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ENTREPRENEURIAL "TWEAKING": AN EMPIRICAL STUDY OF TECHNOLOGY DIFFUSION THROUGH SECONDARY INVENTIONS AND DESIGN MODIFICATIONS BY START-UPS

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Abstract

Existing theories of technological innovation posit a split between the incremental innovations produced by large incumbents and the radical innovations produced by entrepreneurial start-ups. This study presents empirical evidence challenging this foundational assumption by demonstrating that entrepreneurs play a leading role, not a subordinate role, in sourcing incremental innovations through secondary inventions and design modifications. Among the 100 highest-ranked incremental innovations leading to the commercialization of the mechanized reaper and cloud computing services, nearly 90% were attributable to entrepreneurial start-ups. Paradoxically, however, an entrepreneurial start-up had only a one in fourteen chance of garnering returns from a reaper innovation and a one in nine chance of gains from a cloud computing improvement.

Introduction

Much of the literature concerning innovation divides the universe into large-firm incrementalism and small-firm radicalism. Subject to some notable variations based on industry and environmental factors (Acs & Audretsch, 1987), this approach highlights the purported tendency of large firms to extract value from innovations through incremental improvements and efficient-scale replication of emergent technologies (Abernathy & Utterback 1978, Utterback, 1994; Baumol, 2004). Entrepreneurial ventures, meanwhile, are widely believed to possess an advantage in engineering revolutionary breakthroughs (Acs & Audretsch 1990; Banbury & Mitchell, 1995; Baumol, 2004; Acs et al., 2009). Although this incumbent versus entrepreneur bifurcation has gained considerable support, I assert in this paper that the dichotomy is problematic, because in addition to driving radical innovation, new ventures play a pronounced role in the commercialization of breakthrough technologies through entrepreneurial "tweaking."

In the broadest sense, tweaks are "small modifications intended to improve a system" (OED, 2012). In the context of innovation economics, Meisenzahl and Mokyr referred to tweaking as "the myriad of small and medium cumulative micro-inventions that improve and debug existing inventions," by adapting them to more effective uses, and by combining them in new applications (2009:5). The essence of tweaking is that it embodies incremental innovation, which Baumol termed "the increased reliability and enhanced user friendliness of products and the finding of new uses for those products" (2004:16). *Entrepreneurial* tweaking, as I have defined it for this paper, specifically involves the development by start-up firms of secondary inventions and design modifications that are essential to the commercialization and diffusion of new technologies. Secondary inventions are patented incremental innovations, while design modifications are unpatented, but nonetheless significant, incremental innovations. Long thought to be the domain of large firms (Nelson & Winter, 1982; Utterback, 1994; Methe, Swaminathan, & Mitchell, 1996), scholarly conceptions of incremental innovations have resulted in two questionable assumptions:

(1) Start-ups are primarily focused on producing radical innovations; and (2) Large incumbent firms are superior to start-ups in producing incremental improvements.

In stress testing the efficacy of these two assumptions, I ask: *Is it possible that entrepreneurs not only excel at radical innovation but also incremental innovation?* If so, then it is conceivable that entrepreneurs play a central role, perhaps even a dominant role, in "tweaking" breakthrough technologies. The implications of this finding would add considerably to our understanding of technology development and diffusion. It would also contribute new perspectives on the internalization of adopter information costs as well as the creation and appropriation of rents through commercializable innovations. Consistent with the insights advanced by Teece (1986) regarding the appropriation of innovation value, I find that entrepreneurial tweakers face extreme appropriation risks. Despite the central role entrepreneurs play in commercializing breakthrough technologies through incremental innovations, the evidence from mechanized reapers and cloud computing services suggests that incumbents are able to wrest control over the rents created by entrepreneurs through the use of "soft power" (Santos & Eisenhardt, 2009). Building on the Santos and Eisenhardt conception of power in nascent industries and Teece's framework for innovating firms (1986), I find that, paradoxically: entrepreneurial firms, having contributed to the commercialization of new technologies through incremental improvements, rarely participate in appropriating the rents associated with the very technologies that they helped to commercialize.

In the following section, I discuss the theoretical gaps caused by the bifurcation of radically innovating entrepreneurs and incrementally innovating incumbents. Within this framework, I advance and then test a set of four hypotheses that predict extensive and commercially decisive incremental innovation by entrepreneurial tweakers. Following a presentation of the results, I discuss notable implications for future research.

Entrepreneurial Tweaking – the Reaper and Cloud Computing

"Modern economic history has long ago distanced itself from the heroic hagiographics in which the Industrial Revolution was attributed to the genius of a few superstar inventors," wrote Meisenzahl and Makyr (2010:3). Instead, scholars have come to recognize the indispensible contributions of those who were able "to tweak, adapt, combine, improve and debug existing ideas" and in so doing, "turn them into economic realities" (2010:41). To assess this phenomenon in a more systematic fashion, my paper draws parallels between two separate instances involving the diffusion of radical innovations: the mechanized reaper and cloud computing services. Although these examples arose in markedly different environments and eras, each instance demonstrates that without the sustained introduction of secondary inventions and design modifications by entrepreneurs, the dominant designs (Abernathy & Utterback, 1978; Anderson & Tushman, 1991; Tushman & Murmann, 1998) would have remained dormant. In Antebellum America, the mechanized reaper remained virtually unused for two generations after its invention. Similarly, cloud computing remained largely dormant after its original conceptualization because early formulations were laden with operational and strategic risk (Buyya et al., 2008). As with the reaper, secondary inventions and design modifications by entrepreneurs drove the commercializability of cloud computing (Rimal, Choi & Lumb, 2009; Armbrust et al., 2010).

