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SPILLOVERS, SPILL-INS, AND STRATEGIC ENTREPRENEURSHIP: AMERICA'S FIRST COMMERCIAL JET AIRPLANE AND BOEING'S ASCENDANCY IN COMMERCIAL AVIATION

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Building on recent studies on knowledge spillovers and spill-ins, this study traces the post-World War II knowledge spillovers during the early days of the modern commercial aviation industry. It examines the impact these spillovers had on opportunity- and advantage-seeking behaviors (i.e., strategic entrepreneurship) of the leading American incumbents: Douglas, Lockheed, Boeing, and a new entrant, de Havilland of Great Britain. Specifically, it highlights the processes triggered by knowledge spillovers that led to internal knowledge generation, innovations and, ultimately, Boeing's ascendancy in commercial aviation. It shows that knowledge spillovers and the concomitant processes they trigger can provide a powerful lens for studying opportunity- and advantage-seeking behavior in incumbents and entrants and the resultant outcomes of this dynamic. This study sensitizes researchers to examine the nuanced and complex interplay among knowledge generation, knowledge spillovers and spill-ins, and strategic entrepreneurship within a specific industry context to explain performance outcomes.

INTRODUCTION

The emerging domain of strategic entrepreneurship is focused on understanding how firms combine entrepreneurial actions that seek new opportunities with strategic actions that generate competitive advantage (Hitt *et al*., 2002; Ireland, Hitt, and Sirmon, 2003). In this context, the role of knowledge spillovers and how spillovers interact with firm-level capabilities and knowledge generation to enable strategic entrepreneurship is a topic of emerging interest (Agarwal, Audretsch, and Sarkar, 2007). Knowledge spillovers represent external benefits gained from the creation of knowledge that accrue to parties other than the creator (Agarwal *et al*., 2007; Griliches, 1992; Yang, Phelps, and Steensma, 2010). While knowledge spillovers often act as a trigger for new entry, they can also induce new opportunity-seeking behavior, one of the tenets of strategic entrepreneurship, in incumbents.

The extant literature on knowledge spillovers has a long history, starting with the pioneering work of Arrow (1962), who argued that since knowledge is, in part, a public good, knowledge spillovers are often beyond the control of the originating firms (cf. Mansfield, 1985). Adopting this perspective, research has examined how knowledge spillovers benefit recipient firms at the expense of knowledge-originating firms (cf. Arrow, 1962; Cohen and Levinthal, 1990; Griliches, 1992). Recipient firms can use spillover knowledge with little incremental

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cost and, in doing so, substantially reduce the financial costs of innovation vis-à-vis the originator's cost (Arrow, 1962; Yang *et al*., 2010). Studies have shown that knowledge spillovers enable competitive entry into a technological area and that such entry impacts the knowledge originator's ability to appropriate profits from their innovation (Jaffe, 1986).

Since knowledge spillovers influence innovative activity, research has enumerated conditions under which spillovers can be exploited (cf. Henderson and Cockburn, 1996). For instance, Jaffe and his coauthors have shown that the R&D spending of rival firms and universities in a firm's geographical area may influence its patenting activities and profits (Jaffe, 1986, 1989; Jaffe, Trajtenberg, and Henderson, 1993). Research has shown that a firm can access and exploit the knowledge of others more easily when it is developed within its own industry (Henderson and Cockburn, 1996). Also, such a firm is better positioned to exploit a pool of external knowledge developed by others pursuing similar technologies (Jaffe, 1986).[1] The key assertion underlying the literature is that external knowledge spillovers often benefit recipient firms at the expense of originating firms. In contrast, research that examines how knowledge spillovers benefit the firms that helped create such knowledge in the first place is less acute (Yang *et al*., 2010). Also, our understanding of the role played by strategic entrepreneurship in such contexts is only now emerging.

This study examines the phenomenon of knowledge spillovers and the concomitant entrepreneurial processes they trigger in an effort to understand how such processes impact *both* the originating and recipient firms. My intent is to examine the role played by industry- and firm-level contextual factors, which led to strategic entrepreneurship by firms in the fledgling commercial aviation industry. Specifically, I address the role industry context and firm situational factors played in who benefited from spillovers and spill-ins in this industry. Using the emerging literature on strategic entrepreneurship (i.e., Hitt *et al*., 2002) and reverse knowledge flows or spill-ins (Agarwal *et al*., 2007) or spill-backs (Yang *et al*., 2010) to frame my theoretical arguments, I explore how spillovers and spill-ins impact originating and recipient firms as well as society at large. Here, knowledge spill-ins represent reverse knowledge flows that benefit the originators of knowledge (Romer, 1990; Yang *et al*., 2010). I chose to conduct an analysis of the commercial aviation industry (as explained below) because knowledge spillovers, spill-ins, and strategic entrepreneurship played a decisive role in this industry's emergence and evolution.

[1] In this context, it has also been shown that absorbing external knowledge that is dissimilar to its existing competencies can be challenging and costly for any firm trying to assimilate such knowledge (Cohen and Levinthal, 1990).

The emerging literature on spill-ins

Recently, Yang *et al*. (2010) showed that when an originating firm's knowledge spills over to other firms and is subsequently recombined with knowledge from recipient firms, a *knowledge spillover pool* emerges. Such a pool comprises valuable opportunities whereby the originating firm can learn vicariously from recipients and exploit that knowledge.[2] Yang and her coauthors (2010), using a sample of telecommunications firms, showed that a firm's rate of innovation from the knowledge spillover pool is greater when that pool is larger in size and closely resembles the firm's existing knowledge base. By limiting their study to examining spillover pool characteristics they, however, fail to examine how such pools emerge, evolve, and grow. Also, their study did little to distinguish between a firm's internal knowledge pool and the industry knowledge pool and how these two pools coevolve and benefit multiple industry actors. Such an understanding is needed in order to shed light on how knowledge spillovers and spill-ins occur and the mechanisms that might be involved. Although the study's main assertion—that spill-ins provide useful knowledge for originating firms—is novel, determining why and which firms exploit them lies at the heart of strategic entrepreneurship.

Agarwal *et al*. (2007) proposed a *knowledge spillover-based strategic entrepreneurship* framework for a phenomenon that they characterized as *creative construction*. The framework highlights how knowledge spillovers from established organizations are an important source of new entrants into an industry.

[2] These authors argued that an originating firm is better positioned vis-à-vis its rivals to leverage this knowledge spillover pool because the pool is based on its own knowledge. Such a cycle of knowledge generation ultimately helps both the creator and recipient firms innovate. They examined the proposition that firms learn vicariously from the efforts of others and exploit a knowledge pool created when the recipient firm's knowledge is combined with the originator's initial invention along with other complementary knowledge.

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It posited that as new entrants exploit knowledge and networks developed by incumbent organizations, spill-ins become possible, allowing knowledge to flow from new entrants back to incumbents. Agarwal and her coauthors described this cycle as creative construction noting that 'in the face of the strategic management of knowledge spillovers across incumbents and entrants alike, displacement and value destruction are less likely as an outcome' (2007: 264). What is more likely is the continued growth of new entrants and incumbents in a virtuous loop of value creation. Their key assertion is that knowledge investments, spillovers, and subsequent entrepreneurial venturing are critical mechanisms that underlie new venture formation and development at the firm level and economic growth at the societal level.

However, Agarwal *et al*.'s (2007) study views incumbents primarily as knowledge factories for new entrants, particularly when such firms underutilize the knowledge they create. In adopting this perspective, their study underemphasizes incumbent competitive dynamics and the impact this can have on knowledge generation, spillovers, spill-ins, and strategic entrepreneurship. Also, by focusing on endogenous knowledge generation by incumbents, their study does little to identify external sources and conditions under which spillovers and spill-ins can occur and how they can act as a trigger for further innovation. In other words, without a detailed understanding of industry context and firm situational factors, it is difficult to appreciate why and how some firms are better positioned than others to exploit spillovers and spill-ins. Finally, by juxtaposing creative construction and creative destruction (Schumpeter, 1934) as two ends of a continuum, Agarwal and her coauthors discount the possibility that both processes may unfold simultaneously at the societal level and that the net effect of the processes are hard to predict *a priori*.

To address the gaps identified above, this study traces knowledge spillovers and spill-ins in the emerging commercial aviation industry and the impact they have had on opportunity- and advantage-seeking behaviors of the leading incumbents and a new entrant. As noted, the focus is on the modern commercial aviation industry for several reasons. First, modern commercial aviation began with the introduction of jet engine airplanes; the postwar period from 1945 to 1968 provides a fascinating and relevant *real-life* context for examining the phenomenon of interest. The impetus to move from piston engine aircraft—the conventional mode for transportation at the time—to jet-propelled aircraft was, in part, the result of multiple critical knowledge spillovers and spill-ins, including the adoption of sweptback wings, innovations in cabin pressurization, and the use of single pod engines. Second, studying this industry enabled me to examine competitive dynamics between the incumbents (Boeing, Douglas, and Lockheed) and a new entrant, de Havilland (see Table 1). Boeing, one of the marginal players in commercial aviation at that time, was able to parlay critical knowledge spillovers and related spill-ins to the design and manufacture of a product that was innovative and radical—the Boeing 707. This airplane would become the industry's dominant design for jet airplanes (Anderson and Tushman, 1990). The introduction of the Boeing 707 allows for a longitudinal study of the competitive dynamics between Boeing and its rivals and permits one to explore the performance implications of a product introduction on Boeing and other industry players. The introduction of jet engine airplanes had a profound impact on the modern commercial aviation industry and impacted numerous industries, enabling researchers to examine issues pertaining to creative construction and destruction simultaneously.

