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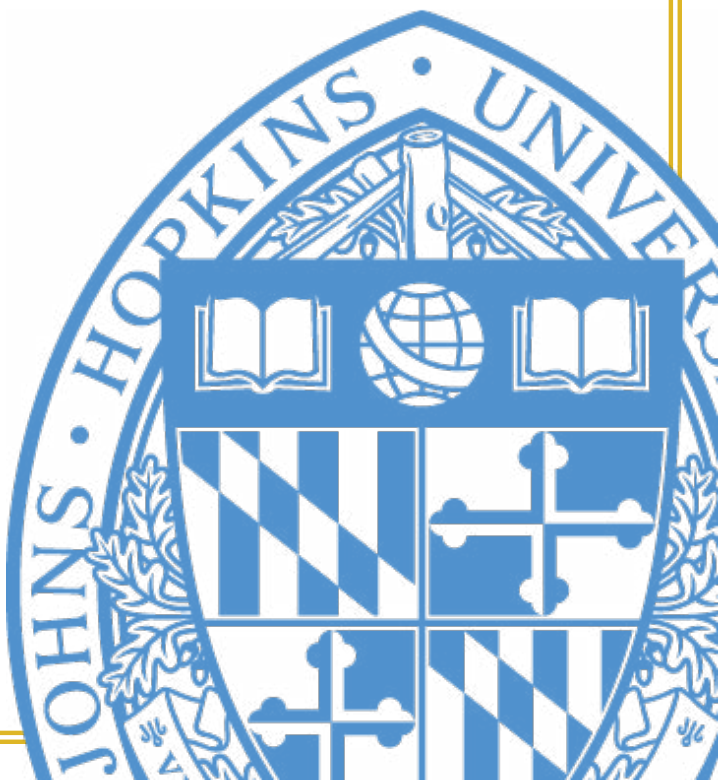

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Entrepreneurial Multipliers: The Long Sequence of Oil

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"Entrepreneurial multiplier" is an interesting phrase in search of meaning. From the Great Entrepreneurs of the late 19th century to the start-up companies that have been the backbone of local economies, entrepreneurship has been a hallmark of the American economy. Beyond Schumpeter's powerful concept of "creative destruction" and engaging personal stories of individual entrepreneurs and their companies and innovations, what can business historians add to our understanding of the economic and cultural impacts of entrepreneurship? Can we find better ways to measure and analyze these impacts as they ripple through the society, as economists have used the multiplier effect to measure the impact of investment dollars as they ripple through the economy?

The Extreme Case of Oil

Oil in the United States presents an extreme case of the broad, cascading impacts of entrepreneurship. As in other natural resource industries, major oil discoveries have created booms that attract ambitious people and generate capital for start-ups. Oil booms have been hotbeds of entrepreneurship for more than a century, and as individuals have taken advantage of these opportunities, a culture of risk taking has developed in the industry and in regions in which oil is a powerful economic force. From Rockefeller to the present, successful oil companies have developed corporate cultures that emphasize innovation, and these companies have

carried across generations innovative ideas about technology and organizational structures.

Entrepreneurial enthusiasm has shaped the development of the oil industry, and it is logical to start the search for entrepreneurial multipliers at the beginning of oil production, the drilling of oil wells. My research focuses on three oil booms in U.S. history: the years after the discovery of the Spindletop gusher in 1901, the move offshore after World War II, and the recent breakthroughs in the production of shale gas and oil. Throughout this history, there is a record of innovation with strong connections across generations. Engineers and scientists have worked at the margins of proven technologies to adapt and extend innovations from the past to meet changing conditions. It is foolish, however, to think that entrepreneurial multipliers will stay neatly contained within drilling or any other single segment of an industry. Once unleashed in a dynamic industry, innovation will tend to spin outward as knowledge from the original innovation points to related opportunities. Expanding networks of entrepreneurs in search of new opportunities have shaped the sustained expansion of oil production and use.

After Spindletop: Local Start-Ups Become Global Powerhouses

The discovery of the giant Spindletop gusher near Beaumont, Texas, at the turn of the twentieth century marked the birth of the modern oil industry. The resulting oil boom drew to the region would-be Rockefellers from around the nation and the world. They quickly spread throughout Texas and adjoining states, finding the major oil fields that made the southwestern United States the global center of oil production for almost half a century. In Rockefeller's era in the late nineteenth

century, oil had been used primarily as an illuminant; after 1901 it grew rapidly as a source of energy, steadily displacing coal in transportation and other markets. The flood of oil from the southwestern U.S. in this era encouraged the ascendance of gasoline-powered automobiles over vehicles fueled by steam or electricity. A booming auto-steel-oil-related complex of industries became the heart of the mid-twentieth century American economy.

