each of the three focus plays [Figure 2-5, Figure 2-6, 2-7].

[4] Information from investor presentation, earnings calls, and press releases for key Haynesville operators (EnCana Corporation, Chesapeake Energy Corporation, Denbury Resources Inc., Devon Energy Corporation) was collected

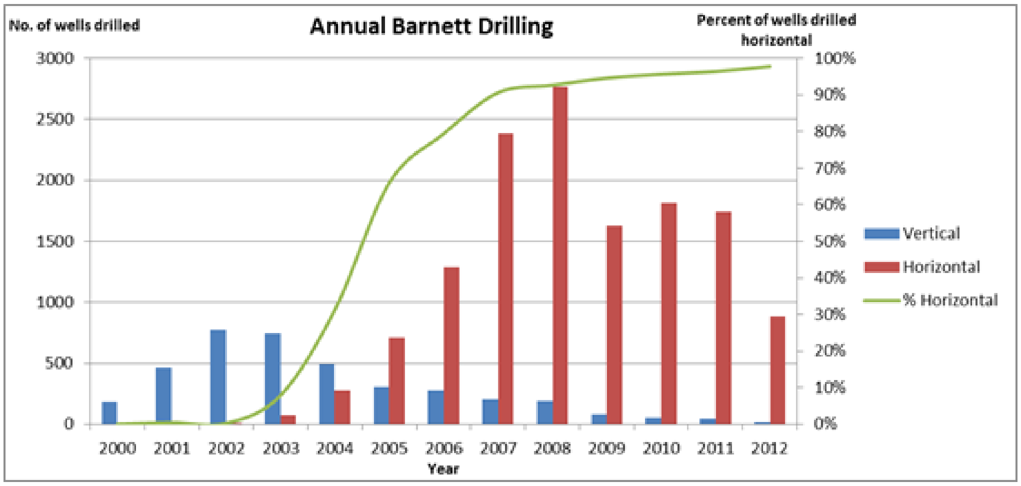

Figure 2-5 Annual Barnett Shale Drilling

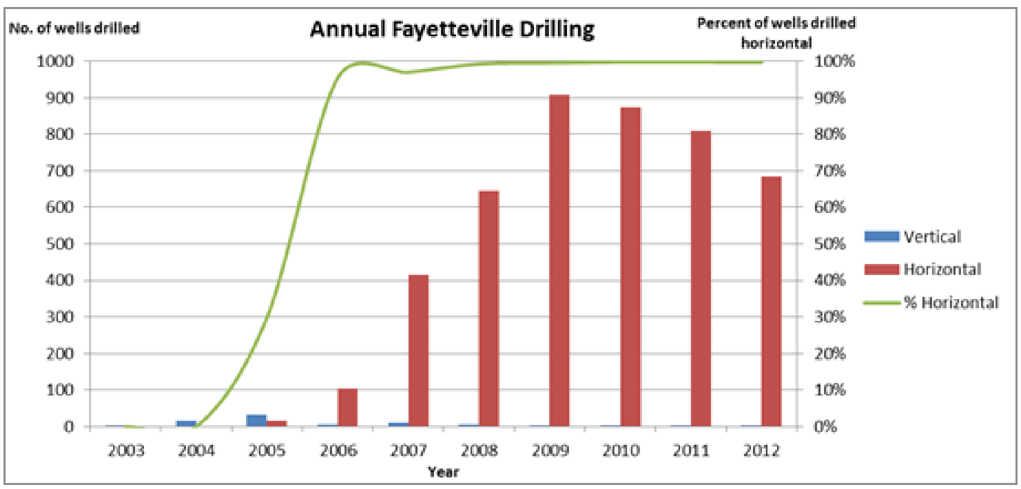

Figure 2-6 Annual Fayetteville Shale Drilling

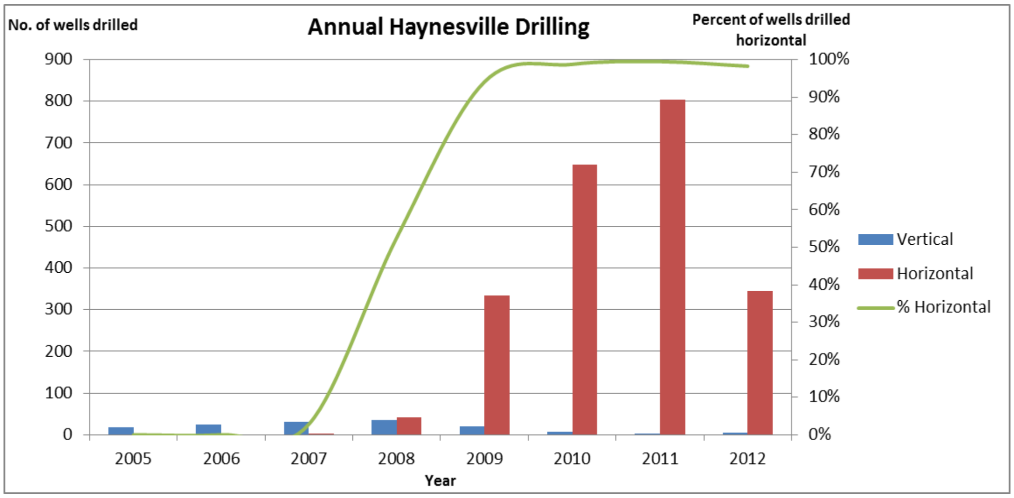

Figure 2-7 Annual Haynesville Shale Drilling

2.2.1.2 Significant uncertainty from price, product, and process risk

As with any resource industry, shale gas operators face considerable risks associated with commodity prices. Moreover, shale gas development is extremely capital intensive making well economics especially sensitive to natural gas prices. In each of the focus plays, modest price swings have considerable impact on drilling IRRs. Although well economics are dependent upon a host of factors, a sensitivity analysis shows that returns are most sensitive to the price of natural gas (Gulen et. al., 2013).

Beyond price risks, much of the uncertainty for early operators stems from reserve volumes and engineering capacity. Although the two are interrelated, reserve volumes can be thought of as the product, while engineering wherewithal is the process necessary to develop those reserves. Proved reserves reported in firms' annual 10-K filed with the U.S. Securities and Exchange Commission are defined as volumes of natural gas that can be economically exploited with current engineering techniques at current prices. Hence, comparing the present value of those quantities with proved and unproved property acquisitions indicates the risk early operators face given the current state of knowledge. For instance, the Fayetteville discoverer's 2004 10'K filling indicated that from 2002 to 2003 (the year in which Fayetteville leasing began) it increased its unproved reserves property acquisitions by 250 percent. Proved reserves increased by a modest 21 percent during the same period.

The pioneering firm of the Barnett struggled for years to successfully exploit the play's gas. Having experimented with different completion techniques and well designs, negative profitability eventually led the company's founder to personally fund operations (Steward, 2007). Similarly, the 2004 announcement of the Fayetteville Shale discovery indicates not only a lack of confidence in drilling costs, but also uncertainty of gas in place, recovery factors, and whether or not the reservoir would respond favorably to hydraulic fracturing[5]. Clearly, incumbent firms face operative risks in emerging plays where future prices, reserve volumes, and technical capacity are each uncertain.

2.2.1.3 A small number of smaller firms dominate the industry

Only a small number of firms typically support an introductory industry; indeed, shale plays whose commercial capacity is yet to be proved are operated by few firms relative to the amount of firms who eventually drill wells in the formation. Each of the three plays analyzed in this paper demonstrate this quality [Figure 2-8]. Moreover, the firms commonly cited as the founder of each play are independent operators with perhaps higher risk tolerances than major oil corporations.

[5] Information from investor presentations, earnings calls, and press releases for key Fayetteville operators (Southwestern Energy Co., Chesapeake Energy Corporation, BHP Billiton Ltd.) was collected.

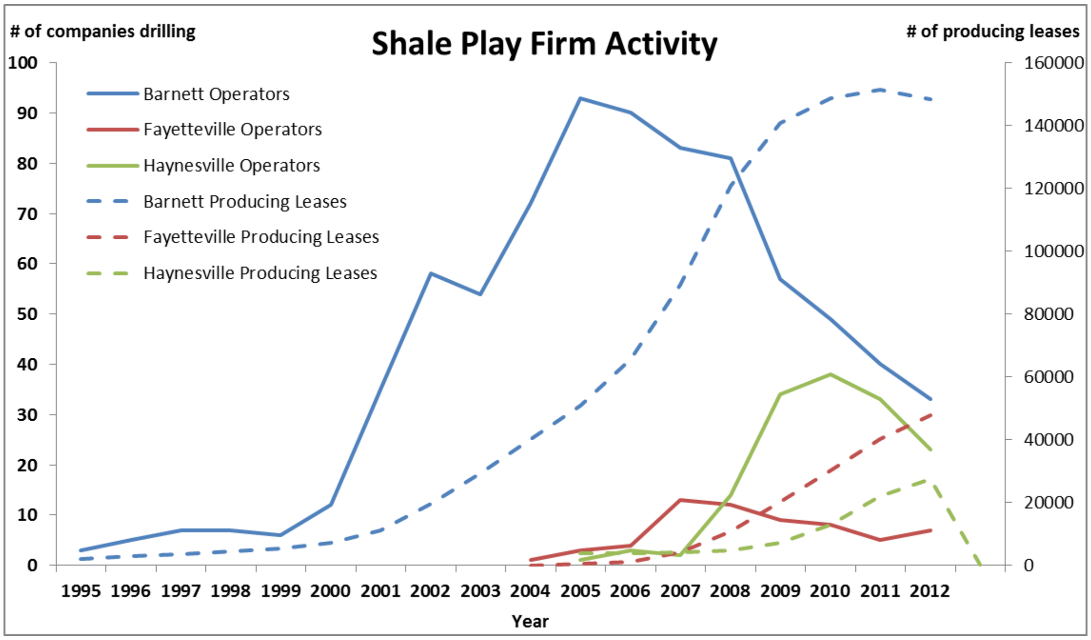

Figure 2-8 Operator Counts and Productive Leases by Play

Until profitability becomes more certain, few operators drill in each play. Leading up to the Barnett's influx of operators in the early 2000's, the play's pioneering firm was still altering fracture designs, spacing, gas-in-place estimates, and horizontal drilling techniques. Yet, by the turn of the century the *Oil and Gas Journal* reported on the Barnett's massive gas reserves. Meanwhile, the incumbent firm's capital costs and revenues had converged – effectively proving commercial potential. Similarly, the "first-mover" firm in the Fayetteville shale began successfully applying hydraulic fractures to horizontal wells in 2005-2006 according to company annual reports. Shortly thereafter, competing operators increased activity in the basin [Figure 2-8][6]. Finally, in its 2007 annual report, the discoverer of the Haynesville Shale only mentioned prospective reserves, but by the 2008 report detailed horizontal development activities and a major

[6] Information from investor presentations, earnings calls, and press releases for key Fayetteville operators (Southwestern Energy Co., Chesapeake Energy Corporation, BHP Billiton Ltd.) was collected.

joint venture in the play[7]. Unsurprisingly, leading up to those announcements relatively fewer firms actively pursued Haynesville targets.

2.2.1.4 The magnitude of innovation positively impacts the time horizon of this stage

Determining the magnitude of innovation is an inexact science. Broadly speaking, however, innovation is the establishment of commercial production potential in a new shale basin. Leading up to that point, incumbent firms tinker with well spacing, completion designs, and drilling targets. That said, the amount of time it takes these firms to arrive at optimal engineering techniques and demonstrate economic viability is not uniform across plays. Moreover, more recent plays demonstrate shorter delineation phases [Figure 2-8].

As mentioned in the previous chapter, the magnitude of innovation required and deployed lengthens the initial stages of an industry. Thus, it would be expected that the first commercial shale play would demonstrate a lengthy introductory phase. Indeed, starting in 1982 it took two decades of drilling, geologic mapping, seismic collection, and engineering experimentation before the Barnett shale's founder had initiated a profitable development program even refining gas-in-place measurements in the late 1990's (Steward, 2007). Obviously, proving a shale formation's commercial capacity for the very first time is a *major* innovation.

Following successful development of the Barnett shale, the Fayetteville shale was discovered by an independent operator who drew upon knowledge of the Barnett shale. In fact, a company press release states that the firm initially began exploring the Fayetteville after noticing similar geologic conditions (thermal maturity, total organic carbon, etc.) relative to those in the Barnett formation of East Texas[8]. Further, the Haynesville shale's discoverer had prior experience in both the Barnett and Fayetteville shales. Thus, in both cases operators could build upon prior experience; and, instead of developing an

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[7] Information from investor presentation, earnings calls, and press releases for key Haynesville operators (EnCana Corporation, Chesapeake Energy Corporation, Denbury Resources Inc., Devon Energy Corporation) was collected

[8] Information from investor presentations, earnings calls, and press releases for key Fayetteville operators (Southwestern Energy Co., Chesapeake Energy Corporation, BHP Billiton Ltd.) was collected.

innovation as dramatic as a hydraulically fractured horizontal well, innovate by applying and fine-tuning prior advancements in a new basin. As such, it is unsurprising that successive shale plays demonstrate shorter de-risking phases before successful drilling indicates attractive economics that entice the steep rise in firm activity characterizing the growth phase of a play [Figure 2-8].

2.2.2 GROWTH

2.2.2.1 Wave of new firm entries

As information regarding successful and economical drilling results from early operators accumulates, a wave of new firms enters the play by leasing mineral rights and replicating drilling techniques. Namely, successful drilling efforts and upgrades in reserve volumes serve to decrease the risk perception surrounding a play. In each of the three plays, we observe a sharp rise in the number of firms who completed a well in the formation shortly after information concerning the plays' productivity is made public [Figure 2-9]. Beyond company reports, engineering and geologic publications serve to disperse that information to industry and academia. It should be noted, however, that the observed increase in firm activity occurs on a lag given that entry is considered to occur in the year that a company completes its first well. In reality, decisions to invest in a shale play occur well before a well is completed. During the year or so between that decision and its first completion, a firm must secure financing and mineral rights, contract drilling rigs, geologically map its acreage, etc.