This study contributes to the emerging literature on spillovers, spill-ins, and strategic entrepreneurship in numerous ways. Its most important contribution is to assert how internal knowledge generation and external knowledge spillovers and related spill-ins are necessary, but not sufficient, conditions for organizations to benefit from such opportunities. In addition to these elements, what is required to exploit the opportunities that present themselves is strategic entrepreneurship or opportunity-seeking behavior. Using fine-grained historical data gathered from multiple levels, it offers a more nuanced understanding of the dynamics of knowledge spillovers and spill-ins in a rich context. At the minimum, the study sensitizes researchers to examine the complex interplay among knowledge generation, knowledge spillovers and spill-ins, competitive dynamics, and strategic entrepreneurship to explain firm-level performance outcomes.

METHODS

Approach

To more closely examine the theoretical constructs of interest and uncover the underlying dynamics of

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Table 1. Players in the emerging air transportation industry following World War II

	Boeing Corporation	Douglas Corporation	Lockheed	British de Havilland
Founding date	1916	1928	1912	1920
Founders	William Boeing	Donald W. Douglas	Allan and Malcolm Loughead (later changed to Lockheed)	Geoffrey de Havilland
Location	Seattle, WA	Santa Monica, CA	Santa Barbara, CA	Hatfield, England
Major commercial airplanes (1945)	377 *Stratocruiser*	DC-4E and DC-6 series	Constellation L049 and Super Constellation airplanes ("Connie")	None*
Wind tunnel access after WW II for high-speed flight tests	Built its own wind tunnel	Accessed wind tunnel facilities at Cal Tech	Accessed wind tunnel facilities at Cal Tech	Accessed the wind tunnel maintained by the Royal Air Force
Commercial jet airplane introduction date	Boeing 707 1958	Douglas DC-8 1959	L-188 Electra (turboprop, 1958)**	Comet-I 1952

Source: Various
*The company was famous for its Mosquito and Hornet fighter planes during WW II.
**Turboprop technology was a competing technology to the jet engine. Initially, the technology was only slightly inferior to the turbojet airlines in terms of cost, but its operating costs were lower. However, passengers preferred the turbojet airplanes for their comfort (lack of piston noise and vibration). Lockheed introduced the L1011 jet airplane in 1970s to compete with Boeing 747 and DC-10. But having sold only 250 airplanes in total, it withdrew from the commercial airplane business.

the phenomenon over time, I used a specific industry context, the modern commercial aviation industry, to address the questions of interest. To uncover the process that unfolded in this industry, I used a narrative approach (Langley, 1999), which involves constructing detailed case studies from raw data obtained from historical sources. My intent was to provide the vicarious experience (Langley, 1999) of a real setting in all its richness and complexity in order to highlight the phenomenon of interest. I also employed visual mapping techniques (Langley and Truax, 1994) to represent knowledge flows, spill-ins, and knowledge pools over time.

This intent represents a combination of theory generation (Eisenhardt, 1989a; Eisenhardt and Graebner, 2007; Langley, 1999) and theory elaboration (Lee, 1999; Lee, Mitchell, and Sablynski, 1999; Siggelkow, 2007). I drew upon the emerging literature on spill-ins (e.g., Yang *et al*. 2010), creative construction (Agarwal *et al*., 2007), and strategic entrepreneurship (Hitt *et al*., 2002) to generate new theory and elaborate and sharpen assertions made in these literatures. I used the research question and constructs highlighted in the extant literature (e.g., strategic entrepreneurship, knowledge spillovers, spill-ins, and the concept of creative construction) to guide my inquiry and frame the analyses.[3]

Industry and firm context

Research setting

The modern commercial aviation industry and the chosen time period provide a powerful and interesting context for studying the issues of interest, one of the primary reasons for using a qualitative process approach (Pettigrew, 1992). The de Havilland Aircraft Company and the Boeing Company developed the commercial jet airplane based partly on knowledge spillovers gained from German labs and partly on subsequent entrepreneurial actions. In response to knowledge spillovers and spill-ins from Boeing's prototype for the 707 airplane, Douglas introduced the DC-8. Using information from Douglas's proposed

[3] Although this approach requires neither the specification of causal relationships among the constructs nor a complete accounting of explanatory constructs, it helps focus the study by identifying what is and is not known about the phenomenon of interest, particularly in terms of identifying those constructs included in the analyses (Eisenhardt, 1989).

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design, Boeing then altered its 707 just before final production in order to compete with the DC-8.

The de Havilland Aircraft Company introduced the first jet engine commercial airplane, the Comet-I. However, as explained later, three Comet-I airplanes crashed in succession less than two years after introduction. All of the major aircraft makers benefited from knowledge gleaned from these crashes, when knowledge about the crashes was made public. The Comet's 1952 introduction and the emergence of the 707 in 1958 represent revelatory cases (Kotha, 1995; Yin, 1994; Rindova and Kotha, 2001) and, as such, present an opportunity to study the phenomenon of interest—knowledge spillovers and spill-ins leading to strategic entrepreneurship. As noted, the introduction of the 707 airplane had a profound impact on modern commercial aviation, and the introduction of the jet airplane subsequently impacted numerous industries, thus enabling me to discuss issues pertaining to creative construction and destruction simultaneously.

Choice of firms

My historical analysis includes the industry's largest U.S.-based incumbents—Boeing, Douglas, and Lockheed—as well as the British entry into the industry. Although to benefit from replication logic I use a multi-case design (Yin, 1994), given the narrative approach employed, I chose the Boeing Corporation as the *anchor* case to conduct analyses for theoretical and pragmatic reasons. On the theoretical front, Boeing was able to parlay critical knowledge spillovers and spill-ins to design and manufacture an airplane that was innovative and radical—the Boeing 707. The airplane would, in due course, become the industry's dominant design. As such, the Boeing Company represented the most interesting organization that provided theoretical insights to study the phenomenon of interest. More pragmatically, Boeing is the only company that still produces commercial jet airplanes and it maintains a rich archive of historical information.

Time frame and unit of analysis

I selected 1945 as my starting point for analysis, since this was when American intelligence officers uncovered Germany's experiments on high-speed aircraft. This time period that eventually led to the introduction of the first commercial jet-propelled aircraft 'was a unique time in history, a turning point when what we take for granted today was thought to be impossible' (Cook, 1991: 267). It provides an important context to study the research question of interest. My chosen endpoint was 1968, 10 years after Boeing's radical jet airplane design was pressed into service. During this crucial period, performance implications posed by the commercial jet age were becoming apparent, not only for industry incumbents but for the society as a whole. This timeframe encompasses events such as the Boeing B-47 bomber design incorporating German knowledge spillovers, as well as Boeing's own experiments placing jet engines on the wings.

My unit of analysis is the firm; the embedded units are the product and the industry in which the firms competed against one another.[4] However, as Pettigrew (1992) notes, process phenomena tend to exhibit a fluid character that spreads over both space and time. While this property enables researchers to consider multiple levels of analysis, it can also make it difficult to separate levels from each other. Hence, in understanding process phenomena, the levels should be considered a continuum rather than a hierarchy with clear delineations (Langley, 1999).

I chose to focus on the Boeing 707 over other aircraft because of its status as a breakthrough product (Bettis, 1991). It was among 16 historic designs identified by *Air and Space* magazine as having revolutionized air transport (Hallion, 2008). As the civilian progeny of the Dash-80 prototype airplane, the Boeing 707 was a radical product, the forerunner of all future jet airplanes, leading to today's 787 Dreamliner.[5] As the first U.S. built jet-propelled airplane, it encompassed a host of innovations and concepts from knowledge spillovers, linking them to knowledge generated by Boeing that would become a crucial marker in the advent of the jet age in commercial air transportation.[6]

[4] It is important to recognize the reciprocal interaction between product (particularly in the case of a breakthrough product, such as discussed here) and firm; the firm designs and builds the product and the product, in turn, can profoundly impact the firm.

[5] Technically speaking, the Dash-80, the experimental plane on which the 707's design was based, is the grandfather of all commercial jets, right up to the Boeing 787 Dreamliner. For practical purposes, the 707 was the first commercial plane introduced into service in the U.S.

[6] The Boeing 707 airplane provided the commercial aviation industry with the generic configuration for the medium- and long-range jetliner (Hallion, 2008). Two structural features—a low-placed, sweptback wing and podded jet engines that hung from the wings using struts—would become the industry standard (the dominant design) and significantly influence all future airplane design. As Sutter, a world-renowned aerodynamicist and chief engineer for the Boeing 747, noted 'the 707 fuselage cross-section has served the world well, having been used not just in the 707 but also in Boeing's subsequent single-aisle models, the 727, 737, and 757. This fuselage cross-section is still in use today by the Next-Generation 737 family of twinjets' (2006: 65–66).

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Data sources

My primary sources of data were archival, supplemented by interviews with Boeing executives, the Boeing historian, and industry experts.

Archival documents

Airplane programs can cost millions (the estimated cost of a new airplane product today is in the billions of dollars). As one industry observer pointed out, aviation executives are gamblers in a high stakes game, facing great odds against success (Newhouse, 1985). Given such huge financial stakes, the design, development, and manufacturing of airplanes are watched closely by academics, industry experts, and the business media. Such coverage provides a wealth of factual material about the design and introduction of airplanes throughout aviation history. Much of my information was drawn from accounts provided by annual reports, the media, and historical books (Cook, 1991; Irving, 1993; Lynn, 1995; Mansfield, 1956; Maynard, 1962; Newhouse, 1985, 2007; Pattillo, 1998; Redding and Yenne, 1983; Sabbagh, 1996; Sharp, 1982; Serling, 1992; Sutter, 2006).