The Spindletop discovery provided the key ingredient for entrepreneurship: ample opportunities for ambitious individuals to better their station in life. In a society that encouraged migration and preached upward mobility, the population of the Beaumont region quickly surged from about 10,000 to as many as 50,000, as people streamed into the region in search of their main chance. The prevailing poverty in the broad agricultural region in the hinterlands of Beaumont pushed many away from the farms; the excitement and the new possibilities presented by the oil industry pulled migrants toward the oil fields. The risk-taking culture of the oil industry along with the boom mentality of the time and place encouraged the creation of hundreds of new companies to serve the needs of the region's new industry and growing population. Stores, oil supply companies, bars, construction companies, food providers, and other local concerns of all sorts sprang into being. Although many of these start-ups did not long survive, they gave the region an entrepreneurial tone while whetting the appetite of many failed hustlers to do better the second time around.

No new Rockefeller emerged from Spindletop, but several of the individuals who later created Humble Oil entered the industry there, failed, and then used their

experience in Beaumont to regroup and organize a successful venture in the Humble field north of Houston. Lessons from their early experiences at Spindletop helped them make Humble Oil a success, and after Standard Oil of New Jersey acquired Humble in 1919, these veterans of Spindletop played central roles in the subsequent success of Standard of New Jersey.[1]

Legal and regulatory realities in early twentieth century Texas encouraged entrepreneurship. The rule of capture shaped the rapid expansion of oil production by forcing each person who had access to the field to pump oil out as fast as possible, since his neighbors were draining the same field. The ownership of subsoil rights by landowners also lent a sense of urgency to the acquisition of leases. Those who owned land owned access to the oil lying underneath the ground. The race of landowners to cash in their land forced oil companies to move quickly and decisively to acquire leases amid great uncertainty. The legal environment in Texas—as in the U.S. as a whole—thus encouraged a frenzied form of entrepreneurship in oil that fostered the very rapid expansion of oil production, along with the waste and environmental damage that accompanied it.

The Texas state government, however, dampened the enthusiasm of one significant competitor, the Standard Oil Company. Fearing the dominance of "the Octopus," state authorities protected space for local entrepreneurs in the early Texas oil fields by passing an anti-trust law that banned vertically integrated companies from operating in the state. By enforcing this law against companies thought to be affiliated with Standard Oil, but not against the major Texas companies created at Spindletop—notably The Texas Company and Gulf Oil--state

government encouraged local interests to expand. Both regulation and promotion have marked the history of government in the U.S. economy, and in the formative years of the southwestern oil industry, government promotion of local entrepreneurs spurred regional economic growth.

One of the most successful of the local entrepreneurs was Joseph Cullinan. While previously employed by Standard Oil, Cullinan had witnessed the extraordinary efficiency of Rockefeller's epoch-defining organizational innovation, vertical integration. As the first president of The Texas Company, Cullinan created an outstanding new company by piecing together a mini-Standard Oil, complete with its own production, refining, transportation, and marketing. His most important innovation was the creative marketing of oil as fuel. By aggressively pushing the superiority of oil over coal, he quickly convinced major energy users on the Gulf Coast to substitute lightly refined crude oil for coal in fueling railroads, breweries, sugar mills, power plants, and other enterprises.[2] The success of oil in regional markets began a century-long process in which oil gradually displaced coal in national and international markets. The rise of oil as fuel altered the trajectory of risk-taking regional companies, which responded quickly and creatively to new opportunities presented by fuel oil. Regional railroads quickly benefited from the use of this more efficient and less expensive fuel while also profiting from diversification into the production and transport of oil. Major law firms in the region followed their long-time railroad clients into local and then national oil markets, opening for themselves much broader economic horizons. The availability of oil for fuel led to far-reaching improvements in numerous other leading industries, a

process best symbolized by the fact that diesel ultimately became the fuel of choice for the long unit trains transporting coal throughout the nation.

More than a few new local companies emerged to exploit a special skill or a useful innovation needed by the oil industry.[3] Two enduring examples illustrate the entrepreneurial multiplier at work in the oil tool and service industries in the southwestern United States in the early 20th century. The first of these was the work of Howard Hughes, the co-founder of Hughes Tool, which evolved into one of the most significant and innovative manufacturers of drill bits in the world. Hughes, a Missourian by birth and a lawyer by training, left a career in mining for the lure of Spindletop. He took a variety of jobs, working at times as a wildcatter. In the southwestern oil fields, he saw first-hand a pressing need: better drill bits to go deeper into the earth while penetrating harder rock. His innovative design for the "Hughes Rock Bit" quickly proved superior to existing bits, and he organized a Houston-based company around the patent for this design he received in 1909. By World War I, Hughes Tool operated the largest manufacturing complex in Houston. Hughes took pride in his company's commitment to innovation: "We purpose never to be satisfied but will continue, with the help of our experienced engineers, to anticipate requirements of the drilling industry." He created what he called a corporate "culture of continuous improvement in bit technology" to foster the innovativeness that kept Hughes Tool (now Baker Hughes) among the leading oil tool companies in the world.[4]

Cameron Iron Works (now Cameron International) was another local oil tool company that successfully responded to the needs of the regional oil industry.