The Mechanized Reaper

The first step in harvesting grain is called "reaping," which involves a cutting and gathering process. When completed by hand, reaping is labor intensive, exhausting and, given the time sensitive nature of the harvest and the vagaries of the weather, literally a matter of life or death (Hutchinson, 1930). So it was with considerable fanfare that the first U.S. patent on a mechanized reaper was issued in 1803 (Quick & Buchele, 1978). The initial enthusiasm was quickly dampened by the fact that among the early prototypes mechanical failures were legendary. One report from a field trial in Maryland captured the flavor of the challenges: "When the horses slowed to a pace less than that being a trot, the cutting bars seized, shaking the machine and team so that one horse fell to the ground and the reaper itself suddenly failed, sending metal parts into the crowd of astonished observers and one blad(e) into the flesh of the fallen horse" (Wood, 1846:33). Such spectacles did little to engender confidence in the new technology.

Development of the mechanized reaper took a notably positive turn with patented improvements by Hussey (1833) and McCormick (1834) of side-draft reapers that were pulled rather than pushed across the fields. The basic features of these two machines constituted the dominant designs in mechanized farm equipment for nearly a century (Quick & Buchele, 1978). However, neither design was immediately viable. In trial after trial, fatal flaws in multiple facets of the devices yielded disappointing results: "The reaper sank in soft ground, uprooted and flattened the tangled oat straw, was prone to clogging, and needed frequent repairs while in the field" (Pusey, 1851:613). To many farmers, early reapers appeared fragile and unreliable. The London Times called it "a cross between a wheelbarrow, a chariot, and a flying machine," (May 1, 1851). Potential adopters generally believed that the new technology was far riskier and ultimately more costly than hand harvesting (Olmstead, 1975; Olmstead & Rhode, 1995). It is in this context of uncertainty that entrepreneurial tweakers pursued secondary inventions and design modifications towards the development of a structurally robust, mechanically reliable reaper.

Cloud Computing

While the reaper was aimed to liberate farmers from the exogenous forces such as weather and labor supply, cloud computing promised to liberate businesses from the impossible task of accurately predicting the vector and velocity of changes in information technology (Catteddu & Hogben, 2009). As with the long march to a commercially viable mechanized reaper, efforts to commercialize cloud services have faced resistance and skepticism as security breaches and performance concerns have cast a long shadow over development efforts (Catteddu & Hogben, 2009). Infamous examples of catastrophic security failures abound, such as the massive outage experienced with Amazon's S3 outsourced cloud solution (Lazard, 2009). In a fashion that is highly reminiscent of the great mechanized reaper field trials of the early 1800s, public failures of cloud computing have underscored the technical deficiencies, which have in turn curtailed support by potential adopters despite tremendous latent demand for a viable solution (Gartner, 2012).

The overarching concept of delivering computing resources through a global network is rooted in the late 1950s and early 1960s. Early pioneers, including computer scientists such as Bremer, McCarthy and Parkhill articulated a framework known then as time-share computing, the conceptual ancestor of cloud computing. The essence of the shared computing paradigm is that computing services function as a utility that are instantaneously scalable web-based resources "that no longer require tremendous hardware/software investments and professional skills to acquire" (Kaplan, 2011). From the very beginning, the stakes were significant. Annual enterprise spending on information technology will approach $2.7 trillion in 2012 (Gartner, 2012), up to 30% of which are related to issues arising from legacy systems, which are residual programs, applications and processing systems that are difficult or even impossible to supplant in an environment of cluster management software (Foster & Kesselman, 1999). Entrepreneurial tweaks addressing cloud security concerns and operational attenuation issues have sought to reduce the perceived risks and thereby hasten diffusion of commercializable cloud computing services, (Armbrust et al., 2009; Rimal, Choi, & Lumb, 2009).

Theory Development and Hypotheses

Technology Diffusion

According to Rogers, "Diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system" (2003:35). Specifically relating to commercializable products and services, diffusion involves the acceptance and spread of new technology in a market or user community (Loch & Huberman, 1999). Diffusion dynamics have been shown to be highly sensitive to specific industries (Acs and Audretsch 1987), the contextual environment (Banbury & Mitchell, 1995) and the degree of ambiguity stemming from the relative newness of nascent-stage markets (Weick, 1995; Santos & Eisenhardt, 2009; Davis, Eisenhardt & Bingham 2009). For these reasons, it is critical to assess the risks associated with new technologies, as they are perceived by potential adopters. Rogers casts this issue as an ongoing challenge by adopters to reduce uncertainty by obtaining information (2003).