Trade and newspaper articles

I accessed selected magazine and newspaper articles (e.g., *Time* magazine), and press releases from this time period. Often media reports can provide more objective and contextual information about industry dynamics and firm-level competitive actions than annual reports (Rindova and Kotha, 2001). I also accessed the Boeing's archival collection, which provided a wealth of information on Boeing and Douglas's history. Boeing acquired Douglas in 1996. These various sources allowed me to triangulate facts and examine data from multiple vantage points (Glaser and Strauss, 1967).

Interviews

I twice interviewed the Boeing corporate historian, a firm and industry knowledge expert, who directed me to many of the important historical sources of this time period and provided access to some important historical documents and internal reports. I also spoke to 18 senior managers as part of a larger study to examine the current launch of a revolutionary airplane, the 787, by the company; almost all of the executives interviewed referred to the 707 project as well as Boeing's early commercial aviation history. Some had worked for McDonnell-Douglas prior to its acquisition. A certain number of these interviews were focused on gaining an understanding and appreciation for the vast archival information available on the 707 airplane project and getting assistance in understanding the salient innovations and events that transpired during the industry's early years. Two senior executives—Joe Sutter and Frank Shrontz (both retired)—worked on the 707 airplane. Sutter went on to become the father of the 747 airplane, while Frank Shrontz served as Boeing's CEO from 1986 to 1996.

I initially analyzed the data based on a case history of the de Havilland Comet, the Boeing 707, and Douglas's introduction of the DC-8. Using numerous sources, I was able to document the evolution of the 707 chronologically, while systematically examining any event that played a role in its design, launch, introduction, and subsequent impact on Boeing, its rivals, and society. Typical for qualitative research (Brown and Eisenhardt, 1997), I checked the validity of insights with executives from Boeing, colleagues, and Boeing's corporate historian. This iterative process resulted in revisions and refinements.

SPILLOVERS, SPILL-INS, AND STRATEGIC ENTREPRENEURSHIP

To discuss the evolution of the jet-propelled commercial airplane and the roles played by knowledge spillovers, spill-ins, and strategic entrepreneurship, I have organized this section into three narratives for ease of exposition. The first narrative highlights the important spillovers and spill-ins that occurred that made commercial aviation possible. The second provides a detailed discussion of the situational context facing the actors in the then fledgling industry and, finally, the last section addresses the performance implication of knowledge spillovers and spill-ins on the industry actors and society at large. Following this discussion, I examine the theoretical implications of this analysis to highlight the study's contribution.

Narrative #1: Important knowledge spillovers and spill-ins

To provide a better understanding and appreciation for the context, I highlight the important knowledge spillovers and spill-ins that occurred in the industry. Specifically, I highlight three major spillovers—the sweptback wing, single pod design, and cabin pressurization—and the related spill-ins that occurred over a 14-year period.

The sweptback wing

May 10, 1945

Germany surrendered to the U.S. under General Eisenhower at the schoolhouse in Rheims, ending the war in Europe. The morning after the surrender, a technical intelligence team made up of mostly academics and Air Force officials, with one industry representative, George Schairer (a Boeing aerodynamicist) arrived at the R.H. Goering Aeronautical Research Institute to assess the state of German aviation. Here they came upon suitcases packed with test reports on airplane wing *sweepback* and its impact on flight speed. Wind tunnel experiments showed the aerodynamic effects of various degrees of sweep (Cook, 1991), information that solved a critical piece of the puzzle regarding high-speed flight.[7]

The findings couldn't have come at a better time. The possibility of surpassing the speed of sound was at the forefront of aeronautical thinking.[8] The data discovered by the team would be made available to U.S. airplane manufacturers shortly (Serling, 1992). Based on the German experiments, it was clear that speeds based on piston engine technology wouldn't be fast enough to take advantage of a sweptback wing. In order to be truly effective, the wing had to be mated with a jet engine, which for large transport planes, was viewed as experimental at that time (Cook, 1991).

Boeing's B-47: leveraging knowledge spillover

On the same day, the U.S. team entered the German research institute, George Schairer penned a seven-page handwritten letter addressed to Ben Cohn at Boeing and in it he wrote that 'the Germans have been doing extensive work on high-speed aerodynamics. This has led to one very important discovery. Sweepback or sweepforward (sic) has a very large effect on critical Mach No. This is quite reasonable on second thought' (1945: 2, underline original). He then went into technical details on how such a wing could enable high-speed flight, instructing Cohn by writing 'I do not know how soon this info will get around to other manufacturers so will you writ (sic) letters to Ozzie, Cl. Johnson, R. Bayless, E. Horky, E. Sheafer, and Darby quoting pages 2–5 for their information' (Schairer, 1945: 7).

September 13, 1945

Exactly five months after the discovery of the wind tunnel tests in Germany, Boeing submitted a proposal to the U.S. Air Force to change its development contract for the B-47 bomber from a straight wing design to a *sweptback* design—with jet engines. In place of the turboprop engines on Boeing's previous proposal, the revised proposal employed four jet engines in twin configurations attached to the wing (also known as dual pods) with one engine at the end of each wing, for a total of six engines. At that time, Boeing was competing with other U.S. manufacturers, including the Northern American Corporation, for a government contract. Evidently, the revised proposal was based on knowledge spillovers from Germany.

The Air Force didn't approve the request, although they didn't reject it either. Intrigued, they asked if Boeing could modify how the engines were mated to the airplane wings for safety reasons. In response, the engineers used struts to hang podded engines from the airplane's wings, which represented a major departure from the conventional practice of locating the engines directly on the wing.[9] Sutter noted (2006: 60, italics original):

> Boeing was the first company to correctly assess jet-age safety concerns and come up with an optimal solution: strut mounting. Mounting the engines on struts below the wings distanced any propulsion-related threats to safety. Cleverly, Boeing designers attached the turbine engines to their struts by means of *fuse pins*. In the event of an out-of-balance condi-

[7] The reason jet airplanes have sweptback wings is because when an airplane approaches the speed of sound, the air can no longer get past its wings fast enough. As a result, it bunches up and shockwaves may begin to form around the wing. This airflow inelasticity at high-flying speeds is known as compressibility. Angling the wings back can delay the onset of compressibility and permit the airplane to cruise efficiently at high speeds (Sutter, 2006).

[8] As early as 1943, the British, who had invented the jet engine, were exploring the possibility of producing a jet engine transport airplane, fearing that the Americans might become industry leaders after the war (Sharp, 1982).

[9] Boeing engineers were concerned with how such an approach would impact the drag experienced by the airplane. However, their in-house wind tunnel tests confirmed that the innovation decreased the structural weight and allowed for better distribution of weight (Cook, 1991). More important, engines hung in this fashion didn't increase drag, and less fuel was burned due to lower structural weight, permitting greater range of flight.

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tion, the fuse pins would shear and the damaged engine would fall away, sparing the airplane.

The Air Force approved the changes, and the B-47 went into production. Thus, an external knowledge spillover, the sweptback wing, combined with a new approach to engine mounting, resulted in America's first military jet, the B-47—a revolutionary airplane (Fredriksen, 2009).

The emergence of an industry-knowledge pool

The B-47's revolutionary design was shared with Lockheed and Douglas when the U.S. Air Force required more airplanes to counter the growing threat of the Soviets. The two companies were asked to produce the airplane using Boeing's design and production drawings. Since taxpayers funded the B-47 project, the production drawings were given to Boeing's rivals. A common industry practice, this approach was responsible for knowledge spillovers regarding the design of jet engine bombers and for the emergence of an industry knowledge pool on experimental jet engine technology on sweepback wings. Once the B-47 airplane was pressed into service, all manufacturers could observe the airplane and, more importantly, learn the science behind this airplane's revolutionary sweepback wing design using wind-tunnel experiments.

Employing a single pod design

Based on the success of the B-47, the Air Force asked Boeing to expand the concept in a larger aircraft with greater range and payload. This led Boeing to develop the B-52 long-range strategic bomber. In the spring of 1949, Air Force Colonel Pete Warden asked Boeing to incorporate a jet engine in the B-52 instead of the turboprop engine proposed by Pratt & Whitney. The turboprop engine program, still under development, was facing technical obstacles and the U.S. Air Force desperately needed a long-range *strategic* bomber to counter the Soviet Union's growing threat.[10] Boeing ended up using the J-57 jet engine.

Both the B-47 and B-52 sparked the company's interest in exploring the feasibility of commercial jet aviation. This led to the Model 473, which was shelved in favor of a jet-powered Air Force tanker (Lombardi, 2008).[11] The new airplane was a jet engine version of the piston-powered KC-97 stratotanker already in production for the U.S. Air Force. The Air Force needed a fast jet engine tanker to fuel the B-52 in flight as the piston engine version was neither fast enough nor safe enough for such maneuvers. To convert the KC-97 to a jet engine tanker, Boeing made a few design changes, as Lombardi noted: 'The design (of the KC-97) was further evolved to include a more streamlined fuselage and the B-52 style pods were separated into four single pods' (Lombardi, 2008: 163). The decision to employ single pod engines represented another crucial innovation in the evolution of jet engine airplane design (Lombardi, 2008). It was the result of knowledge gleaned from monitoring the North American's B-45, a jet engine airplane pressed into service prior to the revolutionary B-47.