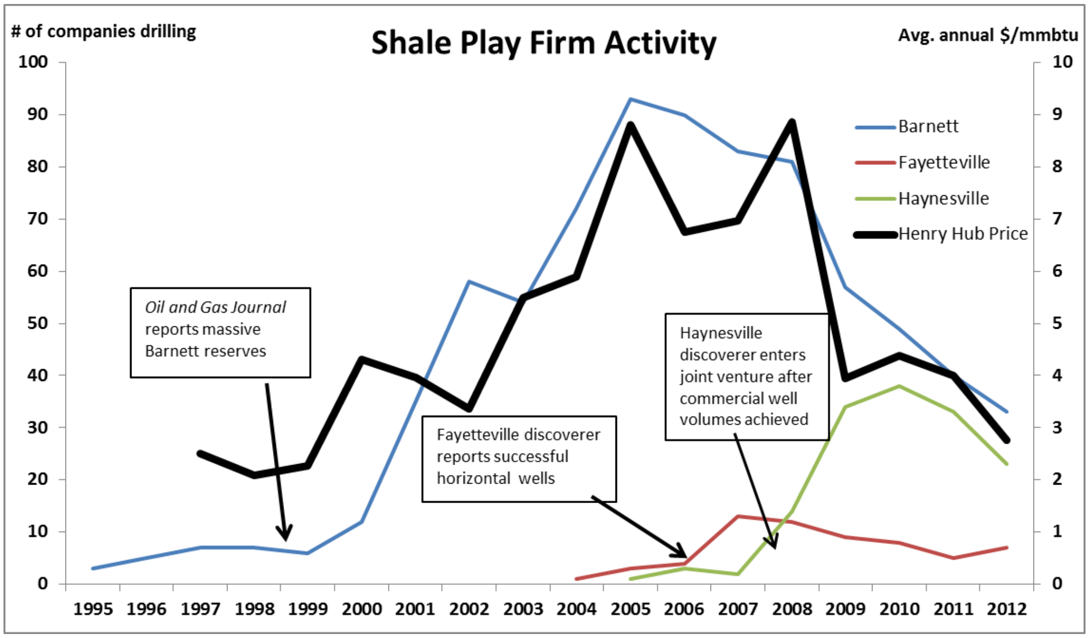

Figure 2-9 Annual Operator Count by Play vs. Natural Gas Price

Although entering firms perceive lower risk during the growth stage, substantial uncertainty still exists regarding prices, reserves, and engineering. With respect to prices, commodities prices are not linked to well-volume results, so potential operators face substantial price risk. While the Barnett's growth phase commenced during a period of relatively low natural gas prices, scores of firms began drilling the Fayetteville and Haynesville shales during periods of historically high prices. Of course, higher prices yield better economics making entry all the more attractive.

The majority of firms entering a play during the growth stage are unsurprisingly small, private companies. However, the growth stage is when major oil corporations or large independent operators first establish their presence in a shale play. In the Barnett a subsidiary of a major corporation began drilling in 2004 with two more majors spudding wells in 2006 and 2007. That same subsidiary began drilling Fayetteville wells in 2007 and Haynesville wells in 2009. Further another major global company entered the Haynesville in 2010 seemingly after the major growth stage had ended. That said, oversupply and decreasing prices had a large negative impact on Haynesville development due to the play's sensitivity to natural gas prices.

Finally, it should be noted that the Fayetteville shale appears to have experienced a low level of entry compared to those seen in the Barnett and Haynesville growth phases. Upon further consideration, however, the Fayetteville shale's discovering firm had already leased a substantial, and perhaps even majority position in the play. Even disregarding undeveloped locations, the firm's well sites cover a great deal of the Fayetteville geography [Figure 2-10]. Accordingly, the competitive landscape of the play is more monopolistic which creates potential barriers to entry – therefore explaining the weaker rise in firm activity.

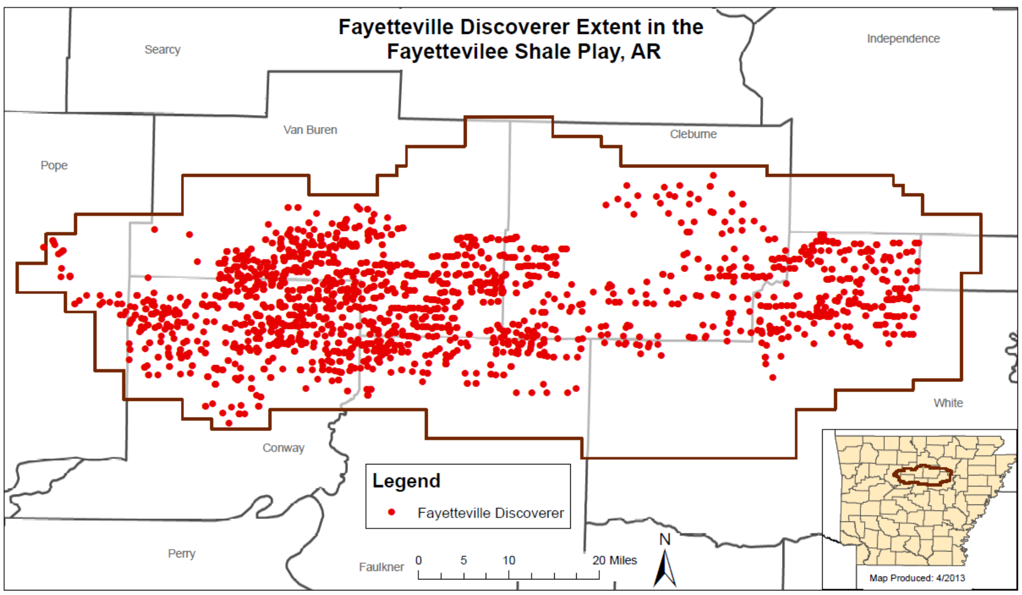

Figure 2-10 Wells Drilled by Fayetteville Shale Discoverer

2.2.2.2 Expansion of productive output, drilling activity, and technological capacity

New operators are not the only component of the growth stage. Rather, the industry as a whole expands. Naturally, with more firms drilling wells into the shale formation the basin expands in terms of productive output, number of wells drilled, and technological capacity. In each of the focus plays, production volumes and well counts rise at the same time as the observed firm entries - circa 2000, 2006, and 2008 in the

Barnett, Fayetteville, and Haynesville, respectively [Figure 2-11]. Although hardly discernible, it should be noted that any lag between firm entries could be accounted for by the fact that new firms must delineate their acreage. The minimal lag, though, seems to indicate that new operators quickly begin replicating incumbents' operations.

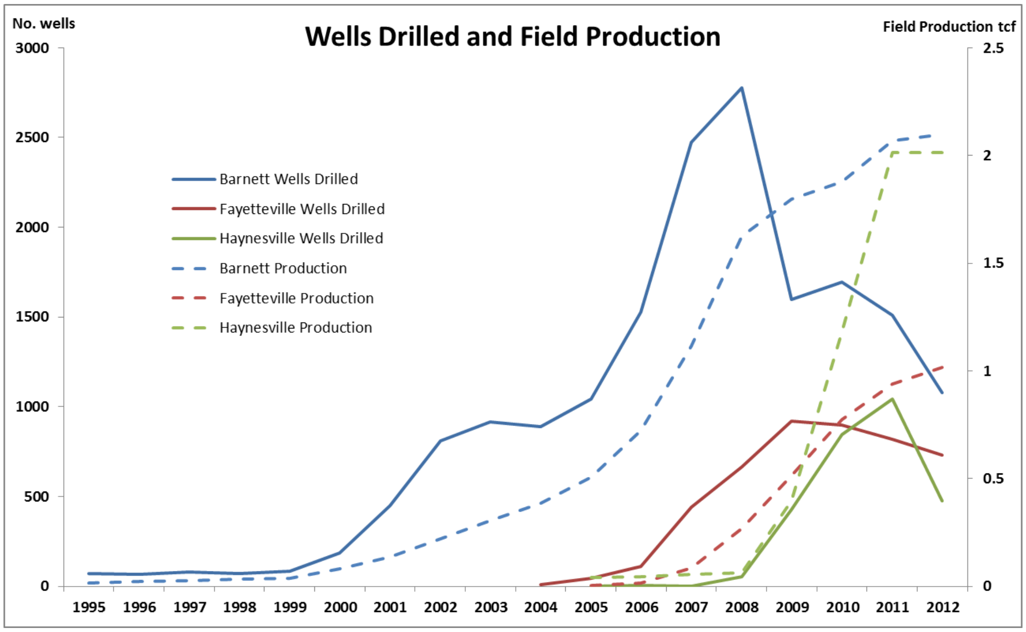

Figure 2-11 Annual Wells Drilled and Field-wide Production by Play

Production volumes certainly expand in part due to more operators drilling more wells in a play. Yet, technological advancements serve to make wells increasingly productive with operators achieving greater efficiency as seen by increasing average well productivity [Figures 2-12, 2-13, 2-14]. The vertical marks in each of the figures roughly define the initiation of each plays' growth phase during which the average 12 month cumulative production of wells drilled in each year, normalized for number of days in each month, shows an increasing trend.

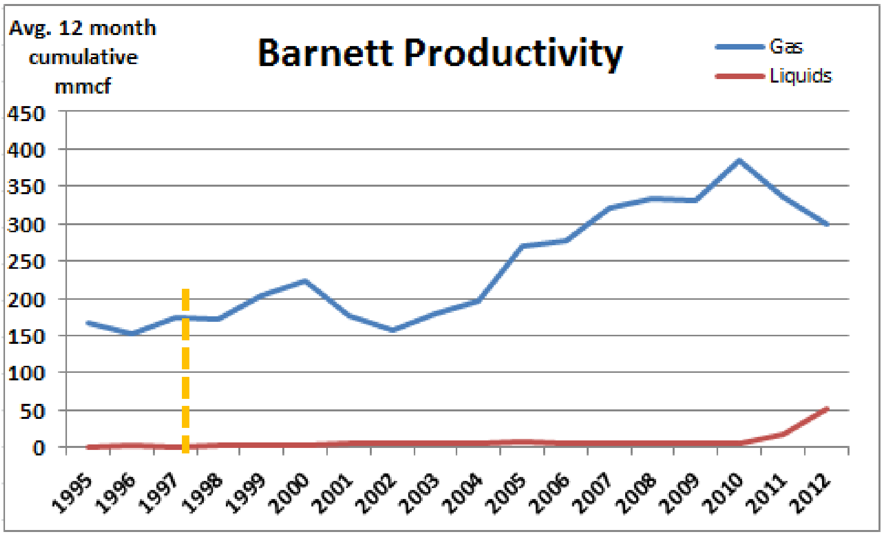

Figure 2-12 Barnett Well Average Cumulative First Year Production

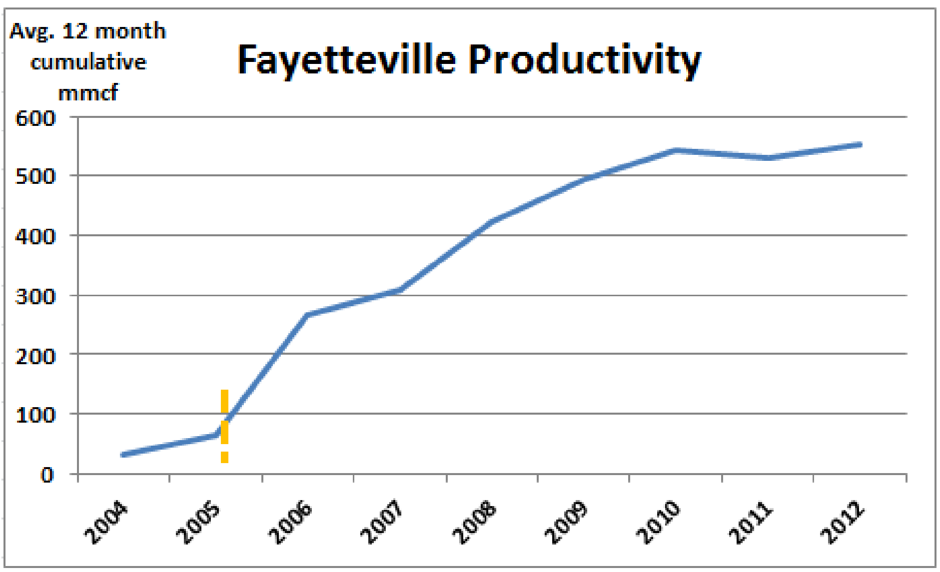

Figure 2-13 Fayetteville Well Average Cumulative First Year Production

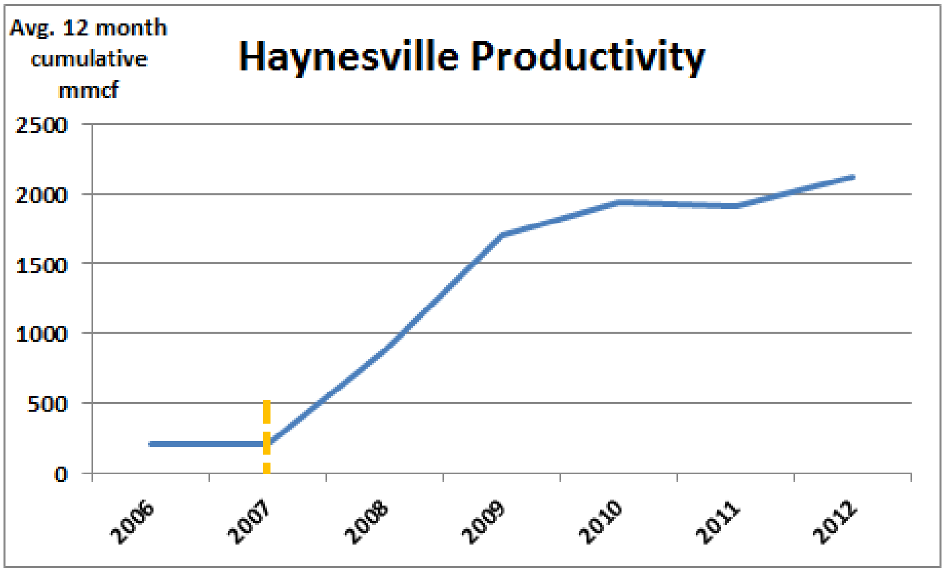

Figure 2-14 Haynesville Well Average Cumulative First Year Production

Productivity gains during the growth phase are the product of not only better understanding of the play, but also of improved technical ability. For instance, in every play there is a general trend of drilling longer horizontals over time [Figures 2-15, 2-16, 2-17]. While longer horizontals are able to contact more of the reservoir and thus produce more gas, they are more difficult to steer within the target formation. As experience and geologic understanding accumulate, however, the task of steering extended laterals becomes more manageable. In each play horizontal wells with a calculated lateral of less than 1,000 ft. were excluded. In each play, median and mean lengths become increasingly extended. In addition, length distributions appear to increase as the plays develop indicating that operators continue experimenting with well designs.