James Abercrombie, a man of broad experience in the region's oil fields, purchased a share in a local metal repair shop so he could repair his own drilling rig. The spectacular blowout that created the gusher at Spindletop had sent a clear warning of the need for better methods to contain the power of oil and gas under pressure in the southwestern oil fields, which were much larger than previous fields discovered in the northeastern United States. After witnessing danger, destruction, and death on the derrick floor from blowouts, Abercrombie sketched out a design for a mechanism capable of stopping run-away wells. He then enlisted the aid of others in his company to build a prototype of his device, turning to the nearby metal works of his friend Howard Hughes to cast the mold for his new, improved blowout preventer [BOP]. As at Hughes Tool, Cameron Iron Works made a long-term commitment to in-house research and development to maintain global leadership in the development of BOPs and other equipment used in oil fields. Throughout the twentieth century, this Houston-based company remained at the forefront of innovations in BOPs for use in response to different conditions around the world.[5]

Other oil tool and service companies emerged from the subsequent booms in the Southwest and West. Two of the most successful of these, Baker Tools (which originated in the early California oil fields) and Halliburton (originally an Oklahoma-based company) prospered by developing equipment that improved the efficiency and safety of drilling. Once successful in a single product line, each gradually diversified into other related products. Like Hughes Tool and Cameron, they capitalized on their early leadership in oil tools and services by improving their

products and adapting them to meet new challenges confronted by the oil industry as it moved into deeper drilling in harsher environments around the world.

From the 1980s forward, waves of mergers and acquisitions left an oil tool industry dominated by a handful of giant, century-old, global companies with deep roots in the early southwestern oil fields. For almost a century, these firms had fostered urban-industrial growth in and around Houston, helping create the conditions in which new local enterprises of many types thrived while steadily transforming the Southwest from an agricultural/commercial economy to an industrial powerhouse. Regional banks--old and new--surged forward with the oil industry. By the 1930s, a substantial glut of oil dramatically lowered its price, threatening the health of the industry and the southwestern economy as a whole. In this moment of crisis, an unusual but effective, network of banks, state and federal regulators, and professional petroleum engineers came together with an innovative set of policies to stabilize oil prices and conserve oil in the ground. In a startling act of political entrepreneurship, regulators in the Southwest created the legal authority for states to limit oil production under the umbrella of federal power over interstate oil transportation. Petroleum engineers brought to the table their growing technical capacity to predict more accurately the amount of oil that could be recovered from a field, and regional bankers used the work of these engineers to "invent" creative new loans that for the first time allowed companies to use oil in the ground as security for loans.[6] Around such specialized oil and gas laws, corporate law firms in Houston and Dallas evolved from local concerns into highly specialized, globally active firms. They forge new bodies of oil law and helped create the legal and

regulatory framework that fostered the emergence of a modern natural gas industry in the United States in the 1940s forward.

In these and other areas of the oil and gas economy, the entrepreneurial multiplier was at work throughout the Southwest. For almost a century, start-up companies emerged from the rapidly growing oil industry. More than a few survived and prospered by nurturing entrepreneurial corporate cultures with the innovativeness needed to satisfy the oil industry's evolving demands for improved technology to succeed in harsher drilling environments.

Offshore Oil: New Opportunities for Entrepreneurship and Innovation:

As it emerged from World War II, the oil industry had an impressive tool chest for finding, producing, refining, and transporting oil. Improved seismic equipment gave geologists much better data for exploration. Independent producing companies joined the major vertically integrated companies in a highly competitive push to discover and produce new reserves. Oil tools and services firms had matured, becoming more like partners than service providers to major oil companies. Increasingly sophisticated refining technology produced more and better refined products from each barrel of crude. A well-developed oil pipeline system that had matured steadily in the first half of the twentieth century stood ready to move crude and refined products.

The technology that allowed these pipelines to transport crude oil, refined products, and later natural gas over longer distances had been developed by both large oil companies and independent companies spun off from them. Improvements in pipeline transportation tied together much larger markets and made possible

safer and cheaper transportation over more difficult terrain, producing a wave of entrepreneurial multipliers that transformed an entire sector of the oil and gas industry. Their lasting impact included the connection of large supplies of natural gas in the Southwest with large sources of demand for natural gas in the Northeast. The result after World War II was one of the most far-reaching episodes of creative destruction in energy history, the rapid decline of the well-established coal-gas industry with the coming of natural gas to northeastern markets. Houston-based natural gas transmission companies—notably Tenneco, Texas Eastern, and Transco--led the charge into the Northeast, adding a new layer of dynamism to the Houston region's economy, which became the natural gas capital of the U.S. The nation as a whole benefitted from the rapid development of a new network of entrepreneurship that arose to supply the needs of the national natural gas industry.[7]

The maturing onshore oil and natural gas industries were well prepared to take the giant step into offshore exploration and production in the Gulf of Mexico, [8] where new supplies of oil and gas awaited production and transportation into a rapidly expanding national pipeline grid. Surging demand for natural gas and refined oil products in the post-war years fed the enthusiasm for offshore drilling.