Learning from North America's B-45 experience

The North American B-45 airplanes (known as Tornadoes) were the U.S.'s first operational jet bombers. In 1943, the idea for a jet bomber was conceived by the U.S. Air Force, prompted by Nazi Germany's advances in the field of jet propulsion. The War Department requested proposals from aircraft manufacturers for a jet bomber and a few manufacturers responded. North American's B-45 (Tornado) was chosen and placed into service in 1948, a few years before Boeing's B-47 went into production. However, the B-45 was plagued by engine failures and other problems before being supplanted by Boeing's B-47. It suffered many dual engine failures when debris from a compressor failure was ingested into the adjacent engine (Lombardi, 2008: 163). According to George Steiner, a Boeing executive in charge of the 707 airplane project

> We (Boeing) had no trouble with dual pods (engines on the B-47), but we found that North American's airplane had very serious troubles . . . They had had some engines that failed and spewed compressor blades out of the front end, only to be inhaled by the adjacent engine. We hadn't thought of that one. We had never had it happen on the B-47. Later on we found that it

[10] The turboprop technology was an alternative to the emerging jet engine and was an attempt by engine manufacturers to extend the technology trajectory of the conventional propeller engines in use at that time.

[11] This airplane incorporated the important elements of a B-47 (sweptback wing and jet engines mounted on struts) and the KC-97's *double loop* fuselage, a piston engine tanker airplane produced by Boeing for the Air Force. It would have a low wing configuration (the wings would join the airplane's fuselage near the bottom instead of the top), an innovation that distinguished it from the KC-97 piston engine transport airplane.

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> did happen a couple of times, but the B-45 had had it happen a number of times. (Steiner and Sutter, 1957: 12)

A group formed within Boeing looked into this issue and recommended that Boeing abandon the dual pod design and adopt the single pod design, which it did.

Cabin pressurization

May 2, 1952 was the day that de Havilland's Comet made its maiden flight with 36 passengers aboard. Each person paid £315 for a trip from England to Rome, Beirut, Khartoum, Entebbe, and Livingston, a journey that lasted 23 hours and 40 minutes. While Boeing was contemplating the introduction of a jet engine-powered commercial airplane, the de Havilland Company, a British airplane manufacturer, stunned the aviation world with its commercial jet—the Comet-I. With this aircraft the British aircraft industry was poised to wrestle leadership away from the Americans, who had dominated commercial air travel with their bigger propeller airplanes (Lynn, 1995). The Comet-I featured a modest 20-degree wing sweep (the B-47's was 35 degrees) based on knowledge spillovers from Germany and photographs of the B-47, making it faster than the best piston engine airliners (Sutter, 2006).

Less than two years after the Comet's maiden flight, it crashed three times in quick succession, with significant loss of life. A British Court of Inquiry concluded that the problem was metal fatigue, a topic that was little studied at that time (Sutter, 2006). Pressurizing and depressurizing the cabin weakened the airframe, resulting in metal fatigue and, ultimately, catastrophic failure should the airplane remain in service (Cook, 1991). The Court of Inquiry found that de Havilland's engineers used *standard* industry methods and technologies and were not to blame. Although pressurized flight was common in the defense arena, techniques were not yet advanced enough for use in commercial airplanes. Writes Sharp (1982: 324), 'The report (of the inquiry) was available to the industry throughout the world, and de Havilland had discussions with the British, American, and other manufacturers and technical bodies to make their experience available to all.'

De Havilland: spillovers and spill-ins

All of the engineers at U.S. manufacturers took note of this critical knowledge spillover. Many, including Boeing, were familiar with high-altitude flights, having conducted them in Boeing's B-29 bombers for the U.S. Air Force toward the end of World War II; thus, the notion of pressurizing a cabin was not novel. Still, commercial airplanes required more testing due to the differences in how they were used, a fact made clear by the Comet crashes.

At the time the de Havilland Comet was pressed into service (in 1952), Boeing was already working on a commercial jet engine prototype, called the Dash-80 after its model number, 367–80. This airplane would become the progenitor of a military transport jet airplane, KC-135, and the 707, Boeing's first commercial jet engine airplane. Based on the knowledge gained from de Havilland, Boeing engineers realized that the onetime pressure proof test de Havilland had used was no substitute for the high-cycle fatigue tests needed to assess the metal strength of the fuselage resulting from pressurizing and depressurizing the airplane in commercial settings. Boeing switched to high-cycle fatigue testing with the Dash-80 (Cook, 1991).

Having learned an important safety lesson from de Havilland, Boeing reciprocated by dispatching a group of engineers to Great Britain. They would assist their British rival in developing better tests to ensure aircraft safety. This reverse knowledge transfer was important, as it represented an effort to reassure the general public that jet engine airplanes were as safe and reliable as their propeller predecessors.

Figure 1 highlights the evolution of the Boeing 707 from 1945 to 1958. The knowledge spillovers and related spill-ins highlighted show how a series of knowledge events impacted the evolution of America's first commercial jet airplane. German experiments provided knowledge on the sweptback wing concept, which made high-speed flight a reality. A second knowledge spillover showed how the operating knowledge from the North American B-45s and Boeing B-47s affected the jet engine design of the Dash-80 prototype, which used a single pod design instead of the twin pod design employed on the B-47. Knowledge spillovers from the Comet crashes led to a better understanding of cabin pressurization and its impact on metal fatigue (Sutter, 2006).[12]

[12] Pressurizing the airplane was important, because in order to benefit from using jet engines, airplanes had to fly at much higher altitudes (about 30,000 feet) than did piston engine airplanes.

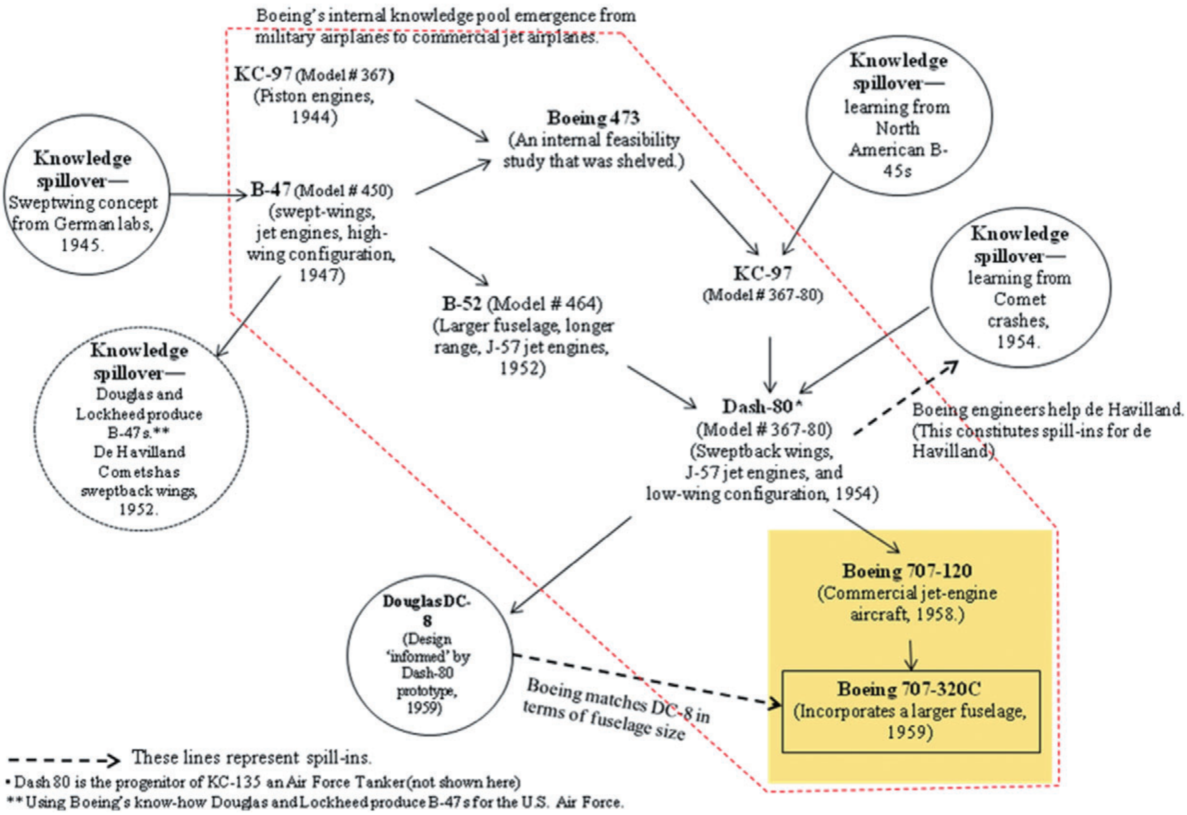

Figure 1. Knowledge spillovers, spill-ins, and the evolution of the Boeing 707 (1944–1958)

The knowledge spillovers that took place throughout this 14-year period were critical. As an external *knowledge spillover pool* regarding jet-propelled flight accumulated over time, Boeing and other manufacturers created their own *internal knowledge pool*. As shown in Figure 1, the 707 represented the culmination of the knowledge based on external and internal sources acquired over a significant period. Even so, this airplane was viewed as a radical new product in the world of commercial aviation.

> The Boeing 707 caused a veritable sensation when it entered service. Sleek and quiet, at least from the passenger's perspective, it was also extremely comfortable. Gone was the fatiguing drone and vibrations of those big reciprocating engines of the propeller era . . . The 707 was also fast and carried more payload. It had about 140 passenger seats. In contrast, the DC-6B—the most successful of the postwar piston airliners—had 66 seats, the DC-7C had 110, and the Lockheed Super Constellation and Stratocruiser (when not fitted with sleeper berths) each had just under 100 . . . This combination of greater speed and greater payload gave the 707 four to five times the productivity of propeller planes. Needless to say, this astonishing jump in productivity made the 707 a very, very popular airplane with the world's airlines! So well did the 707 sell that it single-handedly established Boeing as one of the world's premier manufacturers of airplanes. (Sutter, 2006: 70)

While this was undoubtedly true, when examined in the context of other Boeing innovations, the airplane's evolution was based on a significant internal knowledge pool and innovations acquired by Boeing over a long period.