Individuals participating in nascent-stage industries have a strong incentive to take steps to alleviate the adopters' struggle for quality information. Often, a common set of metrics is developed to communicate relative performance on a standardized scale. In the development of the mechanized reaper, inventor-entrepreneurs staged elaborate, well-attended field trials to demonstrate the relative performance of their respective design modifications (Olmstead, 1975; Olmstead & Rhode, 1995). A key barrier to the adoption of reapers from 1831 to the late 1850s was the tremendous force required to pull the mechanism through the fields, a force known as "draft" (Olmstead, 1975). Unacceptably high draft (i.e. the moment of force, also known as "torque") posed several serious liabilities: the tendency to exhaust or even injure harnessed horses; the prospect of destroying rather than harvesting the crop; and, the common occurrence of stressing the reaper to such a degree that it "collapsed into a heap of cutters and bolts" (N.Y. Agriculture, 1857). Diffusion of the reaper was, therefore, largely contingent upon a meaningful reduction in draft. Newspapers and agricultural magazines from the 1800s are filled with accounts of field trials, each of which meticulously recounted the all-important statistics regarding draft and provided detailed accounts about inventors who achieved meaningful improvements.

Similarly, cloud-computing firms have sought to address adopter risk aversion through field trials, albeit in the form of seminars and trade shows (Kaplan, 2011). Like the reaper, risk aversion constrained the diffusion of commercializable cloud computing solutions for nearly 50 years. Unlike the reaper, there is no unitary metric for cloud computing that comprehensively captures performance and reliability. Nonetheless, reducing the adopter information deficits through the development of clear metrics has been a primary preoccupation of the entrepreneurs, including: probability of a system failure, probability of a security breach, return on IT investments, capital expense to operating expense conversions and new software time-to-full-deployment.

Major technological breakthroughs are rarely, if ever, immediately ready for commercialization. Rather, early competition to develop a "dominant design" (Utterback, 1994) fuels competing conceptions of what constitutes a commercializable solution. A lengthy development process involving incremental improvements necessarily precedes commercialization and widespread diffusion of new technologies. Articulated more formally:

H1: The rate of diffusion for breakthrough technologies is positively related to secondary inventions and design modifications.

Entrepreneurial Tweaking and the Internalization of Information Costs

Adoption lags persist when risk-averse decision-makers judge the uncertainties of alternative technologies to be too significant to warrant acquisition and use (Soete & Turner, 1984; Tushman & Murmann, 1998). Prior literature on diffusion theory (e.g. Rogers, 2003) addresses adopters' search for more and better information. Unless these external costs are internalized, there will be no technology diffusion because decision-makers will perceive that they possess inadequate information to adopt the new technology. My assertion in this paper is that prior attempts to articulate the relationship between decision-makers and dominant designers (Henderson & Clark, 1990; Utterback, 1994; Tushmann & Murmann, 1998) underemphasize the role that entrepreneurial tweakers play in systematically internalizing the decision-makers' information costs by steadily improving the capabilities and performance of the dominant design. Dominant incumbents may be unwilling or unable to internalize adopters' information costs. Therefore, either the dominant design will remain dormant, or entrepreneurial tweakers will produce sufficient incremental innovations to make the dominant design commercializable.

To an increasing degree, there has come to be a tendency to bifurcate innovation into two contrasting sources: revolutionary breakthroughs emanating from entrepreneurial firms and incremental enhancements emanating from large, established incumbents (Acs & Audretsch, 1990; Baumol, 2004; Acs et al., 2009). Baumol hypothesized that a "disproportionate share of breakthrough inventions is contributed by independent inventors, entrepreneurs and small or startup firms, while the large firms specialize in incremental improvements" (2004:7). Acs and colleagues reference and then extend Baumol's conclusions, noting, "We can think of incumbent firms as reliant upon incremental innovation from the flow of knowledge, such as product improvements. Start-ups with access to entrepreneurial talent and intra-temporal spillovers from the stock of knowledge are more likely to engage in radical innovation leading to new industries or replacing existing products" (Acs et al., 2009:16.) The essence of this argument rests upon the belief that innovation stemming from existing sources of knowledge will favor large incumbents. Meanwhile, nascent-stage firms are expected to excel under circumstances that neither require nor benefit from established organizational routines (Nelson & Winter, 1982). The problem with this line of reasoning is that there is no body of empirical evidence providing support for the claim. In reality, entrepreneurial firms are continuously engaged in incremental innovations (Meisenzahl & Makyr 2010). What is more, incumbents desperately need entrepreneurial tweakers to internalize the information costs of potential adopters through a series of improvements that make radical innovations commercializable (Meisenzahl & Makyr, 2010). Accordingly, I predict that:

H2a: New market entrants will be responsible for the majority of secondary inventions and design modifications that lead to the commercialization of breakthrough technologies.

H2b: Technology diffusion is positively related to the ability and willingness of entrepreneurial tweakers to internalize the information costs of risk-averse consumers.

Soft Power

In Teece's oft-cited treatment of economic returns to innovation, he wrote, "It is quite common for innovators - those firms which are first to commercialize a new product or process in the market - to lament the fact that competitors/imitators have profited more from the innovation than the firm first to commercialize it!" (1986:285). The focus of Teece's analysis was directed towards original creators of radical innovations, especially the predicament of innovators failing to possess the complementary assets that are necessary to obtain economic returns from their respective innovations (Teece, 1986). However, a focus on large, publicly traded survivors misses the enabling enhancements contributed by entrepreneurial tweakers. A more accurate conception of value creation and value capture must incorporate the secondary inventions and design modifications by start-ups (Meisenzahl & Makyr, 2010). For this reason, Teece's model is a good starting point, but an insufficient descriptor of the value appropriation phenomenon, particularly in addressing new organizations competing in new markets with nascent-stage technology.