National and regional culture fostered the move offshore. Millions of veterans returned home eager to get on with real life. Military training in electronics, metal work, communications, bridge building, equipment operations and repair, diving, weather forecasting, and numerous other skills prepared them for work in the oil industry. The prospect of helping open a new frontier in the oil industry held special appeal to many of the former soldiers and war-industry

workers on the Texas-Louisiana Gulf Coast. In the relatively poor coastal communities of Texas and Louisiana, as well as in rural areas in the interior of these states wracked by a quarter of a century of agricultural depression, ambitious people accustomed to hard times and hard work eagerly embraced the abundant opportunities offered by the new offshore industry.

In the initial projects in the Gulf of Mexico before World War II, oil companies used onshore equipment and technology to build wooden platforms for drilling and production in shallow water. Then in the late 1940s, numerous companies experimented with new technology as they plunged deeper into the Gulf. The pioneering offshore companies had plenty of technical and financial challenges to overcome, but their key problem in the formative years offshore was the development of mobile drilling equipment. Without new ways to explore for oil, offshore drilling costs would remain much higher than costs onshore, where equipment could be moved to new locations in the event of a dry hole. This new frontier for drilling proved particularly attractive for entrepreneurs. Since no proven design for mobile drilling vessels or platforms for offshore drilling yet existed, no established companies had a head start in this emerging new market.

Local entrepreneurs quickly responded with a wide range of extraordinary innovations in the years after 1945. Practical minded engineers, trained primarily in state universities and the armed services, built successful companies providing drilling equipment and related services suited for varying depths of operations. In the 1950s, a flurry of activities sent entrepreneurs in various directions in their search for mobile drilling systems. At first, major oil companies including Humble

(an affiliate of Standard of New Jersey) and Magnolia (a Mobil Oil affiliate) built larger, more expensive versions of the permanent production platforms traditionally used in wetlands, lakes, and bays. These platforms provided sturdy facilities for exploratory drilling, but they could not be moved in the event of a dry hole. A less expensive and more flexible alternative proved to be the "small platform with tender." Brown & Root, a diversified, Houston-based construction firm, and New Orleans-based McDermott took the lead in developing this approach to offshore drilling. In these years, war surplus landing crafts could be purchased cheaply and stripped down and converted into large storage areas that could be towed offshore and tethered to small platforms with sturdy chains. Thus situated, they could be used to house drilling equipment, supplies, and even living quarters for workers. If exploratory drilling found oil, a permanent production platform could be built; if not, the tender could be moved to a new drilling site and the small platform could be salvaged, greatly reducing the cost of exploratory drilling. This innovative, relatively inexpensive approach played a significant role in early offshore drilling in the Gulf of Mexico, filling an important gap in equipment as others developed more sophisticated drilling systems.

Local entrepreneurs developed a range of approaches suited for particular water depths. In very shallow waters, pontoons on "submersible platforms" could be flooded with water, lowering the platform as much as forty feet to the ocean floor for drilling; when the work was done, the pontoons could be emptied to bring the rig up off the floor to be moved. Pioneers in this early form of offshore drilling included Louisianans John Hayward and Alden "Doc" Laborde, two pioneers in the

offshore industry who helped created the company that grew into ODECO, a long-time leader in the industry.

For deeper waters up to about 350 feet, "jack-up" rigs, pioneered in part by President George H.W. Bush and the Zapata Oil Company, could lift the drilling deck above the sea by jacking the legs of the rig down to the ocean floor. For still deeper waters, a variety of designs mounted rigs on drilling vessels large enough to move back and forth to a drill site under tow or under their own power. A big technological breakthrough in mobile drilling came in the early 1960s when Shell Oil and companies specializing in offshore drilling developed effective semi-submersible vessels with giant pontoons that could be filled with water once the vessel had been towed to location, providing a stable but mobile drilling platform. By this time, a strong foundation for future expansion of mobile drilling had been laid, and as the offshore industry moved into deeper, harsher waters, new generations of entrepreneurs pushed the limits of existing technologies to meet the resulting new challenges.

From the early years forward, the offshore drilling industry had its hands full responding to the demands of different water depths and circumstances around the world. New drilling sites at times required innovations beyond the existing experience of the onshore industry. The founders of the companies that led the way tended to be those with the inventiveness, local knowledge, mechanical aptitude, and the capital needed to design and build new offshore drilling systems. A wave of fast-growing entrepreneurial companies stepped out front with new approaches to mobile drilling, and several of them became global leaders. Most hired and trained

local workers and used local shipyards to build their drilling equipment. In addition to creating a thriving industry critically important for the success of offshore development as a whole, these large, regionally-based drilling companies also spawned an array of regional start-up companies to provide services to the new offshore drilling industry.