Market-knowledge spillovers and spill-ins

As seen in Figure 1, Douglas produced the DC-8 by imitating Boeing's prototype, the Dash-80. The DC-8 was scheduled to reach the market a year after Boeing 707's introduction. In an effort to blunt

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orders for the 707, the Douglas design deviated slightly from Boeing's prototype. Douglas's *announced* version had a fuselage that was three inches wider than Boeing's 707–120. Douglas claimed this *minor* difference would have a *major* impact on the economics of the airplane's operation. The extra three inches provided sufficient width for six abreast seating, three on each side, while the Boeing 707 was configured for five abreast, three on one side and two on the other. The Douglas pitch was 'wait a little longer and you can buy a better airplane' (Serling, 1992: 132).

At the time, Douglas had a solid reputation in commercial airplanes, while for all practical purposes Boeing had none. To Boeing's chagrin, some of the important airline customers (e.g., United Airlines) decided to await the arrival of the DC-8. Imitating Douglas, Boeing introduced the 707–320 (see Figure 1) at the same time that the DC-8 was introduced. In other words, as a result of market knowledge spillovers, Boeing sales executives found out that Douglas's proposed airplane was slightly wider than the Boeing 707 and that this *minor* detail (just a few inches) mattered enormously to airline customers thanks to its impact on airplane economics. As one project manager of the Boeing program explained back in 1957, 'You don't design an airplane and build it and sell it. You design it and design it and somebody is selling it along the way, and any time during the program you may miss a competitive point and lose possibly your entire program. So you have to be fast on your feet in this case and it takes hundreds if not thousands of engineers and a lot of money' (Steiner and Sutton 1957: 15). The revised version of the 707 was an inch wider than the DC-8 and had the same seat configuration, but cost Boeing millions of dollars in retooling. In the competitive marketing battle that followed, Boeing outsold Douglas.[13] Unlike the technical knowledge spillovers and spill-ins discussed earlier, this dynamic between Douglas and Boeing was based on market knowledge and customer preferences for airplane seating configurations.

In sum, a series of critical knowledge spillovers and related spill-ins, both technical and marketing, occurred during the early stages of modern commercial aviation, making Boeing, a weak competitor in commercial aviation, their prime beneficiary (as discussed in detail later).

Narrative #2: Understanding the situational context

It was Boeing that benefited from the introduction of the jet engine commercial airplane, not de Havilland, the first mover, nor Douglas, the industry leader. This raises a question about the role firm situational factors played in the process of who benefited from spillovers and spill-in. Stated differently, why was Boeing better positioned than Douglas or other rivals to introduce America's first commercial jet airplane?

At the time of the 707's introduction in 1958, the Douglas Company was the 'world's undisputed leader in the design and manufacture of commercial airliners' (Sutter, 2006: 58). With its DC series of piston engine propeller planes, Douglas was the world's largest aircraft company, accounting for more than 70 percent of the market share in commercial aviation. Lockheed was another respected U.S. company, with its Constellation aircraft. These firms were followed by Boeing, which had a small commercial division. So what prevented Douglas or Lockheed from introducing a jet-propelled aircraft?

Douglas's situational context

In the late 1950s, Douglas was producing propeller aircraft faster than any U.S. commercial manufacturer. Given its huge share of the U.S. market, the future in propeller airplanes looked bright. However, its DC-7 program, intended to replace Douglas's DC-6, proved to be an impediment. This program was launched to appease one of Douglas's biggest customers, American Airlines, which wanted the more powerful Wright 3350 compound piston engine in order to compete with TWA's newest version of the Lockheed Constellation, which had just been announced. At the time, the DC-6 was the best-selling commercial aircraft; Douglas did not want Lockheed to gain an advantage. Cook writes

> In late 1951 a decision at Douglas to forego the DC-7 in favor of a jet transport would have been quite

[13] In order to keep the scope of this article manageable, I didn't go into the competitive market dynamics between Boeing and Douglas following the launch of the 707 and DC-8. Further for the sake of simplicity and ease of exposition, Figure 1 captures only the significant innovations that led to the first commercial jet engine airplane produced by Boeing. It should be recognized that there were many other innovations, including changes to the design and location of the airplane's leading gear, innovations in flight control systems, the fuel tank design, improvements in cockpit visibility, and design of ground deceleration and thrust reversers, etc. (Steiner and Sutter, 1957).

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> difficult. Douglas would have had to convince C.R. (Smith, the head of American Airlines) to stay with the DC-6 until the jet transport could be developed. But the Douglas preliminary design unit probably did not yet have the available sufficient design studies or wind tunnel test data on jet transports. (Cook, 1991: 232)

As a result, the launch of the DC-7 program absorbed considerable engineering, management, and financial resources at a time when Boeing was building the Dash-80.

In retrospect, Douglas's engineers may have been overconfident that they could transition to jet airplanes without a prototype like the one Boeing was designing and testing. Cook concludes that 'such a prototype would have reduced the time required to develop and introduce the DC-8 (the jet-propelled Douglas airplane). The slowness of the DC-8 program (the company's response to the 707 airplane) prevented Douglas from matching Boeing delivery dates of the 707, and this eventually proved to be a crucial factor in the initial competition to sell jet transports to the airlines' (1991: 233). Lack of a prototype delayed the project, leaving the field open for Boeing at a time when Douglas underestimated the capabilities of Boeing's engineers.

> They (Douglas) ridiculed and dismissed us as a bunch of rosy-cheeked engineers who didn't have a clue about building airplanes. This derision spurred us on and fostered a tremendous rivalry. Trumping Douglas became something we were all very enthusiastic about in Seattle. (Sutter, 2006: 66)

Lockheed and de Havilland's situational contexts

For its part, Lockheed was unsure about the future of jet engines and unwilling to bet on it. In those days, jet engines could best be described as experimental, something primarily developed for military applications and airplanes. Douglas too focused on the next generation of *turboprop* engines because of their promised higher *theoretical* efficiency. Pratt & Whitney, the largest U.S. manufacturer, with an almost 90 percent share of the market for aircraft engines, was feverishly working on the T-34. The company considered the turboprop 'the commercial transport engine of the future, even though Pratt & Whitney already was well along in the development of their J-57 jet engine for the B-52′ (Cook, 1991: 229). Instead, Lockheed focused on stretching its piston engine Constellation, which was launched exactly one year after Pan Am placed its first order for the jet-propelled 707. Unfortunately for Lockheed, its airplane was no match (see Table 2 for a comparison of the different airplane configurations).

Regarding de Havilland, the British were new to the field of commercial aviation, having focused on building smaller fighter planes during World War II.[14] Although the British were inventors of the jet engine, they did not have the depth of experience or operating knowledge about high-altitude flight or cabin pressurization. Nor did the state of their knowledge truly encompass the impact of pressurization and depressurization on metal fatigue. As an unlucky first mover, de Havilland paid a huge penalty. But its failures informed the world about the potential perils of cabin pressurization and, thus, made flying safer for followers like Boeing and Douglas.

Boeing's situational context

The situation at Boeing was far different and more favorable for the start of a *risky* project (Lombardi, 2008; Sutter, 2006). In 1945, a reluctant Bill Allen was appointed to lead the company. Allen, a lawyer by training, was the first non-engineer to take the helm. The defense contracts Boeing depended on so heavily had all but vanished. More than $1.5 billion in war contracts were gone, and one of Allen's first tasks was to lay off 38,000 workers (*Time*, 1954).

Searching for strategic opportunities

Given their dire situation, Allen and others at Boeing were receptive to the idea of a radical airplane design that focused on commercial aviation.

> At Boeing the decision to take a radical approach was comparatively easy, as competing programs with Boeing were winding down. The last Stratocruiser had been delivered in 1950, ending

[14] As early as 1943, British government officials recognized that once the war was over, the Americans would be poised to dominate commercial aviation. They correctly reasoned that many of the bombers used in the war, which were manufactured exclusively by the Americans, could be converted into large commercial airplanes. Recognizing an opportunity and willing to make an uncertain bet, they convinced de Havilland to develop the Comet and provided the necessary technical assistance (Sharp, 1982).

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Table 2. A comparison of the jet airplanes by Boeing, Douglas, and de Havilland

Model #	Boeing Corporation*		Douglas Corporation**	British de Havilland***	
	707–120	707–320C	DC-8–32	Comet-I	Comet-IV
Wing span	130′–10″	145′–10″	142′–9″	115′	115′
Length	145′–1″	152′–11″	150′–6″	93′	111′–5″
Tail height	41′–8″	42′–5″	42′–4″	28′–5″	29′–5″
Wing area (sq ft)	2,433	2,892	2,771	2,027	2,121
Gross weight	248,000 lbs	336,000 lbs	310,000 lbs	105,000 lbs	162,000 lbs
Cruising speed/wing sweepback angle	600 mph/35 degrees	600 mph/ 35 degrees	588 mph/30 degrees	450 mph/20 degrees	500 mph/20 degrees
Passenger capacity/ payload	181	219/96,800 lbs of cargo	176/NA	36/12,500 lbs of cargo	81/12,500 lbs of cargo
Range (miles)	3,000	4,000	4,605	1,500	3,225
Service ceiling	41,000 ft	41,000 ft	41,000 ft	42,000 ft	40,000 ft
Engine (4×)/thrust	Pratt & Whitney JT3C-6/13,500 lbs	Pratt & Whitney JT3D/18,000 lbs	Pratt & Whitney JT4A/16,000 lbs	Ghost-50/5,000 lbs	Avon RA.26/10,500 lbs

*Source: Redding and Yenne, 1983; **Source: Maynard, 1962; ***Source: Sharp, 1982.