Teece's foundational argument concerning the conditions under which innovators witness the appropriation of the value by competitors can be tangibly enhanced by incorporating the entrepreneurial power logics developed by Santos and Eisenhardt (2009), who found that many successful entrepreneurs "wield power by relying on a strategy of using soft power," by which they mean the "subtle influence mechanisms that cause others to willingly behave in ways that benefit the focal agent" (2009:663). Soft power is manifested in three primary tactics: (1) creating illusions through the use of deception, shielding intentions and exaggerating one's importance; (2) exploiting others' natural tendencies, such as risk aversion or relationship preferences; and (3) using asynchronous timing to either preempt or delay competitive activity. Santos and Eisenhardt proposed that firms using these tactics "are more likely to achieve (a) cognitive dominance (become the cognitive referent in a distinct market) and (b) competitive dominance (face a lower level of competition, have greater market share)" (2009: 663). Dominant early-stage firms are thereby able to claim, demarcate and control nascent markets (648).

While the Santos-Eisenhardt conception of soft power does not negate the Teece framework of innovation value appropriation, it does successfully correct for the mistaken emphasis on identifiable complementary assets to the apparent exclusion of soft-power strategies. This is critical when considering innovation in the context of entrepreneurial tweaking because the appropriation of value stemming from secondary inventions is the norm rather than the exception. The operationalization of soft-power strategies by the dominant designers explains why entrepreneurial tweakers lose control over the value as quickly as the value is created. Applying the soft-power logics to Teece's conception of innovation value appropriation, I predict that:

Hypothesis 3: On average, entrepreneurial tweakers will not share in the appropriation of rents created by their secondary inventions and design modifications.

Data and Methods

This paper utilizes two distinct data sets, one highlighting the development of the mechanized reaper and the other highlighting the development of commercializable cloud computing. The first is drawn from U.S. patent data, historical accounts and agricultural equipment catalogues for the years 1803 to 1884. In this time, numerous patent claims were filed for mechanized reapers (Hutchinson, 1930). Virtually all of these patents involved incremental enhancements to the models patented by Hussey (1833) and McCormick (1834). The second data set is drawn from firms involved in the commercialization of cloud computing, an industry that provisions "convenient, on-demand network access to a shared pool of configurable computing resources" (NIST, 2009).

For the analysis of the mechanized reaper, I undertook an extensive review of historical sources to supplement data from the U.S. Patent Office, including 43 field trial accounts. Studies of this era are inherently complicated by the document losses incurred during the 1836 patent office fire. However, Hutchinson's McCormick biography (1930), work by cliometricians (David, 1971; Olmstead, 1975,1995) and a comprehensive review of newspapers, magazines, diaries and catalogues yielded an excellent collection of formal and informal records detailing the incremental innovations of the reaper. In all, more than 500 sources were used to identify 348 secondary inventions (including 147 patents) and design modifications. For the analysis of cloud computing, U.S. Patent Office records revealed 3,882 patent filings related to cloud computing through 2011. 28% of these were assigned to incumbents (e.g. Microsoft, Google, Cisco, etc.) while the remaining claims were assigned to individuals or start-up firms. To evaluate financial and operational performance of cloud computing firms I used data drawn from the Dun and Bradstreet database for all of the 382 firms attending the 2011 Cloud Expo in New York City.

Dependent Variables

In addressing Hypotheses 1, 2a and 2b, I used an aggregate measure of industry activity to evaluate the relationship between incremental innovations and technology diffusion. The measure yields a quantity representing the *Instantaneous Diffusion Rate*, but for the sake of intelligibility is expressed in terms of the instantaneous business activity for reapers and cloud services. For my analysis of the mechanized reaper, I used the measure *Reapers In Use*, based on data from year-end estimates gathered from prior studies (Hutchinson, 1930; David, 1971; Olmstead, 1975; Quick & Buchele, 1978), U.S. census data, and corporate histories, such as John Deere and International Harvester. For my analysis of cloud computing, I employed *Total Revenue* generated from cloud computing services as a measure of diffusion. The cloud computing measures were calculated from a blended rate of values drawn from data compiled by Gartner (2012), Lazard (2009) and Dun & Bradstreet for the population of companies routinely attending premier cloud computing trade shows. In addressing Hypothesis 3, regarding the appropriation of rents, I used a discrete dichotomous variable, *Rents Appropriated*, indicating whether or not an entrepreneur-inventor received payment for the innovation through product sales, royalties or by being acquired.

Predictors

Risk Reduction. This is a continuous variable for the internalization of adopter information costs by entrepreneurial tweakers. For reapers, the measure of risk reduction is *Draft*, the force required to operate a farm implement, as measured using a dynamometer. Field judges and farmers associated high draft with “poor workmanship and faulty design” (Olmstead, 1975:350) since it was indicative of clogging and other inefficiencies that exhausted the horses and damaged both crops and reapers (N.Y. Agriculture, 1857). For cloud computing, the continuous measure of risk reduction is *Security*, the probability of a security breach based on the evolving threshold of deployable encryption (Armbrust et al., 2009). The values range from 0, indicating an utterly open system with no security capabilities, to 1, indicating perfect security. The measure captures the productive security threshold achieved (i.e. the tradeoff between security and dynamic functionality), by assessing the security solution for a system in the context of a specific set of operational requirements (Lazard, 2009; Armbrust et al., 2010; Gartner, 2012).