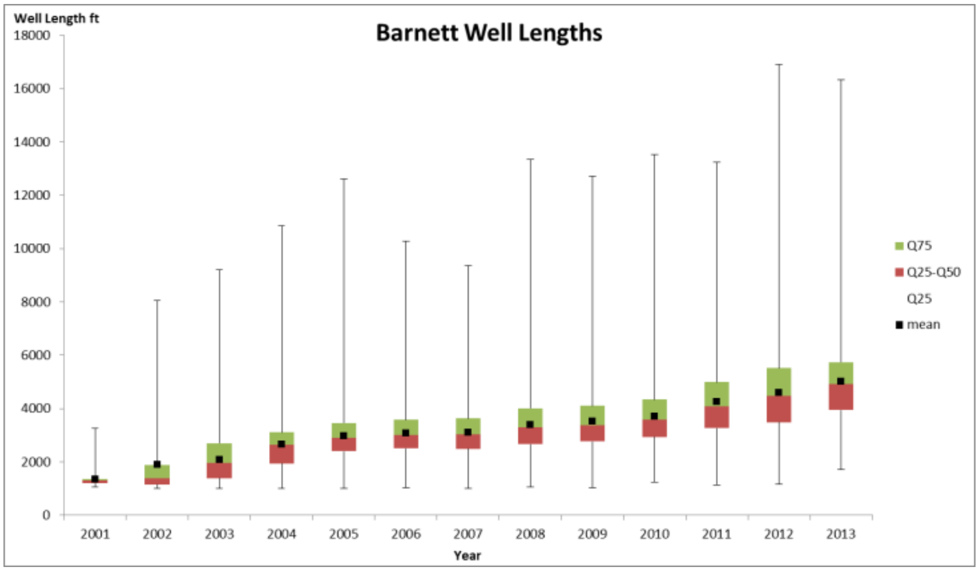

Figure 2-15 Box and Whisker Plot Barnett Well Lengths by Year

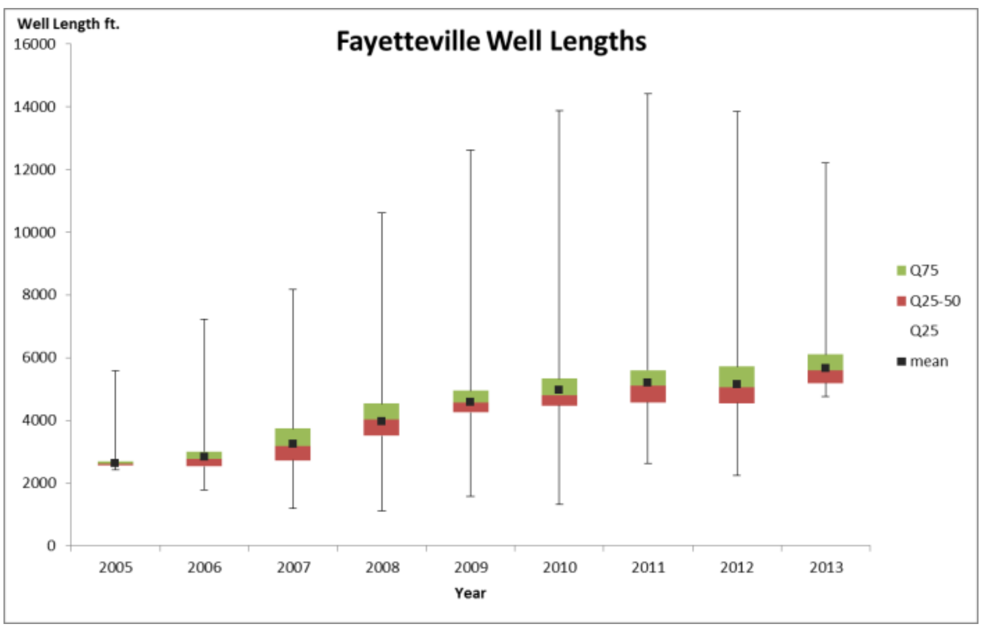

Figure 2-16 Box and Whisker Plot Fayetteville Well Lengths by Year

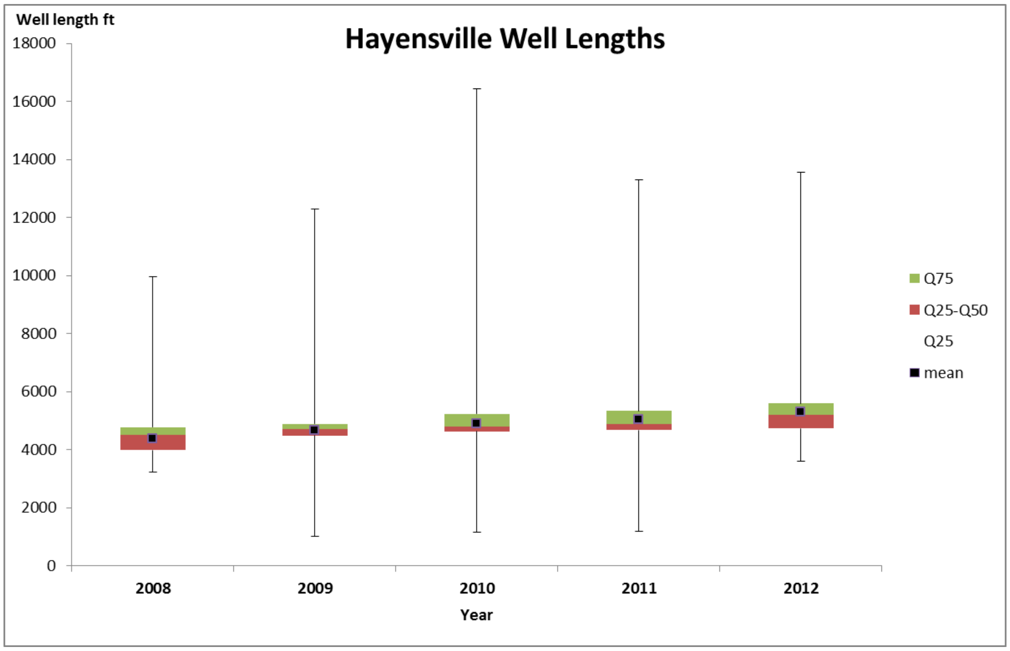

Figure 2-17 Box and Whisker Plot Haynesville Well Lengths by Year

Such steep rises in firm entry, production, and productivity serve to increase competition in a growing shale play. That competition may have several effects including but not limited to: higher lease prices, increasing rig rates, and constrained processing or pipeline infrastructure.

2.2.2.3 Resource rents arise due to differential production sites

The influx of new firms facilitates a land grab during the growth phase of an industry. Accordingly, the number of leases being drilled in a play undergoes a steep increase as a play commences its growth [Figure 2-18]. Although intuitive, an expansion in the number of leases drilled indicates that the play is expanding geographically. Consequently, the afore-mentioned increase in number of wells being drilled is not solely caused by developmental drilling on preexisting leaseholds.

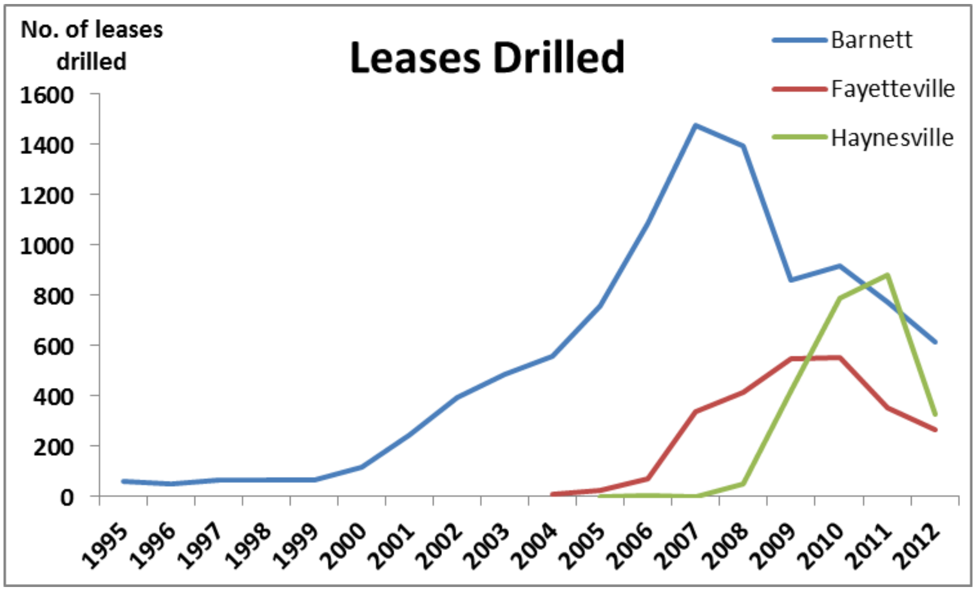

Figure 2-18 Annual Count of Leases Drilled by Play

Moreover, drilling expansion in less productive tiers is predominantly undertaken by non-incumbent operators in the Barnett [Figure 2-19]. In the following drilling charts, the primary vertical axis represents the percentage of each tier's inventory of well locations drilled in the respective year. Inventories are taken from the Sloan study base case production outlook in which inventories vary by tier according to their economic profiles at a $4.00/mmBtu gas price, drainage areas of horizontal wells, and a shape factor reduction to possible well locations in undrilled areas. The shape factors assume that 30 percent of Barnett and 40 percent of Fayetteville and Haynesville well locations in undrilled areas will ultimately be drilled. The purpose of the shape factor is to account for impediments to drilling such as urban developments, stubborn land owners, and the likes. Returning to the charts, the secondary vertical axis and yellow line depict the incumbent firms' share of total field production.

Incumbents are the first firms to drill a basin, and part of the present work's hypothesis is that incumbents have an advantage in their resource position compared to firms who enter later in the growth phase[9]. Indeed, drilling growth in less productive tiers occurred mainly due to non-incumbent efforts in the Barnett shale [Figure 2-19]. Yet, in the Fayetteville where one firm holds a majority of the acreage, drilling growth remains more or less constant between the incumbent firm and non-incumbents [Figure 2-20]. Noticeably, the incumbent firm drastically expanded tier one drilling in 2012. Qualitatively speaking, this is likely the result of that firm's decision to expand into the Marcellus shale[10]. Similarly, the drilling breakdown in the Haynesville remains essentially constant during growth years (2009-2011) likely due to the fact that economic differences between tiers are marginal in the play [Figure 2-21]. For instance, hardly any of the Haynesville shale is economic at gas prices below $4/mmBtu, but at least half of the play breaks even at a six dollar gas price. Such economics largely stem from Haynesville wells being very deep and therefore expensive to drill, but over pressured and therefore highly productive.

[9] Incumbent firms are determined to be those who commenced drilling before 2001 in the Barnett Shale [2000 was the first year of noticeable competition in the play (Steward, 2007)], before 2005 in the Fayetteville Shale [the formation was discovered in 2003 and announced in 2004], and before 2008 in the Haynesville shale [discovery announcement occurred in 2008].

[10] Information from investor presentations, earnings calls, and press releases for key Fayetteville operators (Southwestern Energy Co., Chesapeake Energy Corporation, BHP Billiton Ltd.) was collected.