> Boeing's commercial business for the time being. In 1951 Boeing lost a military competition for a four-engine turbo-prop cargo plane to Lockheed, which would produce the C-130 . . . The jet bomber business had generated a lot of enthusiasm within Boeing, and so management was open to the idea of a commercial jet transport, especially since it appeared to be the one remaining opportunity. (Cook, 1991: 233)

By working on jet engines for the B-47 program and later the B-52 bomber, Boeing largely erased the doubts it had once had about such engines. It also eliminated concerns about the engines' reliability, a major issue when jet engines were perceived as an *experimental* and *emerging* technology (Sutter, 2006).

Investing in knowledge assets

In the late 1940s, long before the launch of the Dash-80, Boeing had made a crucial investment, one that would turn out to be highly significant. Up to that time, there had been only two wind tunnels with advanced capability in the United States; one was located at MIT and the other was at Cal Tech. Boeing, along with Douglas, Lockheed, and others, used the facility in California. Boeing decided that, in order to keep experimental data from leaking to its competitors, the company needed its own wind tunnel and spent a substantial amount to build one in Seattle. In a 1957 presentation discussing the evolution of the 707, Sutter explained,

> You will notice . . . that to do all of the work, going from the B-47 to the B-52 and then finally to the 707, we spent 10,000 wind tunnel hours . . . It is interesting to note that even after the B-52 was developed, there were still 52 wings developed during the 707 series . . . In total, the basic wind tunnel work on these three airplanes took 27,000 hours, so you can image that the wind tunnel is pretty highly used. From the aerodynamicist's standpoint we feel very fortunate to have a wind tunnel of the speed range we have. This is the only company that has its own wind tunnel to do this work. Other people either have to go to co-op tunnels or use a NACA or Air Force facility. Their scheduling in and out of these wind tunnels is much more difficult than ours and their ability to make changes in their progress is much more difficult, so we really are quite fortunate here at Boeing. (Steiner and Sutter, 1957: 42)

The tunnel and accompanying experiments on supersonic flight turned out to be decisive in understanding aerodynamics. Initially, the investment was largely directed at protecting knowledge from spilling over to competitors, as well as gaining an advantage over rivals in landing military contracts. As Cook explains, 'What made the difference for Boeing was the wind tunnel. While at least a few engineers at Douglas felt that the jet age was imminent, without the full time use of a high-speed wind tunnel they could not convince their management to proceed towards building a (jet engine propelled airplane) prototype' (1991: 232). Douglas lacked a prototype; but Boeing had one.

Willingness to assume risk

Building the Dash-80 prototype was no accident. In order to build the Dash-80, Allen committed $16 million (about $160 million in today's currency), an amount that represented Boeing's entire profit since the end of the war (Lombardi, 2008). As head of the company, he took the risk of making a large financial commitment to an airplane that had neither interest from airlines nor a government contract. 'We felt strongly that it was high time some American manufacturer took the plunge and got a jet transport off of and into the air' (Allen, quoted in Lombardi, 2008: 164). This willingness to commit resources to a risky prototype would turn out to be a crucial turning point in the competitive battle between Boeing and Douglas.

It was common practice during these early years for aircraft producers to respond to requests for proposals from the government. Once selected, the chosen proposals were funded and monitored by the U.S. Air Force. Interestingly, this approach was also followed in the civilian sector, where existing airline companies defined the specifications and then requested airplane manufacturing to bid on their proposal for contracts. In contrast to this prevailing practice, Allen decided to build a prototype *without orders and then sell the airplane*. In other words, Allen saw an opportunity and decided to seize it.

Organizational slack, chance events, and theatrics

It was also a time when the B-52 engineering design was winding down, which freed up engineering talent for other programs (Cook, 1991: 232). As luck would have it, the Air Force asked Boeing to incorporate a jet engine in the B-52 instead of the turboprop engine that Pratt & Whitney proposed. Fortunately for

Boeing, the J-57 jet engine happened to be a good fit for the 707-sized transport (Cook, 1991).

Not only was the Boeing 707 a faster and superior airplane relative to the Comet and other propeller airplanes, the company showed the world it was a safe aircraft. A pivotal event, now legend in the industry, dramatically illustrated Boeing's confidence in its new aircraft. In 1955, at a hydroplane event on Lake Washington in Seattle attended by numerous Boeing customers and reporters, Tex Johnson, the legendary Boeing test pilot, flew the Dash-80 low over the race course and, to the amazement of the spectators, performed an unauthorized *barrel roll*. The Dash-80 was the progenitor of the 707–120, Boeing's first commercial jet airplane, which was purchased by Pan Am. Although Boeing officially condemned Johnson's acrobatics, particularly in the context of the Comet's tragic mishaps, such theatrics paid off handsomely for Boeing (Lombardi, 2008).

In sum, the situational factors (industry and firm level) faced by each airplane manufacturer were different and influenced how they viewed potential opportunities in the emerging commercial aviation industry in the face of knowledge spillovers and growing industry knowledge about jet engine flight. Combining the two narratives discussed above, the framework that emerges is a nuanced view of the interplay among knowledge generation, external knowledge spillovers and spill-ins, and strategic entrepreneurship.

Below, I discuss the performance implications the knowledge spillovers have for the new entrant, the incumbent firms, and society at large.

Narrative #3: Impact on originators, recipients, and society

Knowledge originators

Dr. Adolph Bussman is often credited with the theoretical concept underlying the effects of sweepback on airflow at supersonic speeds. In 1935, Bussman, a German professor of mathematics, presented a paper describing the phenomenon in Rome, at a conference organized by General Arturo Crocco (The Fifth Volta Congress of High Speed Flight). Bussman had no suggestions for the practical applications of his concept (Cook, 1991).[15] However, it was the Germans who provided the first concrete evidence, based on scientific wind tunnel tests, of the relationship between sweptback wings and flight speed (Sutter, 2006), though they did not benefit from their findings for obvious reasons.

The British are credited with inventing the jet engine and successfully building jet engine fighters during World War II (Lynn, 1995). While de Havilland was the first to introduce a commercial jet engine airliner, its Comet was plagued by crashes. De Havilland did redesign and placed newer versions into service, the Comets II, III, and IV. Unable to attract interest or sufficient demand for the airplanes, the company withdrew from commercial aviation.

One reason for the airlines' lack of interest in the Comet was the 707 (see Table 2).[16] An article in *Time* magazine captured what the Boeing model meant to U.S. airplane manufacturers:

> America's first entry in the jet-age commercial air race is far more than just an answer to Britain's ill-fated Comet I, or the Comet's bigger sisters, II and III. The 707 is as much of an advance over Britain's early leader as the swift advance of jet-aircraft design will allow. Its graceful fuselage sweeps back 128 ft., a full 35 ft. longer than the Comet I. In its fuselage, almost as wide as a living room and as long as a ballroom, it can carry 130 passengers, versus 48 for the Comet I . . . Its four burly Pratt & Whitney J57 jet engines blast out more than 40,000 lbs of thrust, twice the power of the Comet's four engines, enough to push the 707 through the sky at 550-m.p.h. cruising speed, about 60 m.p.h. faster than the Comet I, about 50 percent faster than the fastest prop-driven airliners. The 707 is designed to fly the Atlantic in less than seven hours, give the sun a race from east to west. It will be able to leave New York at noon, arrive in Los Angeles by 1:30 p.m. (*Time*, 1954)

Knowledge recipients

Prior to the 707, Boeing had been the undisputed king of the bomber builders, producing more than

[15] The first sketch, credited to General Crocco, depicting an airplane with a sweptback wing and propeller blades, was made on the back of a menu (Cook, 1991).

[16] The British Overseas Aircraft Company used the Comet IV for service across the Atlantic on October 4, 1958, three weeks ahead of the 707's introduction. But the Comet IV was 'no match for the vastly superior performance, capacity, and operating economics of the Boeing product. Great Britain's once-bright hopes for a dominant role in postwar commercial aviation faded quickly' (Sutter, 2006: 68).

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22,500 planes, from gnat-like fighters to flying boats.[17] By 1945, Boeing had more than half the nation's installed manufacturing capacity for the B-17 and B-29, bombers that were heavily used during World War II (Newhouse, 1985).

With the launch of the 707 airplanes, Boeing would move toward building commercial jet airplanes. In time, Boeing would become America's premier manufacturer of airplanes, a title held by Douglas since 1934. The commercial aviation business would become a fundamentally different business and over the next decade, Boeing would emerge as its premier commercial manufacturer. In other words, it would transform into a completely different company.[18]

By 1968, Boeing's revenues totaled $3.27 billion. Military aircraft, which in 1958 (the year Pan Am took delivery of the first 707s) represented more than 90 percent of its revenues, now represented just $422 million, or 12.8 percent. Over the decade, a significant change had occurred—Boeing had become a commercial aircraft company. The defense-related activities that had once dominated company activities would provide a smaller proportion of total revenues, a situation that lasted until 1997, when Boeing and McDonnell-Douglas merged.

Societal benefits

It would be an understatement to say that the jet airplane changed transportation or made the world smaller. Initially, these airplanes made airlines more productive by decreasing operating costs, enabling them to reduce fares and render air travel affordable to the public (Lombardi, 2008). The introduction of the jet airplane, first by Boeing, then a year later by Douglas, finally followed by Lockheed, would change many industries dramatically. There were winners and there were losers, but the revolutionary shift from propeller to jet changed the world for the better.