As the industry moved deeper offshore and to regions far removed from the Gulf of Mexico, the mobile drilling industry went through a long era of technological advancement and consolidation. From the 1960s forward, new competitors emerged from the North Sea and other regions as shipping or drilling companies with local knowledge developed mobile drilling rigs attuned to offshore conditions in their regions. New innovations such as tension-leg platforms, which tethered semi-submersible platforms to the ocean floor with cables, provided good service in the rough waters of the North Sea before finding their way back into the Gulf of Mexico. Global feedback loops encouraged the rapid adoption of best practices from around the world in an industry that remained heavily populated by companies that still called the Gulf of Mexico home.

Production platforms--the permanent structures needed to produce offshore oil at one location over decades--used some of the same basic approaches used to explore for oil, with water depth being a key determinant of the type of platform installed. Brown & Root and McDermott gradually moved out of the crowded competitive arena of mobile offshore drilling and became dominant firms in the design, construction, and installation of production platforms in the Gulf of Mexico.

They became global leaders as this segment of the industry moved beyond the Gulf of Mexico.[9]

Both types of platform construction generated entrepreneurial multipliers in the form of start-up companies organized to assist in their operations. A greatly abbreviated list of prominent supply and service firms created by regional entrepreneurs suggests their diversity in size and function:

(1) Tidewater Marine Services (founded by Louisianan John LaBorde) developed efficient purpose-built supply boats to transport workers and equipment to offshore sites;

(2) Pugh Industries (created by Texan Billy Pugh) created a safer "personnel transfer net" widely adopted through the global offshore industry to transport workers from ships to platforms;

(3) PHI (Petroleum Helicopters, Inc.), a company created by Robert Suggs, a Texan transplanted from Canada, transported offshore workers to distant platforms and evacuated workers quickly when hurricanes threatened;

(4) Glenn & Associates, a New Orleans-based company created by a former weather officer from World War II, provided detailed, up-to-date weather data to the offshore industry before the era of weather satellites. The company also provided "hindcasting," which used historical data on past hurricanes to estimate the forces waves and wind from future hurricanes might exert on platforms in the open sea; and

(5) Global Industries, whose roots went back to a Lafayette, Louisiana, was a diving company employed by offshore firms; it evolved into a full service offshore company with operations ranging from diving to pipe-lay barges.

Start-ups firms in these and other supplies, services, and equipment needed for offshore development blossomed within the region. From companies that built and operated large offshore crane barges to catering firms, to specialized insurance and lending companies, hundreds of local businesses grew to provide specialized services. They employed primarily local workers and built factories and headquarters in the region, generating substantial traditional economic multipliers in local economies and illustrating the far-reaching impacts of entrepreneurial activities in the spaces opened by the move offshore.

Major exploration and production companies coordinated the activities of the many enterprises needed to keep the offshore industry functioning smoothly. At times they also worked with service companies to develop technologies needed to allow the industry to continue to move into deeper waters. The master of such coordination in the Gulf of Mexico was the Shell Oil Company (Shell-USA), the subsidiary that managed Royal Dutch–Shell's operations in the United States. Shell was the leader in offshore innovation in the Gulf of Mexico in the mid to late 20th century. Understanding the importance of offshore business to both Royal Dutch-Shell and Shell-USA, management created a distinctive company entrepreneurial culture, hiring outstanding engineers and scientists and giving them considerable autonomy.

For a time, Shell was almost too successful for its own good. In 1962 it acquired leases in the Gulf of Mexico in water deeper than the industry as a whole was unprepared to venture. Knowing that it could not move into deeper waters alone, Shell hit on an innovative solution that reflected its unusual corporate culture. It created a three-week long "school for industry," where representatives of other offshore companies and government agencies could learn the latest in Shell's technology. For an admission fee of $100,000, people from outside the company could learn the latest in offshore innovations from specialists at Shell who had developed much of this technology.[10]

Shell was extraordinary, but not unique. The Shell school illustrated that the offshore industry was a fraternity of competitors that collectively created improved technology to enable the industry as a whole to move into deeper, more demanding waters. By the late 1960s, a network of experts from a variety of oil and gas companies, manufacturers of equipment, providers of services, universities, and government laboratories worked at the margins of existing technology. These specialists could learn from each other in joint ventures, professional and trade journals, and joint research initiatives. They also could keep track of emerging innovations in technical papers presented at the Offshore Technology Conference (OTC), an annual conclave in Houston created in 1969. By this time, much needed offshore innovation and entrepreneurship had moved beyond the efforts of individuals or even leading companies such a Shell to a growing network of engineers, scientists, and manufacturers in a cluster of closely related offshore industries.