Innovation Source. This is a dummy coded variable, with a value of “1” indicating incremental innovations from entrepreneurial start-ups and “0” indicating a large incumbent firm as well as all firms that have a proprietary claim to the dominant design.

Innovation Impact. Consistent with techniques developed by Douthwaite (2001) and Rogers (2003), this is a categorical variable that ranks the relative importance of incremental innovation on a detailed scale ranging from 0 (i.e. no contribution to commercializability of the dominant design) to 5 (i.e. an indispensible contribution to the dominant design). For the mechanical reaper, three licensed mechanical engineers independently ranked all 348 innovations on the 0 to 5 scale. Inter-rater reliability was 0.88. For cloud computing services, five technology professionals (two developers, two sales engineers and one tech columnist) independently ranked a sample of 500 innovations (including 325 randomly selected patents) on the 0 to 5 scale. Inter-rater reliability was 0.83. Both reliability correlations are well above the levels necessary to establish inter-rater validity (Lombard, Snyder-Duch Bracken 2002; Hayes & Krippendorff ,2007).

Cumulative Innovations. The number of incremental innovations at the end of each year.

Cumulative Impact. This variable is product of the aggregate incremental innovations at the end of each calendar year times the innovation impact for each incremental innovation.

Product Sales. Unit sales by year, by company.

Royalties. This is a dummy-coded variable indicating whether or not an inventor received royalties or licensing revenue from each documented innovation.

Acquisition. This is a dummy-coded variable indicating whether or not a firm was acquired.

Cumulative Time. The number of years since the emergence of the dominant design.

Controls

The diffusion rates for reapers and cloud computing were subject to an array of control variables that were grouped into three separate vectors in order to capture year-specific, industry–specific and macro-economic effects. In particular, economic conditions affect the rate of investment in new technologies (Anderson & Tushman 1991). Accordingly, annual GDP growth was controlled. As a broad proxy for financial market effects, a market-weighted average interest rate was incorporated, by year. Specifically germane to reapers, the average price for a bushel of wheat was used as a control variable. Unobserved Fixed Year Effects were controlled through a series of dummy codes. This was particularly important for reaper diffusion effects related to labor market disruptions from industrialization and, of course, the Civil War (Olmstead 1976).

Models

The predictive models for the diffusion of mechanized reapers and cloud computing are derived separately for each of the four hypotheses. The generalized OLS model for Hypothesis 1 (Model 1), examining the relationship between incremental innovations, is formally expressed as:

$$(H1)\ \textit{Instantaneous Diffusion Rate} = \beta_0 + \beta_1 CON_{year} + \beta_2 CON_{macro} + \beta_3 CON_{indus} + \beta_4 CUM\text{-}INNOV + \beta_5 CUM\text{-}IMPACT$$

In Model 2, pertaining to Hypothesis 2a, the source of a given innovation was added:

$$(H2a)\ \textit{Instantaneous Diffusion Rate} = \beta_0 + \beta_1 CON_{year} + \beta_2 CON_{macro} + \beta_3 CON_{indus} + \beta_4 CUM\text{-}INNOV + \beta_5 CUM\text{-}IMPACT + \beta_6 INNOVATION\ SOURCE$$

Hypothesis 2b predicts that entrepreneurial tweakers will assume a primary role in internalizing adopter information costs through risk-reducing innovations. Therefore, risk reduction is added in Model 3 as the product term relating risk reduction to the innovation source. In order to model this effect using metrics that are relevant to adopter information costs, reaper risk is measured using draft improvements, while risk-reducing improvements in cloud services are modeled using system security capabilities. The key will be to see if the product term is statistically significant.

$$(H2b)\ \textit{Instantaneous Diffusion Rate} = \beta_0 + \beta_1 CON_{year} + \beta_2 CON_{macro} + \beta_3 CON_{indus} + \beta_4 CUM\text{-}INNOV + \beta_5 CUM\text{-}IMPACT + \beta_6 INNOVATIONSOURCE + \beta_7 RISKREDUCTION + \beta_8 INNOVATION\ SOURCE*RISKREDUCTION$$

Hypothesis 3, regarding appropriation, is tested through a logistic regression model expressed by:

$$(H3)\ \ Rents\ Appropriated = \beta_0 + \beta_1 CON_{year} + \beta_2 CON_{macro} + \beta_3 CON_{indus} + \beta_4 CUM\text{-}INNOV + \beta_5 CUM\text{-}IMPACT + \beta_6 IMPACT\text{-}RANK + \beta_7 CUM\text{-}YEAR + \beta_8 INNOVATION\ SOURCE$$

Results

Analysis of the empirical data indicates strong support for all four hypotheses, with material effect sizes and a low probability of error. The directionality and magnitude of the key correlations (Tables 3 & 5) are consistent with the hypothesized relationships. Most notably, incremental innovation by start-ups is significantly and positively correlated with escalating diffusion. However, product sales and royalties are significantly and negatively correlated with the source of an innovation. Taken together, this means that start-ups produce innovations leading to commercialization but fail to realize the benefits of having facilitated the successful diffusion.