> By 1967 it was clear that the jet transport had taken over long-range travel. At that time most of the luxury Atlantic Ocean liners had been converted to cruise ships, and the luxury trains between New York and Chicago, the Twentieth Century Limited and the Broadway Limited, had all ended service. In addition, all first class mail had been transferred to the airways. This situation may been predicted by aviation enthusiasts in the 1940s when the four-engine transports with its piston power plants were operating, but it took the demonstration of the jet transport's comfort, speed, and long- range capability in the mid-1950s to bring the idea of mass transportation by air to general acceptance. (Cook, 1991: 1)

In retrospect, some knowledge originators certainly failed to benefit from the emergence of the modern commercial aviation industry. Boeing benefited from knowledge spillovers, but it also created a series of innovations that were imitated by equally competent rivals. While the net benefits to society are positive, untangling all of the benefits of the jet engine airplane is a complicated story that will take years to unfold.

DISCUSSION

Building on the emerging literature that depicts spillovers as a positive force, this study examined the spillovers, spill-ins, and the role strategic entrepreneurship played in the road to America's first commercial jet-propelled airplane. All major industry players benefited from multiple knowledge spillovers and spill-ins that occurred during the period of the study. Boeing and other U.S. manufacturers benefited directly from the German spillover[19] and so did Britain's De Havilland. The DC-8 imitated Boeing's 707 airplane and Boeing, in turn, imitated the DC-8 by enlarging the 707's fuselage. Also,

[17] During the 1920s and 1930s Boeing built the fastest pursuit ships and bombers in the United States. The company pioneered and streamlined metal airplanes, including the four engine Clipper, which helped launch regular transatlantic service.

[18] There are stark differences between the military and commercial aviation industries (Newhouse, 1985). In commercial aviation, the path to profitability is a long and difficult one. The high initial investment needed to produce an airplane may not be recovered for years, if ever. In the case of military airplanes, the government assumes all or most of the cost of developing an aircraft. Military aviation involves one customer, and the number of airplanes in production tends to be more fixed. With commercial aviation, the number of airplanes eventually sold is more uncertain, so the learning curve can be trickier. For military aircraft, standardization is the norm. This is not the case for commercial aviation. Since multiple customers are involved, airplane configurations can vary considerably.

[19] Schairer's (1945) handwritten note to his colleagues left a trail proving that it was German knowledge that lay behind the experiments that led to the B-47's revolutionary design.

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knowledge spillovers from the Comet crash investigations significantly improved airplane safety for the entire industry. As a result of multiple spillovers, an *industry* knowledge spillover pool emerged over time, which influenced the airplane's dominant design and each manufacturer developed a *company*-specific knowledge pool.

Although the knowledge spillover regarding the sweepback wing was key to transitioning the industry to high-speed jet engine flight, neither the Germans nor de Havilland, the first mover, benefited. The Germans lost for obvious reasons, and De Havilland lacked the Americans' experience with high-speed flight and cabin pressurization. Boeing's major innovations implemented in the B-47 were shared with Douglas and Lockheed. The DC-8, Douglas's first commercial jet, was *informed* by Boeing's Dash-80 prototype. Despite all of this, it was Boeing that benefited the most by becoming the industry leader.

CONTRIBUTIONS

This study contributes to the extant spillovers-spill-ins literature in multiple ways. The patterns observed here confirm the early work that knowledge spillovers: (1) influenced innovative activity (Henderson and Cockburn, 1996) as evidenced by the numerous innovations that were triggered after the German knowledge spillover and the launch of the B-47 airplane; (2) enabled competitive entry (Jaffe, 1986) as seen by Havilland's entry into the industry; and (3) benefited recipients at the expense of originators (Arrow, 1962) as evidenced by Douglas vicariously learning from Boeing's 707 prototype without having to invest in its own prototype. More importantly, it also confirms the key assertion of the emerging spillovers-spill-ins literature, which asserts that knowledge spillovers can result in spill-ins or spill-backs that benefit both originators and recipients.

Building on this emerging literature, the study provides many novel insights that are only possible from a detailed, fine-grained examination of the phenomenon. One broad insight is that this phenomenon is emergent and more complex than discussed in the extant literature. The complexity partially stems from the *multiple* spillovers and related spill-ins that occurred at *various* times in the industry, triggering firm-level innovations via endogenous knowledge generation by industry actors over a long time period. It also partially stems from the numerous ways in which spillovers and spill-ins occurred. The knowledge spillover mechanisms in extant literature have focused on employee mobility (Agarwal *et al*., 2007), R&D spending of rival firms, and the role played by universities located in a firm's a geography in enabling knowledge spillovers (Jaffe, 1986, 1989). In contrast, I found that knowledge spillovers and spill-ins occurred in numerous other ways. Spillovers also occurred through: (1) unpredictable events (e.g., knowledge from German labs); (2) catastrophic accidents and the public inquiry that followed; (3) competitive monitoring of rivals followed by imitation and experimentation; and (4) governmental actions that required firms to transfer valuable information to rivals. Complexity also resulted from the different types of knowledge spillovers that occurred, a point that the extant literature has failed to distinguish. The types of knowledge spillovers observed included: conceptual/theoretical knowledge (i.e., knowledge on potential of high-speed flight); experiential (lab and field) knowledge (i.e., details about the sweptback wing design); operating knowledge (e.g., information gathered from operation on the dual pod engine failures; cabin pressurization); and market knowledge (e.g., information gathered from customers and rivals' marketing moves).

The introduction of a jet engine plane was largely an emergent process that unfolded over a long time period. In all, it took 23 years for a safe commercial aircraft to emerge that the general public, not just test pilots, were willing to fly in.[20] Importantly, the dominant design introduced represented knowledge accumulated over multiple iterations based on different knowledge spillovers, internal experimentation, and a fundamental understanding of how to build and test such a product. In sum, these observations taken together suggest that by viewing incumbents merely as knowledge factories for new entrants, the literature grossly underestimates how knowledge spillovers and spill-ins and subsequent innovations unfold in practice (Agarwal *et al*., 2007). Also, by relying extensively on patent citation counts to operationalize and capture the knowledge spillovers, past

[20] It was 10 years from the time Dr. Bussman gave his presentation in Rome on high-speed flight and would be another seven before de Havilland introduced the Comets. Another six years would go by before the 707 airplane was introduced and finally emerged as the *dominant* design.

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research (e.g., Henderson and Cockburn, 1996; Jaffe, 1986, 1989; Yang *et al*., 2010) is yet to address the richness and complexity underlying this interesting and important phenomenon.

This study also contributes to our understanding of the *creative construction* arguments as put forth by Agarwal and her colleagues (2007). From the patterns observed, I was able to marshal only partial evidence to support their assertions. The introduction of jet engine airplanes didn't lead to *creative destruction* as envisioned by Schumpeter (1934), nor did the outcome reflect the *creative construction*. Instead, the reality appears to be more nuanced, with both processes operating simultaneously. Within the context studied, although industry leadership changed, all players continued to maintain respectable market positions well into the future. Also, the introduction of the jet airplane did eventually *destroy* other industries (passenger rail, oceangoing liners, and domestic mail carriers to name a few). From the vantage of these industries, the forces unleashed by the jet airplane's introduction truly represented *value destruction*, to echo Schumpeter. At the minimum, this suggests that more research pertaining to boundary conditions underlying creative construction is needed to better delineate this phenomenon and distinguish it from creative destruction.

The study also contributes to the emerging literature on the spillover-spill-ins phenomenon by identifying factors that played an important role in who benefitted from industry spillovers and related spill-ins. First, the pattern that emerges suggests that critical knowledge spillovers often triggered a cycle of internal experimentation that resulted in accumulating a deep internal knowledge pool in some firms. Also, the internal knowledge pool and the external (industry) knowledge pool coevolved over time, as shown in detail with respect to Boeing. However, the industry pool that emerged resembled a shallow *puddle* more than a deep pool. Also, the firm-specific internal knowledge pools were just as critical, if not more so, in the race to build a commercial jet airplane. Perhaps it is this interplay between the external knowledge spillover *puddle* and a deep firm-specific internal knowledge pool that provides a partial explanation of why some firms are better positioned to leverage and benefit from knowledge spillovers and spill-ins. At the minimum, in addition to size and similarity of the external knowledge pool examined by Yang and her colleagues (2010), this insight suggests that researchers need to account for the direct, mediating, or moderating effects of a firm's internal-knowledge pool to isolate the effects of who benefits.[21]

Second, the study underscores the importance of *opportunity-seeking behavior* to benefit from external spillovers. In this context, opportunity-seeking behavior is the willingness of a firm to take risks and invest in knowledge assets to pursue a *new* opportunity (Hitt *et al*., 2002; Ireland *et al*., 2003). Boeing (and, to a large extent, De Havilland) had the vision and took significant risk producing a commercial jet airplane when the market for such an airplane was uncertain, at best. Boeing, in particular, was actively searching for new strategic opportunities and had invested in its own wind tunnel facility, the only company to make a significant investment in such knowledge assets.[22] Also, its decision to build a prototype was no accident, but a calculated decision that involved significant financial risk, since Boeing did so without government contracts or airline orders. This was a business move that differed significantly from conventional industry practice. Douglas was also seeking opportunities, but was focused on turboprops and not jet engine propelled commercial airplanes. For its part, Lockheed was not seeking new opportunities.

Boeing's situational context provides a partial explanation for its opportunity-seeking behavior. The firm was fortunate to have considerable organizational slack (Nohria and Gulati, 1996; Rothaermel and Hill, 2003), since many of its defense related projects were winding down just as the Air Force's interest in jet flight arose. For its part, Douglas was preoccupied with protecting its leadership status by satisfying its customers using piston engine technology (Christensen, 1997), while Boeing had little in the way of past investments to protect. Lacking experience, Lockheed was reluctant to adopt emerging technology in order to stay competitive (Ahuja

[21] To a large degree, this internal knowledge pool constitutes a firm's absorptive capacity (Cohen and Levinthal, 1990). In contrast to the extant literature, where *absorptive capacity* is often used as a catchall term for R&D investments, the analysis given here fleshes out the concept by detailing how such a capacity is generated. In other words, by analyzing the evolution of the Boeing 707, the complexities, resource commitments, and length of time involved in generating firm-level absorptive capacity become visible.