Innovations in Drilling and the Fracking Revolution

The most recent boom in the oil and gas industry hastened by innovations in drilling has been the development of hydraulic fracturing. In the creation of modern fracking, Houston oilman George Mitchell took the role of Thomas Edison, although instead of searching for the best filament for a light bulb, Mitchell led the searches for the best combination of fluids and drilling technology for efficient fracking. The son of a Greek immigrant, Mitchell grew up on the wrong side of the tracks in Galveston, Texas, south of Houston. He worked his way through Texas A & M University just before World War II, earning a petroleum engineering degree before briefly working for a major oil company. After returning from the war, he chose to build his own company and to focus on a promising region for oil and gas northwest of Dallas-Fort Worth. A long, successful career finding and producing natural gas in northeast Texas gave him valuable local knowledge, as well as considerable wealth. Over time he became obsessed with the tantalizing prospect that the large shale deposits in the region almost certainly contained substantial reserves of natural gas and oil. Believing strongly that someone would find a way to release these reserves from the shale, he made this his personal quest. He committed the resources of Mitchell Energy, his relatively small but highly successful producing company, to shale development in the region he knew best, the Barnett shale near Fort Worth. Despite the protests of younger experts in his company and skepticism from the industry as a whole, he pushed forward for almost seventeen years. It was, after all, his company, his wealth, and his entrepreneurial vision.

Rudimentary forms of hydraulic fracturing had been used in the enhanced recovery of oil for decades, but Mitchell Energy made significant modifications in traditional fracking technology in its quest to produce natural gas from shale. Experiments using different mixtures of drilling fluid finally identified a mix of chemicals and water that produced significant yields of shale gas. A key innovation was an increase in the amount of water, which gave rise to the name "slickwater fracking." With adjustments to the traditional technology, Mitchell Energy created an innovative new process capable of creating fissures in the shale, freeing high quality oil and natural gas to flow up the drill pipe to the surface. The final piece of the puzzle was put in place in2002 after the sale of Mitchell Energy to Devon, an aggressive young Oklahoma-based producing company with the resources and creativity to apply recent improvements in horizontal drilling to the fracking process. A new era of modern fracking began, opening opportunities in the oil industry akin to the discovery of oil at Spindletop or the move into offshore exploration and production.[11]

Spokesmen for the oil and gas industry tend to use Mitchell's story as an example of the transformative power of entrepreneurs unfettered by government intervention. They are more or less right, but closer examination of the Mitchell story reveals several useful additions to our understanding of entrepreneurship in modern America. Unlike the solitary individual great entrepreneur of lore, Mitchell benefitted from federal government subsidies for unconventional natural gas contained in laws passed in a long lost era of natural gas shortages in the 1970s. He also benefitted from advances in hydraulic fracturing by other companies and from

the joint research efforts of the Gas Research Institute (GRI), a non-profit organization created in 1976 to coordinate research and development in the natural gas industry. Until 1998 a surcharge on interstate natural gas transactions put in place by the Federal Power Commission fully funded GRI's activities on the grounds that the industry lacked sufficient resources to fund needed innovations in natural gas.[12] Traditional fracking had emerged decades earlier from an existing network of companies seeking to increase oil production from known fields. Modern fracking emerged from a new network of companies, government labs, and government subsidies, creating a much larger, more innovative, and dynamic industry that spawned a new sequence of innovations in the Southwest and elsewhere.

The shale revolution opened an array of opportunities for entrepreneurs in this emerging new sector of the oil industry. Independent producing companies in the U.S. were in the best positions to capture opportunities in shale development. In the late twentieth century, many of the major international oil companies had fled domestic production in search of larger foreign projects with higher rates of return. As the international oil companies paused to consider the costs and benefits of moving into the domestic shale industry, independent producers with long experience in traditional oil and gas basins near promising shale formations quickly took the risks and spent the capital to become the leaders in the highly competitive production of shale oil and gas. When the international oil companies finally decided to act, they often did so through poorly timed, expensive acquisitions of large successful shale companies.

Also well positioned for shale-related expansion were the giant oil tool and service companies, including long-time leaders such as Halliburton, Schlumberger, and Baker-Hughes. Shale development made use of the specialized skills and rich contacts they had established both onshore and offshore. The potential profits from U.S shale development and the future prospects for shale production in other parts of the world presented opportunities for these companies to take technological leadership from the major oil companies in a new sector with great promise.

Drilling in shale formations differs sharply from traditional onshore drilling, in large part because horizontal drilling requires the regular movement of a rig as it follows the path of the shale. As had been the case with mobile drilling offshore, this regular movement of a drilling rig in fracking is expensive in both financial and environmental terms. An important part of the new industry's efforts to drive costs down has been the "walking drilling rig," which now accounts for more than half of all rigs used in major shale basins. At times supported by research and development by the large oil service companies, entrepreneurial firms have developed and manufactured rigs that use advanced hydraulic systems to move from spot to spot on drilling pads. Although much more costly than traditional onshore rigs, these walking rigs dramatically improve production from some drilling sites while greatly reducing the time needed to move a rig.[13] The drilling process in fracking also has called forth innovations in "down hole" electronics to guide the path of drill bits as they follow the contours of the shale formation during horizontal drilling. Such innovations reduce the costs of hydraulic fracturing, an increasingly important consideration in an era of low oil and gas prices.

