MULTIPLICATIVE-INNOVATION SYNERGIES∗

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ABSTRACT

Additive synergies are contrasted with multiplicative ones in the context of post-acquisition patent content. Multiplicative-innovation synergies are indicated where a firm's prior-art patents were granted in technologies that are different than those of a focal patent's grant. Such content patterns suggest that inventors have searched to utilize technologies that are beyond locally-expected alternatives. In synthesizing these unexpected combinations of technologies, firms can extend their strategic scope by increasing their sources of revenue generation as well as improve returns on the assets that they have expended to explore and synthesize novel inventions. Using a backward-dispersion patent-citation measure to identify firms having patterns associated with higher multiplicative-innovation synergies, we found that such firms enjoyed higher returns on assets.

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1.0 Executive Summary or Highlights

Transactions which combine organizations (*e.g.*, acquisitions, joint ventures, *et cetera*) assume that the resulting entity will benefit from synergies, but they make few distinctions between the types of synergies available. The speed, duration and magnitude with which effects from multiplicative (versus additive) synergies are enjoyed will vary. The learning component of multiplicative synergies makes their realization more ephemeral, but their impact is greater than that of additive synergies if integration successfully occurs.

We use patent-code relatedness patterns to characterize whether inventors integrated exotic technological antecedents into their inventions. (The relatedness-patterns compare the technology-class codes granted to each focal patent with those of pre-existing patents which they have built upon.) Our causal argument suggests that additive-innovation synergies are associated with incremental patterns of patent antecedents while multiplicative-innovation synergies are associated with radical patterns of prior-art citations vis-à-vis the technology-class codes in which a patent's claims are granted. We argue that higher financial performance will be associated with the more-radical, prior-art citation patterns (*multiplicative-innovation synergies*).

We also tested whether an entity's diversification posture explained the same patterns concerning radical backward-citation patterns and higher financial performance. We found that diversification had the *opposite* sign from patent scores in multivariate regressions. We conclude that patents showing higher-dispersion patterns in the variability of their technological antecedents were associated with higher performance—even when accounting for firm diversification—and attribute this result to multiplicative synergies.

2.0 Introduction

Synergy is the working together of two or more agents (*e.g.*, muscles, drugs or other forces) so that their combined effect is greater than the sum of their individual efforts; a firm's synergy plan suggests how to collect rents from resource allocations (or activities) in ways that will generate greater organizational returns. Knowledge-sharing and organizational learning are assumed to occur from working together to capture synergies from operational improvements.

If firms grow and synergize via acquisitions, alliances or other external stimuli, their organizational learning often depends upon having effective processes to learn from transaction partners. Attainment of some operating synergies depends upon having an effective integration process (Haspeslagh and Jemison, 1991; Larsson and Finkelstein, 1999) which exploits the natural gains that may be available from combining related operations if the firm's organization has well-developed absorptive capacity (Cohen and Levinthal, 1989; Goold and Campbell, 1998), while other types of operating synergies call for members of a newly-connected group to create their combinatorial gains as an outcome of learning from their subsequent interactions with each other (Hagadoorn and Duysters, 2002). The quality of their learning activity suggests how well firms can appropriate rents from investing in exposure to novel ideas.

Three types of potential synergies may be available from external stimuli: one-time, additive, and multiplicative. These synergies will vary in the longevity of their effects upon firm performance as well as the speed with which their benefits can be enjoyed. In acquisitions, post-transaction performance is typically *mixed* because enjoyment of benefits from the three types of synergies will be realized at differing speeds and degrees of effectiveness in each respective transaction. The benefits of one-time and additive sources of synergy (which have been much discussed in economic theories of diversification) are realized faster. Because their magnitudes can be estimated by outsiders who use accounting and engineering information (Gupta and Gerchak, 2002), expectations of additive gains often propel takeover bids from prospective investors who can anticipate the magnitude of scale- and scope-economy benefits that may be available from combining operating activities.

The benefits of multiplicative synergy, the third and longest-lived type of synergy, are realized only by the most-skillful firms because the type of learning that is implicit in this type of performance improvement, in fact, may *not* occur, *i.e.*, the risks of introducing products based on combinations of unusual technological antecedents may not pay off. Realization of multiplicative synergies could be fueled by newly-shared information about customers' needs that are satisfied in new ways (*marketing synergies*) or novel technologies that are combined with extant inventive activities to create new products for customers (*innovation synergies*).

In this paper, we explore aspects of additive- and multiplicative-*innovation* synergies. We find that multiplicative-innovation synergies create more valuable (and longer-lived) performance improvements than additive-innovation synergies do—a hypothesis which contradicts results that were reported by Fleming (2001) and others who have emphasized local search processes in innovation (Ahuja and Lampert, 2001; Katila and Ahuja, 2002; Rosenkopf and Nerkar, 2001; Stuart and Podolny, 1996). Our tests of innovation synergies analyze patent content to discern pattern changes which indicate greater radical technological antecedents (instead of incremental ones) in patents that were granted after exposure to external stimuli (*e.g.*, acquisitions).

3.0 Additive versus Multiplicative Synergies

Operating managers can better anticipate the likelihood that multiplicative synergy benefits will be enjoyed after a transaction has been consummated than industry observers and outsiders to the innovation process (who cannot accurately assess the time requirements and risks regarding when and whether organizational learning will occur). The potential synergies that outside observers see are the ones involving volume-driven economies and transfers of managerial practices that private-equity investors typically rely upon (Eccles, Lane, and Wilson, 1999; Jensen and Ruback, 1983; McWilliams and Siegal, 1997; Shleifer and Vishny, 1988). There is evidence that other types of synergies may be available.