In its most general form, the OLS regression indicates that for both the reaper (Table 4, Model 1) and cloud computing (Table 6, Model 1), incremental innovation is significantly and positively related to the diffusion rate. Even without stipulating the source of the innovation, secondary inventions and design modifications account for 48% and 39% of the explanatory variance, respectively, over and above the control variables (Model 0). Both *Cumulative Innovations* and the *Cumulative Impact* of innovations are significant in Model 1, thereby supporting hypothesis 1, which predicts that diffusion is positively related to incremental innovations.

Hypotheses 2a and 2b predicted that start-ups are the primary force in reducing resistance to nascent technologies. In support of Hypothesis 2a, Tables 1 and 2, demonstrate the relatively greater impact of incremental innovations produced by start-ups. Entrepreneurial tweakers were responsible for 74% of all secondary inventions and design modifications leading to the commercialization of the mechanized reaper (Table 1) and 72% of innovations related to cloud computing (Table 2). Further, among the 100 highest-ranked innovations, 89% were attributable to entrepreneurs who tweaked the dominant reaper design and 85% were attributable to entrepreneurial tweaks of cloud computing. These findings are further underscored by the OLS regression results in Model 2 (Tables 4 and 6), in which the source of innovation is found to be a significant predictor of diffusion for both reapers ($\Delta R^2 = 0.17$) and cloud services ($\Delta R^2 = 0.18$). Hypothesis 2b examines the information costs of potential adopters, predicting that diffusion is positively related to the ability and willingness of entrepreneurial tweakers to internalize the information costs of risk-averse consumers. This assertion will be supported if it can be shown that entrepreneurial tweakers were decisive in the reduction of perceived risk and the subsequent increase in sales. The mean differences displayed in Table 1 show that entrepreneurial innovations were 49% more instrumental to the commercialization of the reaper than were incumbent innovations (2.85 versus 1.91. $T_{1,347} = 6.02, p < .001$). Similarly, incremental innovations by start-ups were 32% more impactful to the commercialization of cloud computing (Table 2) than were incumbent innovations (2.79 versus 2.11. $T_{1,499} = 5.12, p < .001$). To further examine this effect, a product variable was added to Model 3 (Tables 4 and 6), relating risk reduction to the innovation source. Importantly, the product coefficient was found to be highly significant for reapers and cloud computing services, thereby supporting hypothesis 2b, which predicted that entrepreneurial start-ups, not incumbents, internalize adopter information costs through the development of secondary inventions and design modifications that tangibly improve the dominant design.

Hypothesis 3 tested the premise that while entrepreneurial tweakers may be indispensible to the creation of rents associated with the commercialization of new technologies, they generally do not share in the appropriation of rents generated by their secondary inventions and design modifications. Table 7 provides the results of a logistic regression examining the probability that the creation of incremental innovations results in value accrued by the entrepreneurial tweakers. The odds ratios reveal two dynamics that are supportive of Hypothesis 3. On the one hand, cumulative innovation and the unique impact of a given innovation strongly *increase* the odds of rents being created. On the other hand, the innovation source strongly *decreases* the odds of appropriation. In fact, an entrepreneurial tweaker had only a one in fourteen chance of deriving gains from a reaper innovation (*Innovation Source* odds ratio = 0.07, $p < .001$) and a one in nine chance of garnering gains from a cloud services innovation (odds ratio = 0.11, $p < .001$).

Discussion

As the foregoing results demonstrate, entrepreneurial tweaking played a leading role in diffusion of the reaper and cloud computing. By voluntarily engaging in incremental innovations, entrepreneurs internalized the information costs associated with lingering doubts among the population of potential adopters. Existing firms, including those who developed the dominant designs, were either unwilling or unable to absorb adopter information costs; yet they were the primary beneficiaries of the diffusion. The ability of incumbents to appropriate rents that were generated by start-ups is a curiosity requiring an understanding of how and why soft power is effectively employed by some firms but not others (Santos and Eisenhardt, 2009).

In this sense, the process of entrepreneurial tweaking is one that the dominant designers simultaneously encourage and decry. On the one hand, tweaking by start-ups is encouraged because without the steady flow of secondary inventions and design modifications, the dominant design will remain dormant. On the other hand, the dominant designers also decry entrepreneurial tweaking because incumbents do not want to see their controlling patents supplanted by new innovations. One interesting example of this tension involved the use of serrated cutting tools for the mechanized reaper. By all accounts, the use of a serrated cutterbar, which was invented by the entrepreneurial tweaker, George Rugg, improved cutting efficiency and reduced the occurrence of clogging (Quick & Buchele, 1978). This, in turn, reduced mechanical failures and maintenance costs (Olmstead & Rhode, 1995). Nonetheless, it was the official position of McCormick & Sons that the patent for serrated cutterbars did not require special consideration despite the fact that the innovation was new and produced superior results (Quick & Buchele, 1978). Conspicuously, all McCormick reapers featured serrated cutterbars by 1853 (Hutchinson, 1930), even though Rugg himself never received financial benefit from this important secondary invention.

The serrated blade issue underscores McCormick's understanding of soft power, which was pivotal in perpetuating the myth that McCormick produced the original and premier mechanized reaper, when in fact, neither was true (Hutchinson, 1930). There were many reapers that were patented earlier than McCormick's and performed better (Quick & Buchele, 1978). In combating these inconvenient truths, McCormick was masterful. For instance, rather than participating in field trials where anything less than a strong first place finish would erode the image of McCormick's preeminence, he focused on advertising abroad. In 1856, important reaper field trials were staged in Maryland, but the McCormick reaper, which typically finished in the middle of the pack of such contests, was not entered. Instead, McCormick was demonstrating his reaper in Hungary, where it performed adequately but received the adulation of amazed onlookers who declared the McCormick reaper "the greatest machine ever invented" (Tucker, 1856:117).