Other parts of the fracking process have encouraged entrepreneurs to create and supply new services and products not required in traditional onshore drilling. One vital new product is "proppant," which is pumped with the fracking fluid to hold open fissures in the shale. High quality sand and synthetic sand fill this need. Hoping to emerge as "sand tycoons," entrepreneurs left jobs with slow-moving major oil companies to create innovative, fast moving new sand firms. Experienced people with backgrounds in the oil industry and related financial companies came together to create Hi-Crush, an early leader in the manufacture and supply of fracking sand. The company raised the capital needed to secure control of large deposits of sand deemed the best "natural" proppant in the land. It established an efficient transportation system to move high quality sand from Wisconsin to the major shale basins in the U.S. Competition arose from others who sought to develop artificial proppants that might outperform even the best sand. The multiplier was at work here, as with other start-ups that emerged to provide chemicals, transport water, and supply all sorts of services needed in fracking.[14]

The long-term future of shale production is as yet unclear. During the current lull in development due to low oil and gas prices, a determined push is on to find ways to lower costs. But perhaps more important to shale's future is a similar effort to find innovative ways to address the environmental issues that threaten the public's acceptance of fracking technology. Entrepreneurs inside and outside the leading shale companies are experimenting with new processes to reduce the use of dangerous chemicals in fracking fluid. Efforts to reexamine the entire cycle of water usage are also underway. In the air are promising ideas for dramatically reducing

overall water usage, for recycling water, and for ensuring the integrity of well casing and operating procedures to prevent the contamination of air and water. As concerns grow about greenhouse gas in the form of "fugitive methane" emissions escaping into the atmosphere during fracking, innovations in monitoring, measuring, and reducing these emissions have emerged. Newly created companies might well herald the coming of a methane mediation industry. Outrage over extensive flaring of natural gas at shale production sites due to the lack of pipelines has encouraged efforts to use natural gas at the wellhead until pipelines are in place. Questions about links between underground storage of wastewater from fracking and earthquakes also have begun to generate specialize studies of the potential impacts of underground pressures from the growing quantities of wastewater reinjected underground. [15]

The long list of innovations needed to clean up shale oil and gas production points out a significant reality about entrepreneurial multipliers in the oil industry: they bring costs as well as benefits. U.S. oil booms historically created frenzies of rapid development in which new technologies of production far outpaced new technologies to control waste and environmental impacts. Entrepreneurial attitudes stressed first mover advantages, often accompanied by the impulse to produce now and clean up later. The passage of stricter environmental regulations in the 1960s and 1970s slowly began to reduce the gap between innovations in production and innovations in controls, as increased societal demands for pollution control increased the focus and the investment on environmental innovations in oil and other energy industries. Gradual changes in national culture drove shifts in

corporate culture. Ongoing efforts to address problems with pollution have cut two ways in the entrepreneurial culture of the oil industry. On the one hand, the regulatory process has slowed the pace of new technology, shifting some capital once available for innovations in production processes into environmental controls. But on the other hand, fundamental advances in the technology to measure and control pollution have emerged as environmental entrepreneurs have aggressively responded to opportunities for innovation spawned by regulatory demands for cleaner processes.

Beyond technical improvements, innovations in the regulation of fracking are needed to find a sustainable, equitable balance between environmental quality, energy security and supply, and economic growth. Under the scrutiny of environmental groups and government regulators, entrepreneurial companies and specialized environmental divisions of existing companies have joined in the search for solutions. Their efforts reflect fundamental changes in the culture of oil and its use. Growing concerns over climate change might well require even more basic changes in the operations of all fossil fuel companies. Indeed, the successful adaptation of shale companies to these environmental concerns will determine their legitimacy in the eyes the nation and the world. This, in turn, will help determine if shale production will have long-term economic impacts comparable to those from the long-term growth of southwestern oil production after Spindletop or the move offshore.

In the three episodes of dramatic changes in drilling I have examined, waves of innovations followed the initial discovery and development of new types of oil

reserves. The impacts of innovations and the new companies they created went far beyond drilling. Indeed, spill overs from this sector into closely related segments of the oil industry steadily transformed much of the existing industry, as new ideas, technologies, and organizational forms reinvigorated processes as different as state regulation of oil production and the competition between natural gas and coal-gas.

I came away from this research realizing that I could have focused on many aspect of oil history other than drilling and found illustrative examples of the impacts of innovation and entrepreneurship. In refining, for example, the coming of catalytic cracking in the 1920s, the fuller unification of refining and petrochemical processes in the post-World War II era, and the development of processes to produce cleaner burning gasoline since the 1970s spurred periodic surges of epoch-defining innovations. The steady improvement of traditional seismic surveying and then the explosion of change introduced by high-powered computers in the late 20th century fundamentally altered the search for oil and gas. Improvements in pipeline technology literally created mass markets for natural gas, a process that continues in the recent past with the maturing of the LNG industry and the resulting movement toward a more global market. The dramatic reduction in air and water pollution from fossil fuels since the 1960s has been possible because of far-reaching innovations in pollution control that very gradually evolved from failed efforts to curb waste after Spindletop and the initial emergence of large Southwestern oil fields.