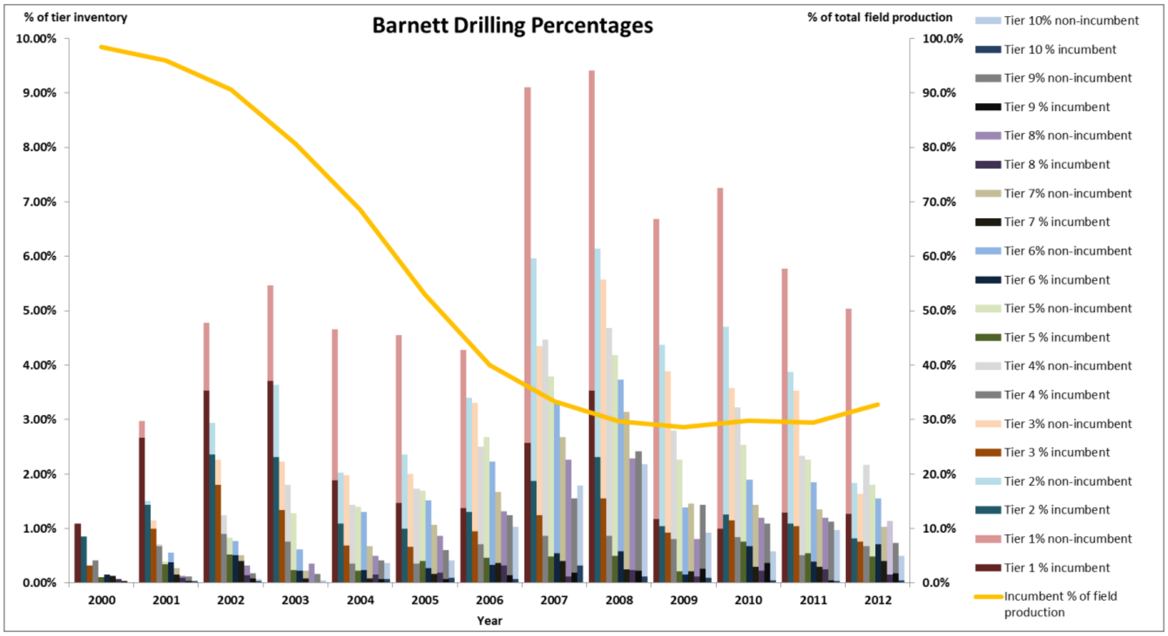

Figure 2-19 Barnett Drilling of Tier Inventory by Year and Incumbent Share of Field Production

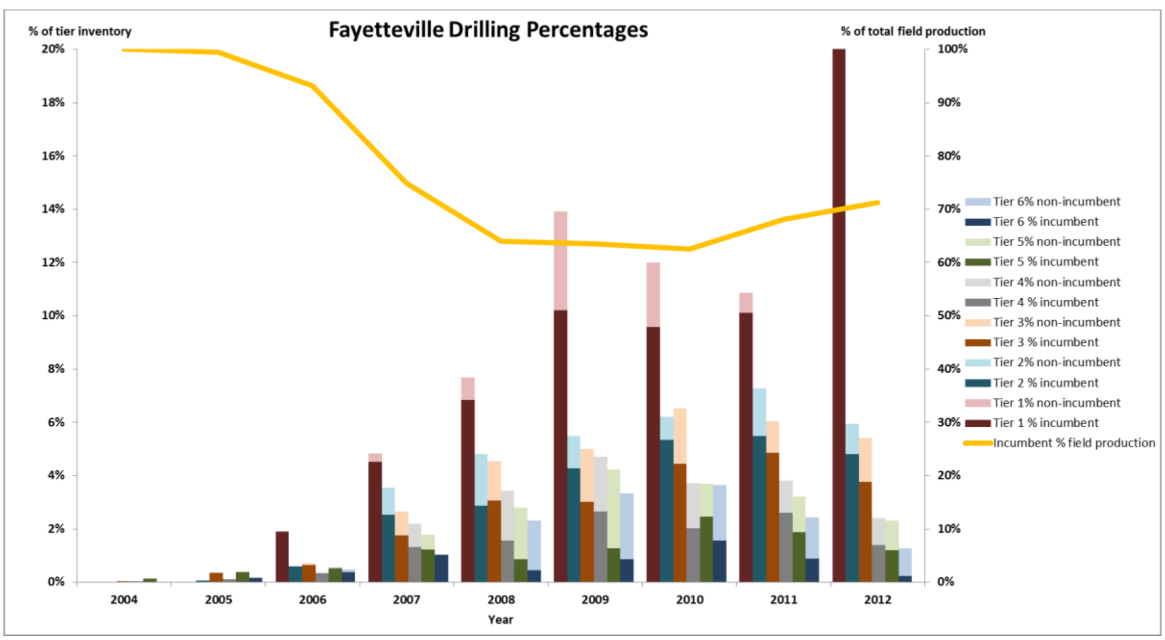

Figure 2-20 Fayetteville Drilling of Tier Inventory by Year and Incumbent Share of Field Production

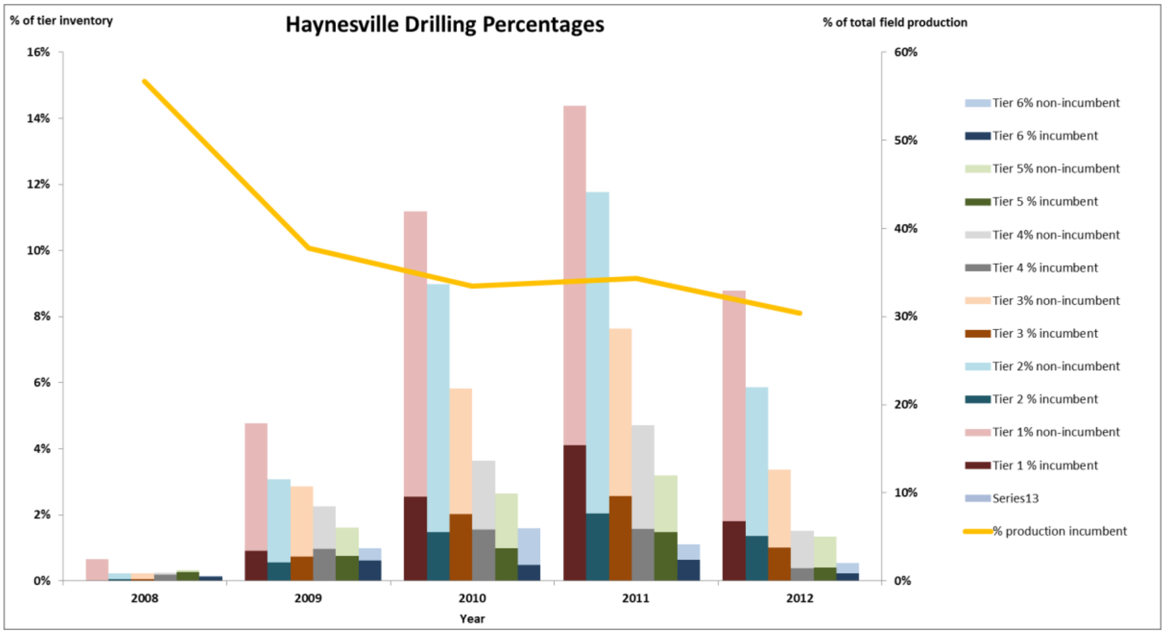

Figure 2-21 Haynesville Drilling of Tier Inventory by Year and Incumbent Share of Field Production

Although the above analysis suggests that resource advantages may be less prominent where virtual monopoly (*i.e.* the Fayetteville Shale) or relatively consistent economics between reservoir areas (*i.e.* the Haynesville Shale) exists, better technical capacity as well as differential resource positions may give rise to rents and explain at least part of the play's shakeout of active operators during maturation. To be sure, however, resource and technical advantages do now allow incumbent firms to maintain essential monopolies on a growing field's production volume as seen by their declining portions of field wide production [Figures 2-19, 2-20, 2-21].

2.2.3 Maturation and Saturation

2.2.3.1 Decelerating Entry Rate

With most of a play's acreage leased, more firms drilling the formation, and heightened competition, prospects for entry become increasingly unattractive. For instance, elevated leasing activity in a basin may raise prices for mineral rights to levels that undermine the net present value of entry and therefore, the attractiveness of investing in a nearly mature play. In the previous sections, the analytical focus as far as annual entries has been on the number of new firms drilling a basin each year. In defining the shakeout process, however, this analysis is focused on the deceleration of firm entry rates. As in the previous sections, entries are defined as when a company first completes a well in the relevant formation rather than when an investment decision is made due to data availability.

Defining firm entry rate as the rate of change between the numbers of new firms each year, the focus plays demonstrate oscillating patterns [Figure 2-22]. Of course, those fluctuations are not in parallel with the smooth deceleration in entries and rise in exits described in much of the literature (Agarwal and Gort, 1996; Horvath et. al., 2001)'.

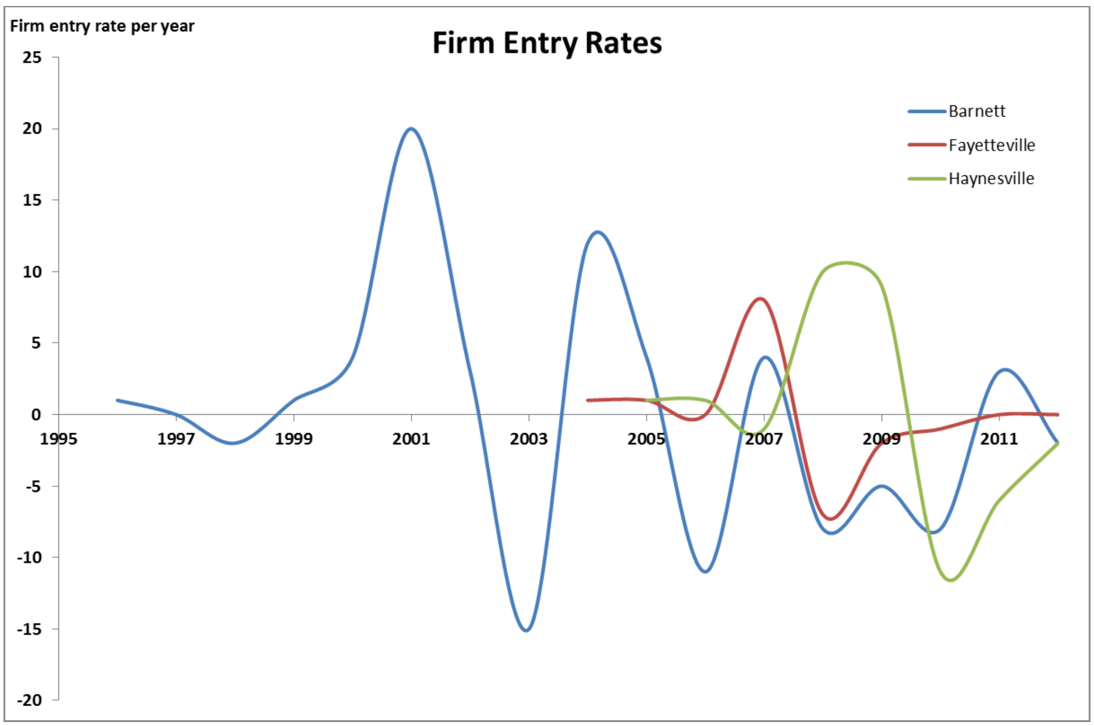

Figure 2-22 Annual Entry Rate by Play

Yet, Barnett entry rates reveal two important facets of shale play entries. First, firm entries occur in clusters similar to the model laid out in Argenziano and Dengler (2013). That model stipulates that investment and entry decisions may be clustered as the payoff of investing early and preempting other entrants converges with higher profits from delaying investment due to lower upfront costs. Often positive externalities bring about the competitive forces and preemptive motivation that entices clustered entries. Indeed, companies in the Barnett shale face obstacles to drilling in urban and suburban areas (City of Dallas Ordinance No. 29228). For instance, drilling is often limited by setback distances from other property lines, but eventually operators may re-strategize and drill those reserves differently or pursue new targets[11]. Because our analysis considers only completed wells, those sorts of obstacles are essentially barriers to entry and help explain why firms enter in clusters as obstacles are lifted.

Secondly and most important to characterizing the shakeout process, the amplitude of the fluctuations declines over time, and entry rates stabilize. Klepper and Graddy (1990) describes that the number of producers in an industry stabilizes following the shakeout process. The authors define that stabilization to occur once the average annual change in number of producer becomes sufficiently small.

The Fayetteville and Haynesville plays demonstrate the same oscillating pattern. Due to their relative youngness, though, the number of iterations and magnitude of stabilization is less obvious. Moreover, rate of entry in the Fayetteville appears to be flattening in recent years suggesting that the existence of a single dominant firm may shorten the time before a play's operator count and entries settle.

2.2.3.2 Shakeout occurs through period of negative net entry.

The shakeout process causes the number of firms in a play to stabilize at a lower level than its peak during the height of its growth stage. Necessarily, the shakeout can be characterized by a period of negative net entry during which more firms are exiting the play than leaving. Table 2-1 shows the onset of negative net entry with a highlighted cell in each pay. For purposes here, the year corresponding to the first year of negative net entry signifies the start of the play's shakeout.

[11] The City of Dallas Ordinance No. 29228 requires that drilling activities occur no less than 1,500 feet form parks, residences, commercial buildings etc.

	Net Entries												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Barnett	3	22	16	6	13	9	-2	1	-13	-5	-17	-10	-14
Fayetteville					1	1	2	7	-1	0	-2	-1	-5
Haynesville						1	2	1	10	15	1	-9	-22

Table 2-1 Annual Net Entries by Play

Following the onset of a shakeout, each play continues to experience negative or at least close to negative net entry through the remainder of the data [Table 2-1]. Of course, this occurrence indicates that the shakeout of a mature shale play does not end once the industry reaches a "stable" number of producers as much of the literature suggests (Klepper and Grady, 1990). Rather, firms continue to exit the industry at a rate greater than that at which firms enter suggesting that the shakeout process may persist even into the decline phase of a shale gas play. One possible explanation for a persistent shakeout would be that firms continuously exhaust their inventory of drilling locations and must therefore exit the play.

2.2.3.3 Incumbents are most likely to survive the shakeout

Beyond inventory exhaustion, firms may also come to learn that a portion, majority, or its entire inventory is indeed uneconomic to drill. Just as Jovanovic (1982) develops a model in which industry entrants are initially unaware of their production costs, new entrants in a shale play may not fully understand their respective well economics when their entry decisions are made. Moreover, the largest expansions in drilling activity come from non-incumbent firms especially in low-quality tiers [Figures 2-19, 2-20, 2-21]. While incumbents do expand drilling activity during the play's growth phase, the lion's share of incumbent drilling is extended into higher projected EUR portions of the play[12]. Further, incumbents across plays and across tiers keep their percentage of inventory drilling nearly constant from year to year.

[12] Projected EURs used for tiering were determined by the Sloan study based on the physical properties of the reservoir and the cumulative production potential of a well with a 25 year life expectancy.

Non-incumbents have historically drilled larger portions of the low-quality tier inventories during the growth phase and subsequently curtailed those drilling levels. Based on the Sloan study production forecast, only the top three, two, and one tiers are currently economic in the Barnett, Haynesville, and Fayetteville plays, respectively. Additionally, it is the hypothesis here that non-incumbent firms lack the same level of technical wherewithal in the basin as incumbent firms who have more experience operating in the basin. It therefore follows that the negative net entry characterizing shale play shakeouts are largely due to exits by non-incumbents who drill lesser quality rock, with less adequate technical ability. As a result, incumbent firms are expected to demonstrate better survival rates than later entrants.

To test this hypothesis, a method similar to that used to analyze survival rates in Klepper (1997) was utilized. Operators in each play were divided into cohorts according to when they first drilled ("entered") the play. The percentage of a cohort's firms still drilling in each year after entry is then calculated to be the percent of survival to that age with year 0 being 2000 in the Barnett, 2003 in the Fayetteville, and 2007 in the Haynesville. Confirming our hypothesis, earlier cohorts of firms display greater survival chances, and subsequent cohorts exhibit progressively worse survival rates [Figure 2-23, 2-24, 2-25].