The effects of soft power have not been diluted in the 130 years since McCormick. As the data indicate, start-ups have played a dominant role in the development of innovations that led to the commercialization of cloud computing services, yet incumbents have successfully convinced adopters that their interests are best served by working through better-known entities, such as Salesforce.com, Oracle, Microsoft, HP, IBM, Cisco, EMC, VMware, SAP and Google (Lazard 2009). Soft power tactics have played a prominent role in this nascent industry. For instance, the propensity to exaggerate one's importance while exploiting risk aversion would appear to play a primary role in the quick disappearance of entrepreneurial tweakers. One particularly brazen gambit of self-promotion occurred when Dell sought to trademark the term "cloud computing" (Koman 2008). The U.S. Patent and Trademark Office repudiated Dell's demarcation attempt, but the effort is indicative of tactics used by incumbents. In similar fashion, HP, EMC, Cisco and IBM have each invested heavily in advertising that cautions adopters to be careful when taking "a leap of faith to find solid footing in the cloud for mission critical applications" (Wallis, 2008).

The exercise of soft power notwithstanding, the analysis provided here casts substantive doubt on the dichotomy that bifurcates innovation into incumbent incrementalism and entrepreneurial radicalism. Whether the circumstances are situated in Antebellum times or the modern era, the leading role of entrepreneurial start-ups in generating indispensible incremental innovations finds strong support. Although the detailed examination of mechanized reapers and cloud computing services cannot anticipate all the differences across various industries, the study of these disparate contexts nonetheless suggests startlingly similar antecedents and outcomes. Absent the willingness and ability of start-ups to internalize the information costs of potential adopters, diffusion of these important technological breakthroughs would have remained in abeyance.

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TABLE 1: Mechanized Reaper – The Impact of Incremental Innovations

These data represent the results of a forced ranking of 348 secondary inventions and design modifications for the mechanical reaper from 1803 – 1884 (inter-rater reliability: 0.93). Start-ups produced 74% of all incremental innovations and accounted for nearly 90% of those that most profoundly reduced adoption risk and facilitated commercialization.

	Incumbents		Start-ups		Total	
Innovation Impact Rating (5 = Highest)	#	%	#	%	#	%
0	8	47%	**9**	**53%**	17	5%
1	26	46%	**30**	**54%**	56	16%
2	35	36%	**61**	**64%**	96	28%
3	10	11%	**83**	**89%**	93	27%
4	6	12%	**43**	**88%**	49	14%
5	4	11%	**33**	**89%**	37	11%
Total	89	26%	**259**	**74%**	348	100%

	Incumbents	Start-ups
Average Impact Value	**1.91*** **	**2.85*** **
Standard Deviation	**(1.20)**	**(1.29)**
Mean Difference	**$T_{1,347} = 6.02$, $p < .001$**	

TABLE 2: Cloud Computing – The Impact of Incremental Innovations

These data represent the results of a forced ranking of 500 secondary inventions and design modifications for cloud computing services from 1960 – 2011 (inter-rater reliability: 0.86). Start-ups produced 72% of all incremental innovations and accounted for more than 85% of those that most profoundly reduced adoption risk and facilitated commercialization.

	Incumbents		Start-ups		Total	
Innovation Impact Rating (5 = Highest)	#	%	#	%	#	%
0	17	45%	**21**	**55%**	38	8%
1	28	41%	**41**	**59%**	69	14%
2	45	34%	**89**	**66%**	134	27%
3	30	26%	**87**	**74%**	117	23%
4	16	16%	**85**	**84%**	101	20%
5	5	12%	**36**	**88%**	41	8%
Total	141	28%	**359**	**72%**	500	100%

	Incumbents	Start-ups
Mean Impact Value	**2.11*** **	**2.79*** **
Standard Deviation	**(1.29)**	**(1.35)**
Mean Difference	**$T_{1,499} = 5.12$, $p < .001$**	

TABLE 3: Mechanical Reaper - Correlation Table

Variable		Mean	s.d.	DV	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DV	Reapers in Use (Year End)	239652	291691	x							
1	Risk Reduction (Draft Improvements)	458	278	0.43**	x						
2	Innovation Source	0.74	0.44	0.32**	0.31**	x					
3	Innovation Impact	2.61	1.33	0.28**	0.27**	0.37**	x				
4	Cumulative Innovations	168	115	0.17*	0..13*	0..14*	-0.11*	x			
5	Cumulative Impact	439	300	0.27**	0.29**	0.22*	-0.07	-0.1	x		
6	Product Sales	0.04	0.20	0.08	0.39**	-0.34**	0.11	-0.03	-0.28**	x	
7	Royalties	0.04	0.20	0.02	0.07	-0.22**	0..07	-0.08	-0.22**	0.04	x
8	Acquisitions	0.02	0.15	0.03	0.03	-0.09	0..03'	-0.05	-0.03	0.06	-0.04
** p < .01, * p < .05											