The case of oil convinces me that the phrase "long sequence of an entrepreneurial multiplier" points to something important—and too little

unexplored--in business history. Business historians have rubbed up against this process in biographies of individual entrepreneurs and their companies; authors of corporate histories often have included detailed discussion of the process of technical and even administrative innovations in their work on successful technologically-intensive companies; historians of technology have analyzed the process of innovation as a cumulative process that can work across generations and individual companies. The closest thing to explorations of the impacts of long sequences of entrepreneurship over time probably has come in the best histories of individual industries, which suggest how innovations by entrepreneurial companies can push entire industries through major transformations.

Concluding Observations

(1) Understanding the impacts of entrepreneurship requires greater concern for culture than traditionally afforded to it in economic and business history. A readiness to take risks and an eagerness to innovate marked the behavior of many in the southwestern oil industry in its formative years, the early years offshore, and the coming of the shale revolution. Was there something distinctive about the region or the industry that encouraged a culture of entrepreneurship? If so, have the economic benefits of this approach been high enough to make up for the environmental and social costs? The late George Mitchell, now referred to as the father of modern fracking, was no ordinary Texan. An environmentalist at heart and an entrepreneur from head to toe, he called for stronger regulations of fracking, perhaps because he understood more than most in his industry that the future political legitimacy of largely unrestrained entrepreneurship in the U.S. would

require higher standards of environmental stewardship. He remained convinced that these standards should be set and could be met, in large part through the innovations of entrepreneurs responding to the technical challenges posed by stricter regulations.

(2) In the early oil boom in the Southwest, successful entrepreneurs in companies such as Texaco, Hughes Tool, and Cameron Iron Work opened space for second waves of innovation and company building. This process had very visible economic impacts similar to those quantified with the traditional concept of economic multipliers. Yet more than dollars flowed through the society. The habit of entrepreneurship also took hold as migrants to the region responded to the fertile ground for innovation and the creation of new companies in the formative years of the southwestern oil industry—and later in the Gulf of Mexico and shale basins.

(3) In the oil industry, the impacts of entrepreneurial activities flowed forward through time. Each generation's entrepreneurs established attitudes and developed institutions needed for future innovation. This was most visible in the evolution of individual companies such as Hughes Tool and Cameron, which made long-term commitments to technological leadership in their product areas. Similarly, Shell Oil created and maintained a corporate culture that stressed technological leadership in innovations needed to move into deeper waters offshore. In the history of drilling, incremental improvements through time prepared the way for the bigger jumps forward needed to drill wells in deepwater and to frack shale. Experience in horizontal drilling from offshore platforms, for example, helped prepare the way for the further innovations in this technology needed for onshore fracking.

(4) Fossil fuels deserve fuller analysis as important networks of entrepreneurship. Innovations in the production and use of coal, oil, and natural gas fueled the industrial revolution of the 19th and 20th centuries. The long sequences of innovation in fossil fuels reached across to other major industries, notably the railroads, automobiles, modern steel, air travel, natural gas, petrochemicals, agribusiness (machinery and pesticides), and the generation of electricity. Fossil fuels shaped the pace, timing, and intensity of the industrial revolution from the late nineteenth through the mid-twentieth centuries.

(5) One conclusion stands out sharply in my experience working in the oil industry early in life and then studying it for the last 45 years as a historian. The case of oil forcefully illustrates the far-reaching impacts of the digital revolution across industries from the 1960s forward. The stunning impacts of digital advances transformed the oil industry's operations from top to bottom. Innovations in computing spilled over into seismic mapping, refinery controls, directional drilling, dynamic positioning, down hole guidance of drill bits, and other sectors of the industry too numerous to name. The cumulative impact of these changes created what amounted to a new oil industry. The early impacts of the long sequence of innovation in computing rippled through an ongoing long sequence in oil, opening vast new spaces for innovation in an industry that earlier in its history had done the same for a variety of industries dependent on fuel quality, availability, and price for their own success.

(6) The effort to analyze entrepreneurial multipliers faces several basic challenges. Can we find creative approaches to discuss the overlap between the closely related

concepts of entrepreneurship and innovation? If so, where are the existing studies that provide the best starting points? Would new streams of data about patents, job creation, or the introduction of new products, for example, might help us move beyond stories about entrepreneurs and the comparison of the length and density of the long sequences of entrepreneurship?

More difficult to imagine are sets of data that might help us analyze a key issue facing the systematic analysis of entrepreneurial multipliers: what are the impacts of national cultures and corporate cultures in fostering or dampening the impacts of these multipliers? Thinking more systematically about culture would be a good start in evaluating the often unexamined assumption that the United States is blessed with a national DNA and history that makes it uniquely entrepreneurial. One hopes that future business and economic historians will do more to give this type of analysis a firmer quantitative as well as qualitative foundation. Given the central historical role of entrepreneurship in U.S. economic history, the results should be well worth the effort.

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[9] For a history of Brown & Root's offshore activities, see Joseph A. Pratt, Tyler Priest, and Christopher J. Castaneda, *Offshore Pioneers: Brown & Root and the History of Offshore Oil and Gas* (Gulf Publishing Company, 1997).

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