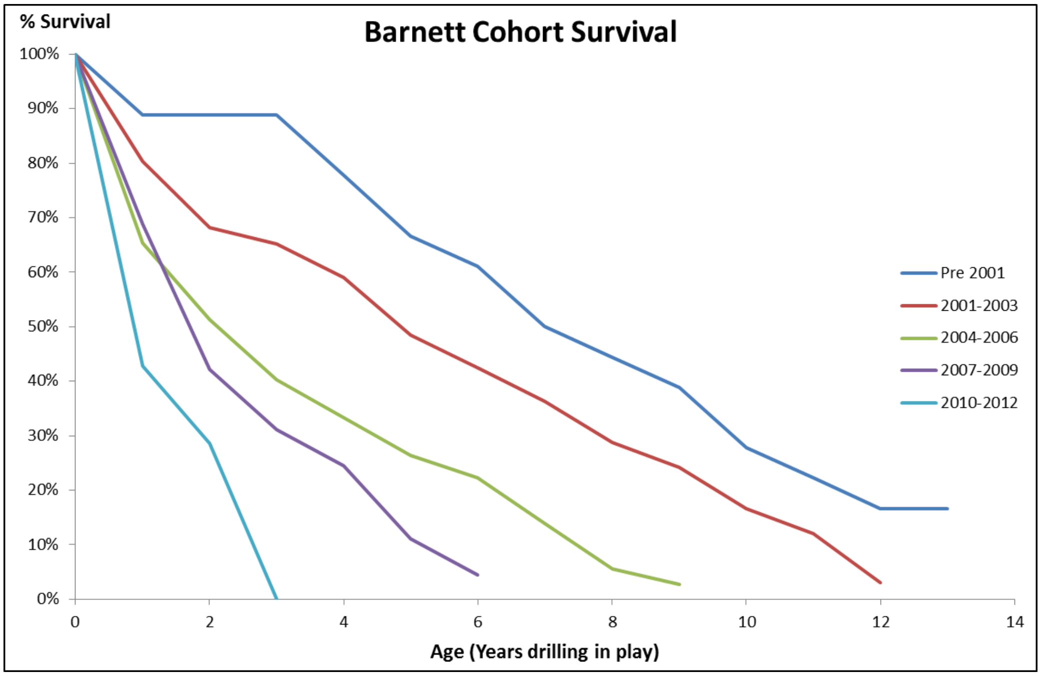

Figure 2-23 Barnett Survival Percentages by Entry Cohort

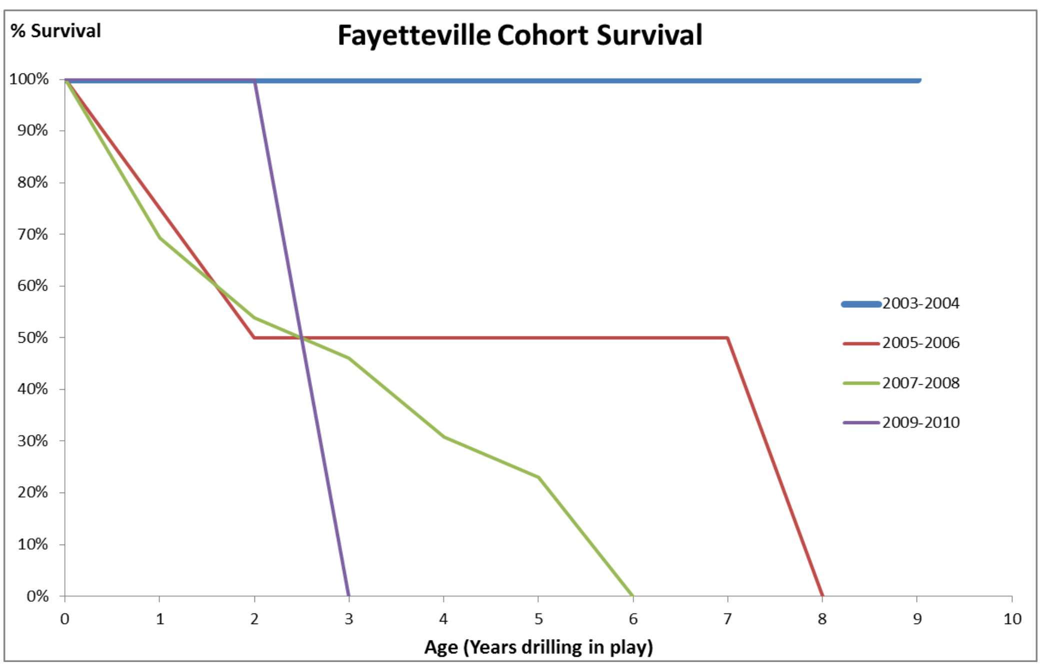

Figure 2-24 Fayetteville Survival Percentages by Entry Cohort

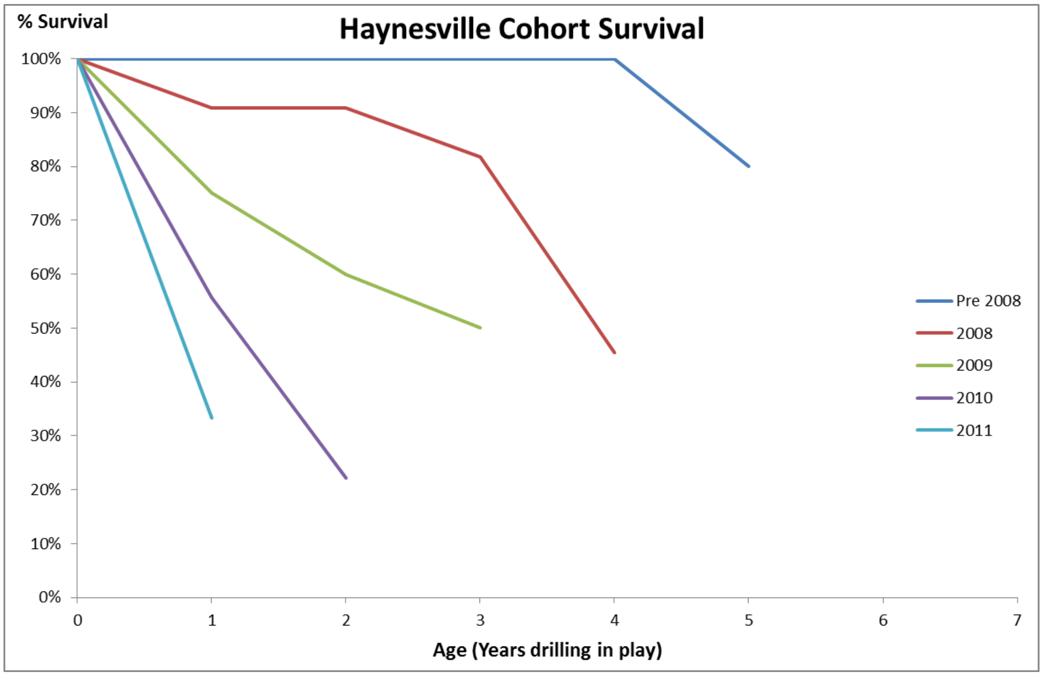

Figure 2-25 Haynesville Survival Percentages by Entry Cohort

To be clear, a firm is considered to have not survived or exited in the year after the last year in which it completed a well. Additionally, it is important to maintain that a non-surviving firm is not necessarily one which failed to make profit and exited the industry at a loss. Rather, smaller firms often sell their business or acreage to larger firms. In such cases, it is not that those firms fail in terms of profitability, but instead cannot generate competitive cash flows from continued operation in comparison to the acquisition offer. Larger firms may also exit when the specific basin position no longer fits their long term asset portfolio. Thus, acquisition-based exits are likewise a result of inability to compete in a maturing play which is a key driver of the shakeout process. Finally, it should be noted that natural gas prices have a significant impact on well economics, and thus may be a major contributor to weak survival rates especially in the Haynesville where natural gas prices below $2.00/mmBtu rendered essentially the entire play uneconomic.

2.2.3.4 Market Shares stabilize

Beyond stabilizing the number of firms in the industry, the shakeout stabilizes overall industry structure in terms of incumbent and fringe firm market share. Looking at the percentages of field-wide daily production accounted for by incumbent and fringe firms where the incumbent firm is considered to be the plays' discoverer. Although in the Barnett, it comes to include the incumbent firm's acquirer beginning in 2002. In each play, the incumbent firms ultimately capture the largest share of a plays production and become the most active driller of wells in the basin.

		Barnett			Fayetteville			Haynesville		
Year	Avg. HH price	Fringe	Incumbent	No. Firms	Fringe	Incumbent	No. Firms	Fringe	Incumbent	No. Firms
2000	4.31	19%	81%	29	--	--	--	--	--	--
2001	3.96	23%	77%	51	--	--	--	--	--	--
2002	3.37	30%	70%	75	--	--	--	--	--	--
2003	5.49	37%	63%	98	--	100%	1	--	--	--
2004	5.90	47%	53%	118	--	100%	1	--	--	--
2005	8.81	60%	40%	151	1%	99%	2	--	--	--
2006	6.75	69%	31%	170	7%	93%	4	--	--	--
2007	6.98	72%	28%	194	25%	75%	14	--	--	--
2008	8.86	74%	26%	197	36%	64%	18	81%	19%	60
2009	3.95	77%	23%	201	37%	63%	20	76%	24%	73
2010	4.39	73%	27%	195	37%	63%	20	75%	25%	76
2011	4.00	74%	26%	192	32%	68%	20	72%	28%	75
2012	2.75	70%	30%	195	29%	71%	20	75%	25%	78

Table 2-2 Annual Incumbent (discoverer) vs. Fringe (all other operators) Percentages of Field Production

Because the number of incumbent firms is fixed over the course of the play, it is obvious that the growth in firm numbers observed in each play is the result of fringe firm entries. Firm counts in Table 2-2 do not match previous operator counts because they are defined as the number of *producing* rather than *completing* firms. Although individual fringe firms typically produce minuscule portions (less than 5 percent) of the total fields' daily gas, the influx of those firms along with the production attributed to some of the large, but non-incumbent firms is strong enough to capture large portions of incumbent market shares. These large firms are often early movers in the play with substantial capital to commence large scale developmental drilling once a play is proven.

The Barnett and Fayetteville have historically shown similar production patterns [Table 2-2]. In the Barnett the incumbent firm and its acquirer steadily lose production share until 2010. Although the shakeout occurred before 2010 in the Barnett, it is reasonable that the shakeout must persist before the incumbent can recapture market share. Moreover, Table 2-1 indicates shakeout with an exiting firm being one who fails to complete a well. A firm who does not complete a well may still produce from its preexisting wells, however. The shakeout therefore precedes a rise in incumbent market share in this analysis. Likewise, the Fayetteville's incumbent firm starts with a 100 percent share of production. Yet, fringe firms erode that share until around 2010-2011 when shares stabilize. Again, that stabilization and reversal of the decreasing trend in incumbent share lags a couple of years behind the shakeout [Table 2-1].

The Haynesville, however, shows a slightly different pattern. Namely, the play's incumbent firm does not start out with as substantial of a share in production for two conceivable reasons. To start, the Haynesville Shale, Cotton Valley formation, and Bossier shale have long been considered a source rock to overlying formations and were known to hold significant accumulations of hydrocarbons (Hammes et. al., 2011). While the Haynesville discoverer unlocked the play's commercial potential in 2007, other companies had been testing the formation, likely attempting to replicate successful efforts in the Barnett and Fayetteville plays. Thus, the incumbent's initial share of production competed with production residual from those previous efforts.

Further, Haynesville wells are extremely deep making drilling costs relatively high compared to those in other shale plays. High well costs pose a barrier to entry and make fringe firms that try to enter less relevant than in the other plays. Thus, companies must be well-funded with significant access to capital in order to pursue Haynesville natural gas. Accordingly, the play's industry structure is composed of more large, but non-incumbent operators who are able to capture upwards of only ten percent of the field's production. By drilling roughly twice as many wells as the next biggest operator, however, the play's incumbent firm was able to account for more and more of production until the major price collapse in 2012, when activity in the play was largely put on hold due to weak economics.

In sum, the Haynesville was in many respects more competitive from its inception. Yet, just as in its predecessor plays the incumbent firm eventually begins gaining back its production share. To that extent, evidence from the Barnett and Fayetteville plays shows that competition may erode the initial market share of incumbents. The eventual shakeout, though, begins to restore and stabilize market shares as the play's industry structure steadies.

2.2.3.5 Competition drives incremental efficiency and process innovations

A play's economic potential and commerciality has been established by the time it reaches maturity through the innovative forces at work in the introductory and early growth stages. However, dwindling inventories of well locations and increased competition incentivize firms to seek efficiency improvements. Furthermore, those firms unable to successfully innovate their processes may well be those who fall victim to the shakeout process as a play's industrial organization stabilizes.

Unfortunately, data pertaining to individual firms' innovative capacity is unavailable here making it difficult to test this hypothesis. Nonetheless, returning to each play's operators' tendency to drill longer wells [Figures 2-15,2-16,2-17] with higher productivity [2-12,2-13,2-14], it is apparent that those operators still active in a play continuously improve their production processes even after the shakeout has begun. Although average well productivity of natural gas in the Barnett shale [Figure 2-12] appears to decline in recent years, that decrease is a reflection of an increased drilling focus in the play's wet (higher liquids content) window. The sharp increase in liquids productivity reflects that development.

2.2.4 DECLINE

2.2.4.1 Production volumes decline

The most obvious manifestation of a shale play's decline can be observed through declining production volumes. As a play's resources dwindle, fewer operators drill wells, and existing wells produce less natural gas, the field's total production will eventually drop as well. That said, production declines will lag behind the shakeout and lower drilling rates given that new wells- even if fewer- will replace production from declining wells especially as well productivity continues improving. In all three plays, even as the number of wells drilled annually has declined, production growth has continued to climb in the Barnett and Fayetteville and stabilized in the Haynesville [Figure 2-11]. In addition to productivity gains, many of the firms falling victim to the shakeout sell their leases to operators who continue to develop and produce from those reserves. As such, the number of producing leases in each play increases even as operator counts fall except for in the Haynesville shale [Figure 2-8].