[22] Boeing built this facility to stop knowledge spillovers to its California rivals, Lockheed and Douglas, whenever it used the wind tunnel facility at CalTech in California. It suspected that vital information from its experiments was spilling over to its rivals. Spillovers in this case were through graduate students hired by Lockheed or Douglas who had helped manage the CalTech facility and run tests for Boeing prior to graduation.

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and Lampert, 2001; Stuart and Podolny, 1996), and this clearly was not the case with Boeing. The generalizable pattern that emerges suggests that firms with (1) greater slack resources; (2) a broader market rather than a customer-specific orientation (Slater and Narver, 1998); and (3) considerable experience with emerging or experimental technology are more likely to leverage knowledge spillovers and spill-ins. In other words, the willingness to act on knowledge spillovers is situation specific and endogenous to firms in the industry.

Finally, the competitive dynamics between the British and Americans and the battles between the 707 and DC-8 also provide a partial explanation of why Boeing benefited more from the transition to commercial jet airplanes. On the one hand, in discussing the impact of competitive dynamics on focal firm performance, strategy researchers often evoke the notion of Red Queen competition to explain how each firm's performance is contingent upon the firm's matching or exceeding the actions of rivals (Barnett and Hansen, 1996; Derfus *et al*., 2008).[23] According to Barnett and McKendrick, the characteristic of such Red Queen competition 'is that one organization's solution becomes its rivals' problem. The resulting increased constraints, again in turn, are likely to trigger responses among rivals, again intensifying competitive constraints on the first organization, and so on' (2004: 540). Derfus *et al*. (2008) observe that the effect of such competition is incremental and coevolutionary and as such it is consistent with Schumpeter's *creative destruction* argument.[24]

On the other hand, technology and innovation researchers have evoked the metaphor of *leapfrogging* to describe how new entrants adopt radical innovations to dislodge existing incumbents and, thus, gain a leadership position within an industry (cf. Schilling, 2003). Since leading incumbents have little incentive to innovate in the face of radical technological change (Christensen, 1997; Schumpeter, 1976), they invariably lose their leadership position to new entrants who are willing to adopt such innovations to *leapfrog* incumbents. Often this is the outcome when the radical innovation becomes the established technological paradigm (Dosi, 1982).

The competitive dynamics observed here appear to be a mix of these two characterizations of competition. Boeing took a risk and adopted a radical technology—jet engines—to launch a revolutionary airplane, a move that Douglas had little incentive to pursue given its leadership position. However, Douglas reacted to Boeing's competitive move by adopting the radical technology, and the competitive dynamics that ensued reflected elements of the Red Queen competition, as discussed in the literature.[25] In other words, Boeing leapfrogged its rivals by changing the technological paradigm, but in the process triggered a Red Queen sort of competition with Douglas. In this case, using market knowledge spillovers, Boeing modified its product to meet customer needs and gained industry leadership over the next few years.

In sum, this study demonstrates that the effects of knowledge spillovers and spill-ins on performance are complex and dependent on many factors that literature is yet to address. A generalizable framework that examines why some firms, and not others, benefit from knowledge spillovers and spill-ins should, at the minimum, account for many of the factors I've highlighted. Doing so can provide a holistic explanation of the spillovers-spill-ins phenomenon and help researcher better delineate its impact on originators of knowledge and recipients alike.

LIMITATIONS AND FUTURE RESEARCH

This is one of the first inductive studies to examine the role of knowledge spillovers, spill-ins, and their impact on strategic entrepreneurship in a specific context. While this may limit the generalizability of the findings, it has enabled me to take a more fine-grained approach to analyzing how knowledge

[23] Red Queen competition is based on the conversation between Alice and the Red Queen, both characters in the book *Through the Looking Glass* by Lewis Carroll (1960). Alice notices that despite running as fast as she could, she is unable to get anywhere relative to her surroundings. The Red Queen explains Alice's situation by saying 'Here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!' (Carroll, 1960: 345).

[24] As noted earlier, when firms innovate to gain an advantage in the marketplace, they often see this advantage erode as a result of their rivals' competitive moves (Schumpeter, 1976).

[25] In this context, the rendition of competitive dynamics as Red Queen competition appears more in line with the early discussions of knowledge spillovers (i.e., spillovers primarily benefit rivals and not the originating firm). Rivals, using spillovers, can imitate the knowledge-originating firm thereby providing it with only a short-lived relative competitive advantage.

spillovers and related spill-ins impacted the dynamics leading to the first U.S. commercial jet airplane. Such detail would be difficult—if not impossible—to capture through large sample studies (Poole and Van de Ven, 1989). However, more studies are needed before it is possible to generalize and isolate the processes that played a critical role in this instance.

The current study examined an industry where product life cycles are relatively long; an average commercial airplane can remain in service for close to 25 years. Also, the launch of a new airplane involves significant investment. This alone makes it difficult for competitive entry and rapid technological paradigm shifts (Dosi, 1982). Thus, it would be interesting to examine industries with fast product cycles (consumer goods, software, and electronics), where knowledge obsolescence is more rapid. The importance of technological spillovers, spill-ins, and strategic entrepreneurship will likely differ in such high-velocity environments (Eisenhardt, 1989b). Such an undertaking would enable researchers to draw boundary conditions for a number of the assertions presented here and would be a logical extension in examining the assertion that knowledge spillovers and spill-ins are context-specific.

Much of the literature on knowledge spillovers and, more recently, knowledge spill-ins (Yang *et al*., 2010) has focused on the critical role played by *technical* knowledge spillovers and their impact on firm-level innovation. However, since both technical and market knowledge are both potentially important in entrepreneurial situations (Abernathy and Clark, 1985; Agarwal *et al*., 2004), researchers need to distinguish between the two types and examine the approaches that firms may use in order to benefit from them. In the case of the 707, Boeing executives were locked in a competitive marketing battle with the Douglas DC-8 after the technical details had been finalized and the airplane was already in production. As a result of market knowledge spillovers, Boeing sales executives found out that Douglas's proposed airplane was slightly wider than the Boeing 707 and that this minor detail (a matter of few inches) mattered enormously to airline customers because of airplane economics. This illustrated the importance of market knowledge spillovers and their potential in significantly impacting commercial outcomes. Thus, distinguishing and examining different types of knowledge spillover and their impact on firm-level outcome is a logical extension of the research.

Many of the extant studies on knowledge spillovers have relied exclusively on patent citation data to empirically examine firm-level outcomes resulting from spillovers. There are numerous drawbacks associated with the use of patents for capturing knowledge flows among firms, a fact which needs no elaboration here (cf. Alcacer and Gittelman, 2006). In general, studies using patent citation data limit their capacity to highlight the importance of knowledge spillovers for the subsequent innovation they produce (Yang *et al*., 2010) and rarely capture the net economic benefit that results from this phenomenon. To better understand its impact, it is important that researchers examine performance outcomes other than the innovation impact on originating or recipient firms.

In many arenas (e.g., urban planning, city planning, and medical research), state-of-the-art knowledge and our understanding of a phenomenon are considerably advanced when unpredictable catastrophes occur. I have shown how the Comet airplane crashes provided invaluable information about cabin pressurization and metal fatigue, a relatively unknown phenomenon during the early days of high-altitude commercial flight. In this instance, de Havilland's executives made it their mission to educate airplane producers about this potential danger. Such deliberate knowledge transfers resulted in devising advanced metal-fatigue tests that made jet airplanes safer and also helped the industry gain legitimacy in the eyes of a reluctant public. If the originators of this knowledge had been unwilling to share it, it is unclear how the emergence of the jet commercial industry might have been impacted. Few researchers have examined how knowledge spillovers from catastrophic events impact industry emergence or how they enable or hinder critical innovations that could impact the legitimacy of an emerging industry (or a product category) or function as a source of entrepreneurial opportunity.[26] Who benefits from such knowledge flows and how

[26] Companies involved in such events, it could be argued, have a moral obligation to provide such knowledge to other firms so that public safety and human lives are not at risk. This is especially true in the case of knowledge generated from drug trials, but may be equally important in other industries. For example, the issues that face Toyota regarding accidental or unanticipated acceleration are a case in point. If it is determined that such effects are due to the growing use of electronics in automobiles, shouldn't that information be provided to all car manufacturers? In other words, what are Toyota's obligations for making this information available to its automotive rivals? How might it benefit from doing so?

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such events can impact the legitimacy of emerging industries, is an area worthy of further exploration.

CONCLUSIONS

Knowledge spillovers and the concomitant processes that they trigger can provide a powerful lens for studying opportunity- and advantage-seeking behavior in incumbents and entrants and the outcomes of this dynamic. To conclude, this study's most important contribution is to assert how internal knowledge generation and external knowledge spillovers and related spill-ins are necessary, but not sufficient, conditions for organizations to benefit from opportunities. What is required in addition to these elements is strategic entrepreneurship—having the foresight to seize opportunities and the willingness to make the necessary knowledge and financial investments needed to exploit the opportunities that present themselves. This study sensitizes researchers to examine the interplay among knowledge generation, knowledge spillovers and spill-ins, and strategic entrepreneurship. Additionally, researchers need to account for situational and competitive dynamics in order to explain firm-level performance outcomes. I hope the knowledge spillovers from this work will motivate researchers to study this phenomenon in other settings and that we as a field will dig deeper into the complexities they yield and their impact on new and existing firms.

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