TABLE 4: Mechanical Reaper – OLS Regression Results

	Model 0 Controls	**Model 1**	**Model 2b**	**Model 2b**
Hypotheses	*D.V. is Reapers in Use*	*Diffusion is Positively Related to Incremental Innovations*	*Start-Ups Generate Majority of Incremental Innovations*	*Start-Ups Internalize the Information Costs*
Independent Variables				
Constant	Incl	Incl	Incl	Incl
Macro Effects	41.4*	27.3*	25.5*	19.40
	(26.0)	(18.8)	(17.8)	(14.3)
Fixed Year Effects	47.8*	33.4*	26.1*	11.50
	(22.4)	(17.7)	(14.3)	(8.2)
Fixed Industry Effects	11.30	2.65	2.58	2.40
	(4.72)	(1.78)	(1.65)	(1.61)
Cumulative Innovations		177*	172*	161*
		(53)	(51)	(47)
Cumulative Impact		343**	320**	174*
		(72)	(65)	(41)
Innovation Source (Startup = 1)			5789***	3994***
			(1270)	(991)
Risk Reduction (Draft)				760***
				(51)
Risk Reduction * Source				1141***
				(190)
Adjusted R^2	0.09	0.57	0.74	0.87
F-value	11.2	38.8	47.6	63.9
Non-Standardized Coefficients. Units are expressed in Incremetnal Reapers				
*** p < 0.001, ** p < .01, * p < .05				

TABLE 5: Cloud Computing Services – Correlation Table

Variable		Mean	s.d.	DV -1	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DV	Cloud Revenue (Year End $MM)	87000	191000	x							
1	Risk Reduction (Security Improvements)	0.37	0.51	0.30**	x						
2	Innovation Source	0.72	0.45	-0.27**	.14*	x					
3	Innovation Impact	2.59	1.37	0.24**	-0.08	.38**	x				
4	Cumulative Innovations	250	168	0.19*	0.23*	.20*	-0.17*	x			
5	Cumulative Impact	727	418	0.29**	0.41**	.25**	-0.25**	-022**	x		
6	Product Sales	0.02	0.153	0.07	0.09	-0.22**	0.05	0.10	-0.11*	x	
7	Royalties	0.05	0.21	0.06	0.07	-0.13*	0.04	0.07	-0.16**	0.07	x
8	Acquisitions	0.06	0.234	0.12*	0.11*	0.05	0.01	0.04	0.02	0.09	0.07
** p < .01, * p < .05											

TABLE 6: Cloud Computing Services – OLS Regression Results

	Model 0 Controls	Model 1	Model 2b	Model 2b
Hypotheses	*D.V. is Reapers in Use*	*Diffusion is Positively Related to Incremental Innovations*	*Start-Ups Generate Majority of Incremental Innovations*	*Start-Ups Internalize the Information Costs*
Independent Variables				
Constant	Incl	Incl.	Incl.	Incl.
Macro Effects	0.31*	0.15	0.14	0.13
	.(0.18)	(0.12)	(0.11)	(0.11)
Fixed Year Effects	0.18*	0.12*	0.11	0.12
	(0.20)	(0.12)	(0.12)	(0.10)
Fixed Industry Effects	0.18*	0.17	0.13	-0.14
	(0.14)	(0.14)	(0.14)	(0.15)
Cumulative Innovations		1.198**	1.17**	1.02**
		(.65)	(.60)	(.57)
Cumulative Impact		1.37***	1.03**	0.89*
		(.88)	(.79)	(.51)
Innovation Source (Startup = 1)			5.45***	3.13***
			(1.28)	(1.13)
Risk Reduction (Security)				2.30***
				(.37)
Risk Reduction * Source				2.88***
				(.79)
Adjusted R^2	0.12	0.51	0.69	0.81
F-value	14.7	31.3	42.2	55.7
Standardized Coefficients				
*** p < 0.001, ** p < .01, * p < .05				

TABLE 7: Mechanized Reaper and Cloud Services – Logistic Regression Results

The following data demonstrate that while secondary inventions and design modifications increase the probability of rent appropriation, start-ups face of low probability of harvesting value.

	Model 3 - Reapers		Model 3 - Cloud Services	
	Rent Appropriation from Incremental Entrepreneurial Innovations		*Rent Appropriation from Incremental Entrepreneurial Innovations*	
Independent Variables	**Odds (s.d.)**	**Value Creation and Appropriation**	**Odds (s.d.)**	**Value Creation and Appropriation**
Constant	Incl		Incl	
Macro Effects	0.96*		0.98*	
	(0.19)		(0.08)	
Fixed Year Effects	1.02*		1.07	
	(0.22)		(0.15)	
Fixed Industry Effects	0.97		0.99	
	(0.14)		(0.21)	
Cumulative Innovation	8.34***	8x odds that value is created	7.63***	8x odds that value is created
	(6.87)		(5.32)	
Innovation Impact	13.82**	14x odds that value is created	9.48***	9x odds that value is created
	(2.91)		(3.58)	
Innovation Source (1 = Start-Up)	0.07***	1 in 14 chance of start-up appropriating value	0.11***	1 in 9 chance of start-up appropriating value
	(0.03)		(0.13)	
χ^2	74.4		63.8	
Predictive Accuracy	95.6%		91.7%	
*** p < 0.001, ** p < .01, * p < .05				