Haynesville shale wells are extremely over pressured, and therefore demonstrate faster decline rates than those in the Barnett and Fayetteville shales. Consequently, the lag between curtailed drilling and production volumes will be shorter. Given the bottoming out of prices to below $3.00/mmBtu in 2012 and its effect on drilling in the capital intensive Haynesville formation, as well as rapid decline rates, it is no surprise that the play has experienced declining drilling and levelling production [Figure 2-11]. That said, a more favorable price environment could foreseeably entice expanded development and renew production growth.

As noted from Figure 2-11, the Barnett and Fayetteville shales have not exhibited declining production as of the end of 2012. Yet, production growth appears to be slowing in both plays particularly in the Barnett where production growth will likely flatten and begin to turn negative in the near future (Browning et. al., 2013). Because none of the focus plays have shown conclusively waning production volumes, it is difficult to characterize the nature of future decline curves. However, the dashed lines in Figure 2-11 indicate that production growth does slow and appear to flatten towards a decline stage (*e.g.* the Barnett shale), especially if price sensitivities greatly deteriorate a field's well economics (*e.g.* the Haynesville shale).

2.2.4.2 The industry's core assets and activities are threatened

Although a slew of factors (e.g. low natural gas prices, regulation, inadequate midstream infrastructure) may contribute to declining production from a field, another possibility is that well locations in high-quality portions of the reservoir become limited. To that extent, firms tend to drill better portions of the reservoir first, meaning the most economic portions of a reservoir are depleted first. In addition, sizeable shares of a shale play are uneconomic at current natural gas prices. For instance, an average well drilled in the worst productivity tiers of the Barnett Shale will fail to turn a profit at a zero percent IRR, even at historically unprecedented prices of up to $12.00/mmBtu. Given a zero percent IRR, only the best productivity tiers manage to break even in the current price environment (Browning et. al., 2013).

With only portions of a play's acreage posing favorable economics, a basin's most valuable productive assets will eventually exhaust themselves, even given likely reservoir life extension from advancing technology. Turning to historic drilling, operators in each play have drilled well inventories at much faster paces in lower tiers where well economics are more favorable [Figures 2-26, 2-27, 2-28]. As of 2012, operators in the Barnett and Fayetteville shales have drilled over 70 percent of available tier one inventory and 40 and 30 percent of tier two inventories, respectively [Figures 2-26, 2-27, 2-28][13]. On the other hand, over half of inventories in all tiers remain to be drilled in the Haynesville shale where depressed prices have stymied drilling in recent years.

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[13] Inventories of undrilled well locations in each productivity tier are determined by the Bureau of Economic Geology shale gas study according to average well lengths, the plays' geographic boundaries, well-spacing units that reflect reservoir drainage areas per well, and a shape factor that reduces the number of locations to account for impediments to drilling.

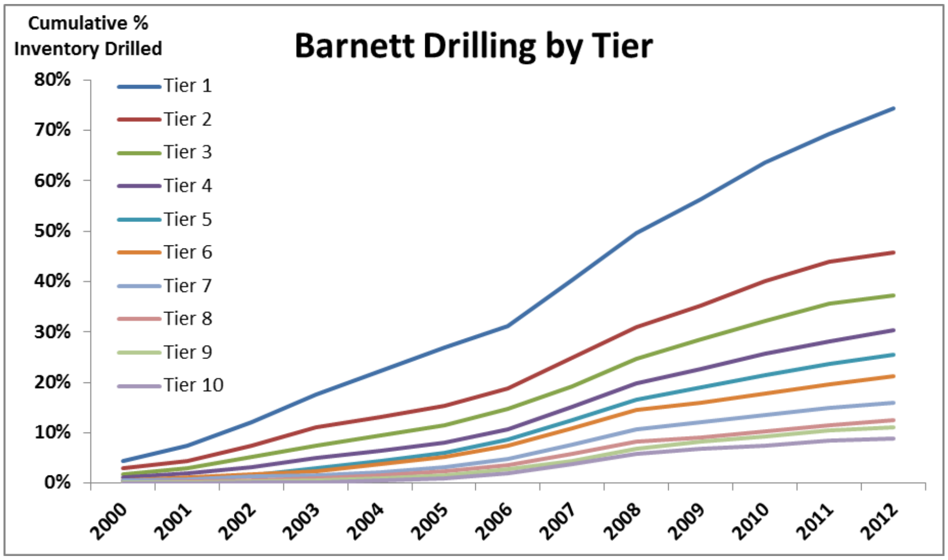

Figure 2-26 Cumulative Percent of Barnett Tier Inventories Drilled

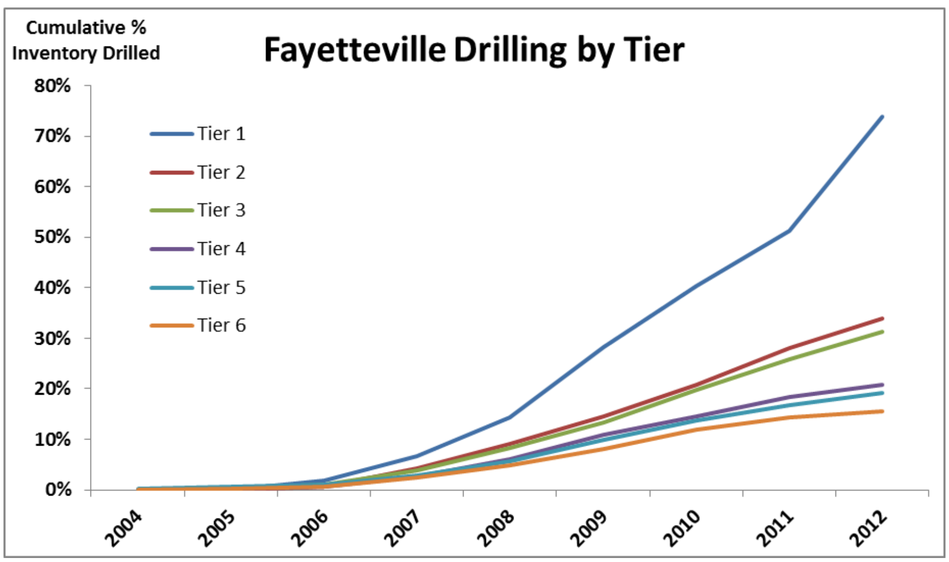

Figure 2-27 Cumulative Percent of Fayetteville Tier Inventories Drilled

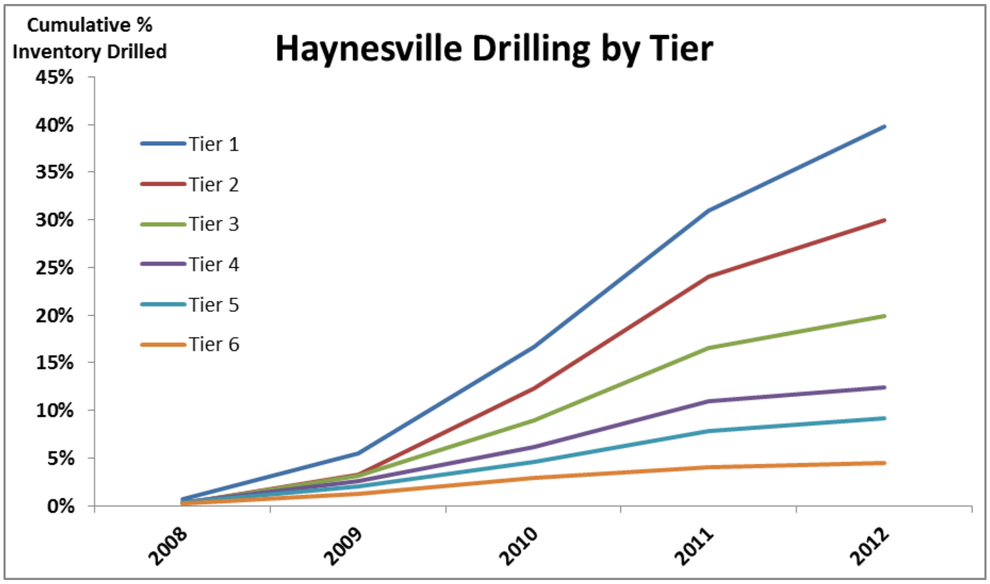

Figure 2-28 Cumulative Percent of Haynesville Tier Inventories Drilled

The above figures indicate that there is a substantial amount of wells to be drilled in the most economic zones of each play. But, the Barnett and Fayetteville charts suggest that the most economic inventories do deplete rapidly as a play develops. With locations left in high quality areas, these plays do not appear to be in decline, but these historical drilling patterns suggest that once a play's economic inventories are depleted the play begins to decline. Fortunately, this can be modeled reasonably well.

2.2.4.3 Degree of decline is variable

If technological advancements were to cease, drilling rates remained constant, and future prices could be predicted with certainty, one could derive a reasonable forecast for a play's decline. But, because these factors are uncertain and none of this work's resource plays have begun a definitive decline, such a projection is difficult. Additionally, the shape of a play's decline is undoubtedly variable depending on individual characteristics, the macro economy, and industry conditions. To that extent, technological advancement and secondary recovery may allow for exploitation of residual resources. For instance, operators have experimented with secondary hydraulic fracturing. Although, the added production volumes do not appear to economically justify the costs in most parts of the play, given today's technology (Browning et. al., 2013).

With respect to a shale gas play, the potential for secondary recovery and technical gain is especially pertinent given the low recovery factors observed in the mid- to low-quality rock of shale plays to date[14]. For purposes here, however, it is not integral to estimate precisely what a decline would look like. Rather, it should be noted that these three plays show the potential for entering a decline phase given weakening production growth, and diminishing inventories of high quality drilling locations.

2.3 Aggregate Shale Industry Evolution

The focus of the analysis has thus far focused on the evolutionary theory as applied to individual shale gas plays. As has been shown, individual plays develop in an anticipated and evolutionary manner, yet the analyses do reveal instances where shale play development deviates from features described in other industries and literature. While these distinctions will be described in the following chapter, it is important to give empirical consideration to the shale gas industry as a whole.

To reiterate the previous discussion of the aggregate shale gas industry, evolutionary theory stipulates that the overall sector can be described as a collection of plays. As such, some of the analyses performed above can be collectivized as a characterization of the entire industry despite the fact that per play characteristics pertaining to geology (original gas in place) and engineering requirements (well costs) prohibit certain cross-play aggregations. Before empirics are presented, however, it should be noted that the industry, as described here, is composed of only three basins. In reality, a number of basins have been explored, tested, and developed. Further, while most of these other basins have not delivered the same magnitude of growth and success as the three focus plays, the Marcellus shale has seen enormous growth in recent years, and has been the target of vast amounts of industry investment. Development in the

[14] Recovery Factor is the percentage of Original Gas In Place that a well ultimately produces from its drainage area.

Marcellus shale, though, has occurred recently enough to limit the amount of data available and is therefore ill-suited to provide deep insight to the present work.

2.3.1 Industry Growth through Reinvestment in Geographic Submarkets

The previous sections described that a shale play experiences a rapid growth phase in which numerous firms enter once the play's commerciality has been proven. Following that influx, mergers and acquisitions, inadequate resource economics, and competitive forces (*e.g.* suppressed natural gas prices) stimulate a shakeout process in which firms exit a play. Of course, some of the firms exiting an individual play will not begin drilling another shale gas formation, but others will do just that. In the context of industry evolution, these are the firms reinvesting in sub-industries that in effect may prop up the total number of drillers in the industry.

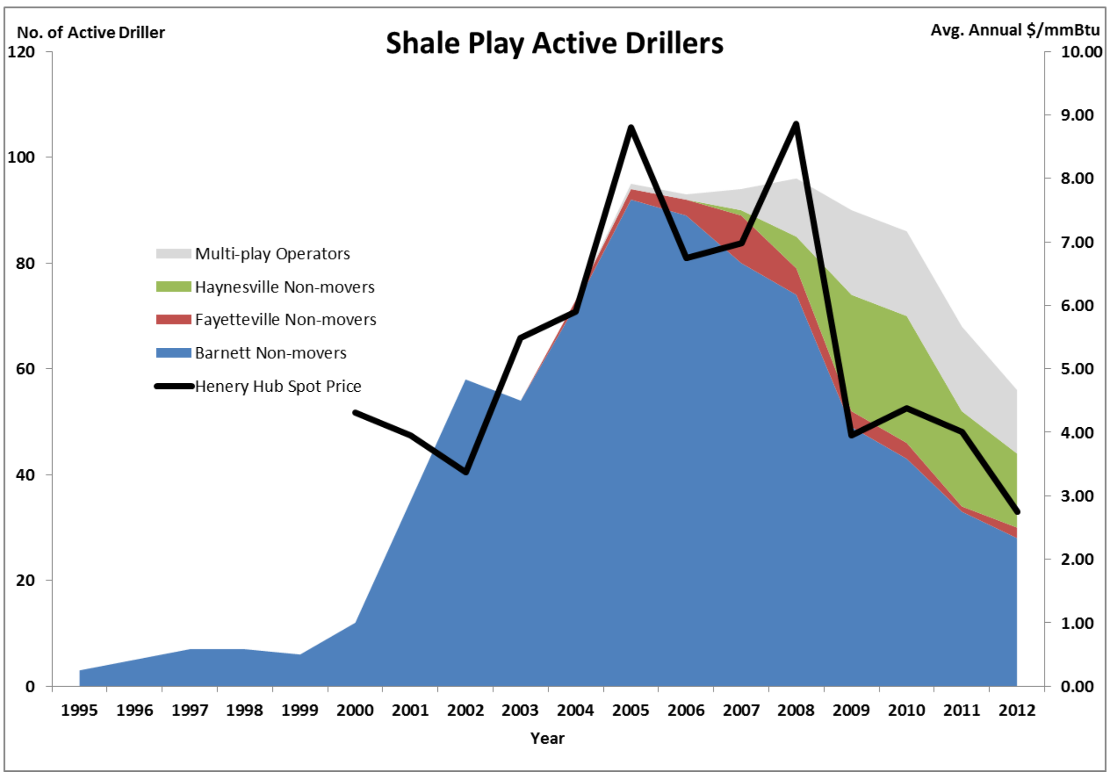

Figure 2-29 Number of Active Shale Gas Operators by Play

Taken together, the four categories shown in Figure 2-29 represents the total number of operators actively drilling in the three focus play with each category representing their respective portions of that total. Moreover, the active drillers in each year are separated in the following manner: Barnett Non-movers only drill in the Barnett, Fayetteville Non-movers only drill in the Fayetteville, Haynesville Non-Movers only drill in the Haynesville, and Multi-play Operators drill wells in at least two of the three basins. Consistent with theory, the number of total drillers continues increasing until 2008 once the Barnett and Fayetteville have begun their shakeout processes at which time multi-play operators and Haynesville Non-movers make up for losses in the two predecessor plays. The post-2008 decline in active drillers does not necessarily indicate industry decline, however. Firstly, the fall in drillers could be the result of price sensitivities in shale gas plays given that average annual natural gas prices also decline during the same period. Second, some operators may merge or be acquired, reducing the number of operators, but not necessarily the drilling activity in a play. Another reason for the industry's apparent decline in drillers is that other plays including the Marcellus shale are not included. For example, 21 operators drilled Marcellus shale wells in 2012.

A key insight of this preliminary analysis of the shale gas industry's structure is that the number of multi-play operators is increasing over time except for in 2012 [Figure 2-29]. Including operators in the Marcellus adds another 4 operators to the multi-play category. Taking into account operators in other plays such as the Utica and Antrim shales would also likely contribute to the multi-play classification. Given that the industry experiences a growing number of diversified operators, evolutionary theory would posit that those operators anticipating decline pursue growth in new geographic areas or expand to another product. That said, postulating the nature of these migrations is beyond the scope of this paper. After all, well-capitalized operators may not be anticipating decline insomuch as they are hedging operating risks by diversifying their assets. Nonetheless, multi-play operators appear to play an important role in floating the entire industry's growth profile.

2.3.2 PRODUCTION VOLUMES CONTINUE RISING AS A FUNCTION OF EMERGING PLAYS

Just as on a per play basis, production does not begin tapering simultaneously with a decrease in the number of firms completing wells due to residual production, increasing productivity, aggregation of firms, and offsetting new wells. Indeed, total production from the three focus plays has climbed each year with signs of flattening only recently occurring in 2012 [Figure 2-30].

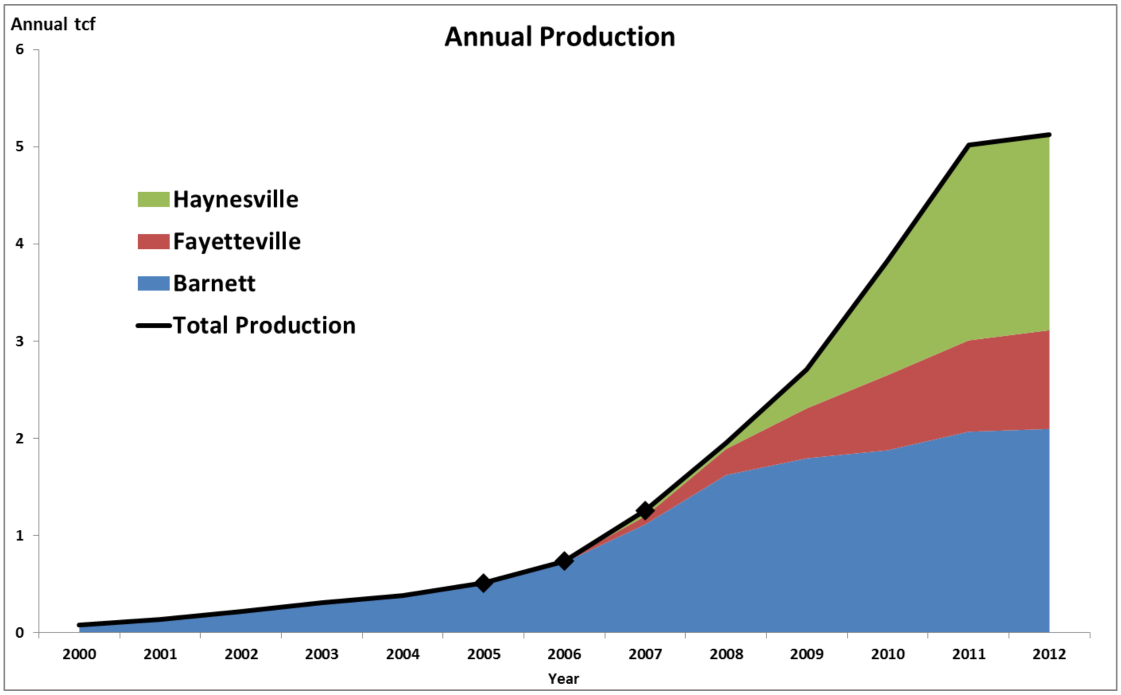

Figure 2-30 Annual Natural Gas Production

The total production line shows three important slope changes each marked with diamonds. First, production growth accelerated in 2005 once hydraulic fracture treatments had been successfully applied to horizontal wells in the Barnett shale in 2004. Not coincidentally, 2004 and 2005 are the years in which operator numbers reignite in the Barnett [Figure 2-29]. The second acceleration occurs in 2006 when operators began ramping up production in the Fayetteville shale. Similarly, the next production boost occurs in 2007 following the discovery of the Haynesville shale. Presuming these three plays represent the entire industry, this crude analysis shows that the industry as a whole is rejuvenated by the emergence of individual plays.

2.3.3 Summary of Analyses

Characterizing the entire shale industry's evolution is intrinsically complicated by macro-economic factors, regulatory environments, social attitudes towards hydraulic fracturing, the state of drilling technology, and other factors. Moreover, corporate strategies vary depending on capital requirements and technical ability. Attempting to describe the interplay of these factors with the formulation of strategy would require extensive examination, and offers intriguing opportunities for further research. In addition, describing the shale gas industry exclusively from the larger shale industry is problematic. Namely, many shale plays produce dry natural gas as well as oil and natural gas liquids. Better drilling returns stemming from more favorable pricing in condensate and oil plays have led many operators to invest in those basins making it difficult to consider the shale gas industry as a collection of only dry gas producers who strategize only to enhance growth through dry plays.

Despite these complications, the evidence presented herein supports the notion that the industry as a whole behaves as an envelope of underlying shale plays. On the one hand, that realization implies that the shale gas industry's future growth is dependent upon the discovery and development in frontier plays. The potentiality of technological innovation may likewise rejuvenate existing plays and the industry as a whole. These hurdles, along with some of the inconsistencies between the shale gas industry and evolutionary theory will be described in the following chapter.

Nonetheless, conceptualizing the industry as one composed of individual plays, each of which will follow an evolutionary path of introductory exploration, growth, maturation and shakeout, and eventual decline may be beneficial for investors, producers, and regulators. For instance, investment dollars may be better spent exploring in new basins rather than obtaining leases in a previously established play given historical survival patterns [Figures 2-23, 2-24, 2-25]. Likewise, regulators should anticipate drilling and production declines when formulating severance tax regimes. As has been shown throughout this chapter, observing the shale gas industry in the context of evolutionary theory provides a useful mechanism for establishing such valuable insights.

CHAPTER THREE: CONSIDERATIONS OF INDUSTRY EVOLUTION AND SHALE GAS

3.1 Industry Evolution in Shale Gas plays

The previous chapter's analysis sought to analogize the development of the shale gas industry and three of its most prominent plays to the theories of evolutionary economics. Of course, no two theories hinge upon the same facets, just as no two plays undergo the same patterns of development. That said, evolutionary economics can be a powerful tool as applied to the shale gas industry. As the analyses have shown, the three focus plays and industry have developed in a manner consistent in many respects to what would be expected in an evolutionary framework.

To start, the shale gas industry's introductory phase spanned more than two decades with government policies as well as entrepreneurial motivation driving the innovative efforts. Eventually, the Barnett shale's discoverer unlocked the commercial potential of the play, without even utilizing the tax credits and deregulated prices offered by governmental policy. As Schumpeter would have predicted, the shale gas industry was given its greatest impetus through internal, profit-seeking innovation.

As successive plays emerged, the magnitude of the innovations necessary to prove their commerciality became less and less. In other words, rather than proving the entirely new concept of hydraulically fracturing a horizontal well in a shale formation, pioneering firms were able to prove that those processes allowed for economic extraction from formations with similar geologic properties to other shale plays. As theory would predict, later plays require lesser magnitudes of innovation, and have shorter introductory stages. Indeed, the Fayetteville and Haynesville plays each demonstrated shorter delineation phases in which the plays earliest developers drilled primarily vertical wells and invested in unproven reserves. Also congruent with theory, the Barnett and Fayetteville shales were discovered and proven by essentially one firm. On the other hand, numerous firms had tested and established small land positions in the Haynesville Shale before it was officially announced by its "discovering" company. In all three plays, however, the first-movers were independent operators with sufficient access to capital, but who were sufficiently small and flexible enough to navigate the risky environment of an emerging resource play. That said, several other shale gas basins were tested and proved to be uneconomic for a variety of reasons, mostly geologic. As such, there remains room for scientific and engineering progress in order to allow for better high-grading early in the life of shale plays. This is especially important as shale gas exploration expands globally.

Following delineation, the industry growth phase of shale plays has historically adhered to that of an evolutionary model. As information regarding a play's productive and economic potential disseminates via investor presentations, earnings calls, academic papers, and industry reports, a wave of typically small operators enter the play by leasing mineral rights on new leases and drilling wells. Naturally, expansion in the number of wells drilled and field production characterize the growth phase of the three focus plays. Moreover, there is not a significant lag between the increase in operators drilling and field production indicating that imitating entry firms quickly replicate the processes of incumbent firms. Heightened competition in each of the plays has another effect common to growing industries which is that incumbent firms lose market share in terms of their stake in field-wide production.

Despite the large-scale innovations of the introductory phase, operators continue to innovate and achieve efficiency gains during the industry growth stage. With more firms drilling increasingly longer wells, and enhanced technical and geologic knowledge triggering increasingly productive well results; growth stage operators in the Barnett, Fayetteville, and Haynesville shales by no means cease their innovative efforts.

Along with increasing operators' motive to improve such operational efficiencies, elevated competition and its effects on lease prices, rig contracts and the like, limit the attractiveness of entry for outside firms. Just as theory would predict, the Barnett, Fayetteville, and Haynesville shale plays each enter a period of negative net entry signaling a shakeout of operators following their growth phases. Moreover, incumbent operators demonstrate better survival rates than the later movers. As in other evolutionary industries, the shale plays analyzed here demonstrate a shakeout of namely non-incumbent firms during their maturation.

Exit and cease-drilling decisions are difficult to quantify, but this analysis clearly shows the survival advantage of earlier-movers. Also, later movers often account for the growth in drilling of low-productivity tiers with lesser average well economics. Along with more experience and technical ability, resource advantages are a likely source for the competitive advantage bestowed on incumbent operators. That being said, fringe firms and late-entrants do capture large portions of incumbent market share. Following the shakeout process, though, incumbents are able to reclaim a small portion of field production as market shares stabilize. Additionally, operators in all three plays continue drilling longer wells and increasing average well productivity indicating that process innovations – driven by competition - do not cease through the shakeout and maturity stage of a play.

Following industry maturation, the play itself can be expected to enter a decline phase. Indeed, each of the focus plays has experienced declining drilling activity in terms of the number of wells drilled annually. Yet, an oversupplied natural gas market and suppressed prices have certainly impacted drilling incentives. Nonetheless, lessening drilling activity would be congruent with evolutionary theory's view of a declining industry.

A common cause of industry decline is that core assets become threatened. To that extent, well economics in each of our plays are heterogeneous with only portions of the reservoir demonstrating profitable rates of returns. In each play operators have focused drilling in those regions effectively decreasing the available drilling inventories of wells in profitable areas. As that trend continues, it is plausible that the plays' most productive assets will become limited and possibly entice substantial decline. However, operators have experimented with technological gains from the likes of secondary fracturing and recovery. These efforts speak directly to the fact that a play's decline is variable and dependent upon the success of such practices.

Clearly, the development of the Barnett, Fayetteville, and Haynesville shale plays has in many respects adhered to the introductory, growth, maturity, and decline stages commonly cited in economic theory and literature. Yet, considering the entire shale gas industry as a collection of these plays echoes the theory that an industry is made up of a collection of "sub-industries." In the case of shale gas, the industry's sub-markets are differentiated by geography as well as product since each play produces a slightly different mix of hydrocarbons that are delivered to distinct local or regional markets. The industry itself may therefore be rejuvenated and achieve new growth through the emergence of new plays or sub-markets via investments by firms operating in the other spaces of the industry. In that light, the number of shale gas producers operating in more than one basin has been shown to increase overtime. Likewise, the slope of the industry's production shifts upward as successive plays enter their growth phases.

The shale gas industry has historically adhered to the principles of industrial evolution as evidenced by the analyses of this work and their summation presented here. On the other hand, a portion of those empirics indicate that the shale gas sector presents unique challenges. Rather than discounting theory, these contests lend themselves to possible stipulations to the theory when applied to shale gas. The relevance of and possible explanations for these deviations are discussed in the following section.

3.2 Diversions of the shale gas industry from industry evolution

The evidence from the shale gas industry presented in the last chapter is not entirely congruent with the theories described in the first chapter. Moreover, inconsistencies are observed in each of the unique evolutionary stages in the plays as well as in the aggregated industry. These subsections elaborate upon the divergences of shale gas development from the theoretical framework.

3.2.1 INTRODUCTION

Industries most often evolve from an introductory phase in which a miniscule number of firms compete in a highly innovative and risky environment. The Barnett and

Fayetteville shales both demonstrated this sort of evolution with one firm being primarily responsible for discovering and proving the plays' economic potential. The Haynesville shale's commerciality was also discovered by one firm. Differently though, other firms had been testing the Haynesville shale prior to that discovery in 2008.

Specifically, IHS production data shows that six other companies completed wells from 2001-2006 prior to the founding firm's first completion in 2007. The activity of those firms is partly reflected by 2005-2006 operator counts in the Haynesville [Figure 2-8]. In addition, the fringe percentage of production begins markedly high in the Haynesville [Table 2-2] due to those operators' production volumes before the play was fully established. At first observation, the existence of operators ahead of the founding firm seems to break the evolutionary framework described in the other two plays. Such testing by operators other than the eventual incumbent, however, is expected given that oil and gas companies with the right risk profile seek to reap the financial rewards of discovering a play. With gas bearing shale formations established as producible reservoirs, it is no surprise that these wildcatters would be testing a formation as well known as the Haynesville. Moreover, as the industry continues to reinvent itself through new plays it may become more common to see more firms testing a play before its eventual discoverer enters the field.

3.2.2 GROWTH

Each of the three focus plays show significant increases in number of firms following their delineation as operators begin recognizing profitable opportunities. Compared to the Barnett and Haynesville plays, though, that increase is noticeably subdued in the Fayetteville shale which was largely controlled by its founding firm. According to IHS production data, that operator has drilled on 53 percent of all drilled leases. Together with the next largest operator, the two firms have drilled 77 percent of all leases. In addition, the Fayetteville shale, with 38 tcf of technically recoverable gas, is a much smaller-scale play relative to the others (Browning et. al., 2014). Comparatively, the Barnett shale is estimate to contain 86 tcf of technically recoverable free gas

(Browning et. al. 2014) [15].With fewer reserves and two firms dominating the field's available acreage, it is apparent that competition in the Fayetteville is less pertinent. That imperfect competition lends itself as an explanation for the play's shallower and less significant growth in operator counts.

Another discrepancy that has been mentioned previously is that the metrics used to depict each play's growth fail to account for lags between entry decisions and the completion of wells. That analysis includes the number of wells and leases drilled, the number of companies actively drilling, and field-wide production. Of course, the upward trajectory of those variables indicates a growth phase. Yet, their timing may be misconstrued. For instance, the growth phase in terms of entry decisions would actually occur up to a year earlier. Doing so would require looking at the number of leases outstanding rather than those drilled. With that data being limited, it is important to maintain that operators cannot immediately drill on as many leases as they likely acquire. That notion, however, may be clouded by the potential for joint venture, farm-ins and the presence of small operators who may own a small number of leases with the goal of being acquired rather than developing reserves. The current study is limited in its ability to account for these potentialities, yet recognizing their existence helps explain the lack of any lags between firm entries, leases, and production volumes.

3.2.3 Maturation

Rather than a smooth deceleration of entry rates, the three focus plays demonstrate oscillating entry rates leading up to their shakeouts [Figure 2-22]. Cluster entries are entirely possible in competitive industries, and certainly seem plausible here as drilling obstacles arise and limit entry (Argenziano and Schmidt-Dengler, 2014). The alleviation of such obstacles then reopens entry prospects. Further, the volatility of entry rate declines through the shakeout process indicating the sort of stabilization often described by theory. Differently, the shakeout seems to continue as seen by persistent

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[1515] Technically recoverable reserves are those hydrocarbons which can be exploited with current technology regardless of what sort of returns they may generate.

years of negative net entry [2-1]. Rather than each play “shaking out” and reaching a steady number of firms which would be characterized by close to zero net entries, each play has demonstrated more or less increasingly negative net entries following the shakeout.

More than one explanation for a continuous shakeout is immediately evident. First, natural gas prices have a significant impact on well economics (Gulen et. al., 2013). Thus, the collapse of natural gas prices in 2009 and then again in 2011 [Figure 2-4], may have destroyed returns for operators and caused an exaggerated shakeout process. That possibility raises an important point: natural gas is priced regionally (not globally fungible) and thus the shale gas industry is capable of oversupplying natural gas markets and suppressing prices. In such an environment, it can be expected that firms with inferior economics will continue exiting a play or pursue target formations with better priced liquids. The potential for LNG exports and rising demand may fundamentally change such market dynamics, however. Additionally, operators developing reserves continuously deplete their asset base. After sufficient development, operators may have very little inventory left or may be unable to generate sufficient returns to continue operations. Moreover, many firms will opt to sell their leasehold for a higher value than they expect to reap from future drilling. In sum, low prices, sensitive economics, competitive acquisitions, and depleting reserves may each offer insight into why the shakeout process has been more persistent in shale gas plays than in many theories of industrial evolution.

Evolutionary theory often predicts that incumbents possess large competitive advantage over later entrants. An obvious expression of that advantage is the better survival rates of incumbents in each play [Figures 2-23, 2-24, 2-25]. In the case of a shale gas play, it would therefore be logical that a major component of that advantage is the higher quality acreage positions held by incumbent operators. In that light, the incumbent firm in the Fayetteville shale is responsible for the majority of high productivity tier drilling [Figure 2-20]. Incumbents in the Barnett and Haynesville shales, on the other hand, account for the majority of high-quality drilling early, but as the plays mature those portions decline [Figure 2-19 and 2-21] signifying that incumbents do not necessarily maintain overwhelming resource advantages, especially in more competitive plays than the Fayetteville shale. Contrarily, lower-quality tier drilling growth is primarily through non-incumbent firms in each play which indicates the lesser resource positions of those firms. Given that incumbents also drill low productivity tier wells, though, and that drilling in all years is concentrated in higher-quality tiers, low-quality tier drilling is likely the end result of lease maintenance, acreage delineation, or tax incentives. For instance, intangible drilling costs are tax deductible and tax allowances are often granted to unconventional wells. For these reasons, operators may drill poor wells in poor areas in order to realize favorable tax treatment. All said, drilling charts seem to show a resource advantage in the Fayetteville shale, but fail to clearly demonstrate the same in the other plays [Figures 2-19, 2-20, 2-21]. That ambiguity, along with the clearly better survival patterns of incumbents, suggests that technical superiority accounts for a significant amount of incumbent advantage.

3.2.4 Decline

It has been noted throughout this work that the decline of a shale gas play is likely to be highly variable, subject to change, and has thus far not begun. To date, each of the shale plays studied have experienced a decline in number of wells being drilled annually and number of producers drilling those wells [Figures 2-9 and 2-11]. According to theory these falloffs would seem to signal a decline in production. But, the Fayetteville and Barnett plays display continued field-wide production growth, and the Haynesville shale has just recently displayed a leveling in production [Figure 2-11]. Productivity and decline rates likely describe this divergence. First, well productivity in terms of average first 12 month gas production in every play has continued to increase in each play except in the Barnett where operators have focused drilling in wet areas of the play. Although fewer wells are being drilled, the fact that production has resisted decline indicates that those wells that are being drilled, albeit fewer, are productive enough to replace declining production from existing wells. Thus, technological improvements and productivity may prolong production declines in a shale play.

As has been noted, the Haynesville is the most price sensitive of the three basins. As such, operators experiment less with pulling more natural gas from the formation and more on how to do so economically. Because natural gas prices have been prevailingly low, however, many operators have also either curbed drilling efforts or focused capital dollars on higher return projects. Rising natural gas prices may create a sort of renaissance in drilling activity that could reverse the course of field-wide production deterioration especially in more price sensitive plays like the Haynesville shale. Again, these issues render the decline phase the most difficult to describe in the context of evolutionary theories of an industry.

3.2.5 Aggregate Industry

Describing the entire shale gas industry is subject to many intricacies. Despite the utility of conceptualizing the industry as an amalgamation of individual plays that each adhere to the evolutionary path described in this paper, consideration must be given to the factors that perturb that analysis. Most notably, shale plays and the shale industry are extremely price sensitive. In recent years that sensitivity has led many firms to focus their capital expenditures on liquids-focused plays, given a low natural gas, but higher oil and liquids price environment. With investment dollars flowing into wet plays rather than shale gas plays, the shale gas industry would naturally show signs of decline. Yet, revitalized natural gas prices could easily change this course as returns from dry plays would better compete with those realized in oil-bearing shale formations. Additionally, multi-play operators are becoming more and more prominent within the industry [Figure 2-29]. Thus, examining the strategic decision making of these firms' capital expenditures would be necessary to wholly describe the industry's organization at any given point in time. Doing so in a quantitatively rigorous manner is undoubtedly difficult.

Another difficult task presents itself in distinguishing the risk profiles of incumbent discoverers firms. Congruent with theory, the analysis of this paper has shown that the emergence of new plays helps fuel industry-wide growth, and is largely the result of exploratory efforts from independent, risk-tolerant operators. Not only is assigning risk tolerances to individual firms problematic, but the risk perception of frontier plays is also unclear. While risks will always be involved in up-and-coming plays, industry players may come to relax their views on those risks. In such a scenario, major oil corporations may begin to target undiscovered shale plays as a mechanism for reserve replacement. If industry develops in such a way, the evidence provided in this study, and shale plays' propensity to follow an introductory phase in which smaller players delineate new plays must be revisited.

Notwithstanding these caveats to the theory of industry evolution's application to the shale gas industry, this work has shown its usefulness in describing the U.S. shale gas experience to date. Moreover, these stipulations provide avenues for continued research on firm behavior, price effects, and the inclusion of shale oil plays to shale gas investigations. Beyond unveiling these opportunities, the last chapter's analyses and this chapter's discussion have a host of implications to the future of the shale gas industry both in the United States and worldwide.

3.3 Further considerations and implications

The core of this thesis describes the evolution of the U.S. shale gas industry via an in-depth assessment of three plays. Through that work it has been shown that evolutionary economics are a powerful tool for explaining the sector's development and current state. An obvious implication is to apply the same principles to a forward-looking narrative of the industry, which would be valuable to a host of industry constituents. For instance, midstream pipeline contractors can use this analysis to inform their strategy in drawing up new contracts in shale plays. Given weak survival patterns of non-incumbents and poor economics in substantial portions of shale plays, those firms are best served to enter agreements with incumbent operators drilling in highly productive tiers in order to ensure volume and counter-party certainty. Similarly, water regulators can expect rapid growth in fracturing water demand as a newly proven play rapidly expands, but for that demand to stifle in low price environments or once a play undergoes shakeout. So too should policy makers deciding upon LNG exports anticipate the contributions of innovative firms and technological advancement to the supply side of the North American natural gas market.

Although such implications are bountiful, the past should not be taken to fully describe the future given the range of uncertainty regarding the future of shale gas development. Uncertainty stems from numerous sources, some of which are described here. First, LNG exports from the U.S. could positively impact domestic prices as well as benchmark global natural gas prices away from their oil-price indices and to the price at Henry Hub (Wang et. al., 2014). Public opposition and environmental concerns may pave the way for regulatory reform, as well. These issues include the possibility for potable water contamination, increased methane emissions, and induced earthquakes related to disposal of produced water. Regulations aimed at curbing these externalities could increase well costs by up to 7 percent (Wang et. al., 2014). Obviously such regulations could drastically change operator economics, and their potential should be given consideration in industry forecasts.

Another question facing industry is how and when shale gas development will expand beyond the United States. China, Mexico, Argentina, and Poland are among a slew of countries assessing their shale gas potential (Wang and Krupnick, 2013). Although many aspects of evolutionary theory may apply globally, this thesis has described the experience of the U.S. To shed light on global shale gas potential it is important to consider the gamut of factors that led to success in the U.S. and whether or not those factors are present elsewhere. For instance, the United States allows for private mineral rights ownership. Under that system, companies are able to lease land at low prices and sell later at high prices that compensate for them for establishing the technical ability to exploit reserves. Where private ownership is limited- as it is in most of the world- companies will have a harder time monetizing their technical ability (Wang and Krupnick, 2014). Furthermore, the U.S. had encouraged shale gas development for decades leading up to the last decade’s expansion in the industry through research and development programs and price incentives. The effect and existence of such policies along with geologic characteristics, infrastructure capacity, etc. are essential in determining the potential for shale gas exploitation outside of North America.

These possibilities and their prospective impacts on the future of domestic and global shale gas development undoubtedly warrant further research. In conjunction with the evolutionary framework shown to describe much of the U.S. shale experience, that research would be valuable to industry players, policy makers, and planners speculating the future of the industry. Yet taken by itself, industry evolution and its application to the shale gas sector is best used as a mechanism for describing the past and what may occur moving forward.

3.4 Conclusions

The shale gas industry in the U.S. has undergone swift growth since the turn of the century leading to a plethora of research concerning its development and what sort of factors led to its expansion. These studies have described economic, political, and technological environments, but often fall short in providing data driven analysis of the industry. This work not only serves to bolster that research with empirical evidence, but also to demonstrate the usefulness of evolutionary economics in describing the historical development of the industry.

Utilizing completion and production data from individual wells as well as the analysis conducted by the Bureau of Economic Geology's shale gas study, three of the most pertinent shale gas plays in the United States were shown to demonstrate several qualities of an industry following an evolutionary pattern. Namely, the Barnett, Fayetteville, and Haynesville shale plays have each undergone introductory, growth, and maturation phases in addition to revealing signs of what may characterize a shale play's decline. Through that analysis, it is evident that incumbent operators and a play's discoverer are the most likely to survive a shakeout process due to some combination of resource and technical advantage. That said, the collapse in natural gas prices due to an oversupplied market has had a negative impact on drilling economics, and certainly contributed to some of the trends apparent in the three plays.

Although operator counts, drilling activity, technical progress, and production volumes have progressed by and large as theory would predict, the three plays studied in this analysis have demonstrated certain discrepancies. In addition to providing the base for further research, these inconsistencies demonstrate the multi-faceted nature of a shale play's development. Each shale play offers a unique geologic setting in which operators must optimize completion techniques and development patterns. Economically, basis differentials, water access, and takeaway infrastructure all impact drilling economics and returns. Given these variables, each play poses a distinct operating environment. Necessarily, each shale gas play must be given unique consideration. Nonetheless, evolutionary economics sheds valuable light on the developmental path of the focus plays to date. Taken together, the shale industry can therefore be effectively conceptualized as an envelope of individual plays or sub-industries each of which undergoes the distinct phases described in evolutionary economics and resource-based theories of the firm.

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