In analyzing why firms lost money in making acquisitions, Sirower (1997) concluded that—where high premiums had been paid in transactions—the synergies from additive cost reductions alone would not generate the types of *required performance improvements* (RPIs) needed to recoup acquisition outlays and avoid destroying investor value. The business-model improvements necessary to earn RPIs had to be found by monetizing the learnings of the newly-combined firm's personnel. Those necessary, multiplicative synergies were sometimes unexpected sources of improvement, such as those that Barney (1986) described as being unique and unforeseen synergistic situations in which particular combinations of firms' resources created more value than other potential combinations would have accrued (and the success of which industry observers could *not* foresee—and thereby incorporate into their proposed transaction price). Other multiplicative synergies were enjoyed because the combined firm learned to reinvent its scope in unforeseen ways. RPIs were repaid from the increased revenues that were generated from finding less-obvious sources of performance improvements; gains resulted from learning that occurred through interactions that involved lucky combinations of personnel and resources that could not have been easily predicted by outside observers.

Like Sirower's (1997) RPIs, realization of multiplicative synergies is more ephemeral (hence riskier) than is recognized—just as the *exploration* activities required to push the envelope of a firm's innovation activities ultimately may not pay off. The serendipitous nature of multiplicative-innovation synergies makes them more difficult for the market to price at the time of a transaction—leaving more opportunities for managers to reap those benefits themselves.

3.1 Additive synergies

Distinctions can be made between one-time synergies gained from cost reductions enjoyed after transactions—such as the benefits from tax-loss carryforwards and the elimination of redundancies—versus the benefits of operating synergies that may be compounded combinatorially through subsequent, shared activities within a combined organization (although realization of such performance improvements is not guaranteed). The impact of one-time redundancy reductions is felt immediately in financial statements (just as tax benefits from utilizing a firm's past tax losses are one-time synergies) since these activities do not change the ongoing firm's future business model. These same types of redundancies may also be removed during the turnaround process by decreasing the firm's resulting scope of operations.

Additive cost reductions realize innovation synergies by discovering ways of combining activities and facilities to improve capacity utilization and through-put economies (Tassey, 2010); the ability to share common inputs across related business units (to enjoy scope economies) is limited by the indivisibility of those inputs (Penrose, 1959), so potential additive performance improvements are finite and offer decreasing returns to scale over time (Henderson and Cockburn, 1996). In the context of technology strategy, patent thickets which are created to protect a firm's extant competitive position (Galasso and Schankerman, 2010) accrue additive-innovation synergies because they exploit *known* technologies which will improve performance incrementally.

Additive synergies improve the economics of known activities in a stepwise manner to strengthen the combined firm's extant competitive position in the markets that it serves—until the next stepwise cost improvement is realized (or competitive shock must be absorbed). When the activities of acquired organizations add opportunities to improve the resulting cost structure further by changing how intra-firm linkages are exploited, cost-reduction synergies face a downward-sloping curve that continues to improve—albeit asymptotically—as long as sister business units continue to optimize their ongoing operating relationships with each other by learning and adapting through incremental innovations. The outcome of such organizational learning could potentially provide increasing returns by increasing revenue-generating opportunities; at that point, the nature of synergies being enjoyed becomes multiplicative.

In summary, additive synergistic performance improvements can arise from organizational innovations that use extant resources in novel ways to reduce costs and improve productivity—albeit asymptotically—by combining activities and leveraging resources that can be shared. Fleming (2001) reported that combinations of familiar technological antecedents led to more certain and successful inventions (but led to the exhaustion of opportunities to innovate in the future). Nerkar (2003) and Rosenkopf and Nerkar (2001) found value in revisiting older technologies which a firm may not have used recently in their local search. Their findings are consistent with the idea of additive synergies; in the context of innovation strategy, additive synergies are reflected by inventions that build on incremental increases in technological knowledge.

3.2. Multiplicative synergies

The additive benefits of enlarging a firm's scope of patented inventions arises from volume-based advantages of scale and scope (through relatedness of technologies). The *multiplicative* benefits of greater scope and novelty can increase customers' willingness to pay through differentiation (or may generate a broader stream of royalty-generating assets to license to users for greater subsequent revenues). Firms can increase their revenues additively by exploiting patents that they may have acquired—just as they would exploit other assets garnered from an external transaction. Firms can increase their revenues *multiplicatively* when their combined inventive group wins patents on inventions that neither party to their transaction could have created alone. In acquisitions for technology, additive-innovation synergies can be realized by commercializing newly-acquired inventions (Singh and Agrawal, 2011); multiplicative-innovation synergies may be realized by combining the technological knowledge of newly-acquired inventors with knowledge mastered by ongoing inventors in order to synthesize unexpected commercializable products and serve new types of customers (Song, Almeida, and Wu, 2003).

Activities that extend the boundaries of a firm's knowledge envelope through independent exploration could produce the types of radical innovations (Dahlin and Behrens, 2005; Henderson, 1993; Lettl, Herstatt, and Gemuenden, 2006; Schoenmakers and Duysters, 2010) which move researchers into technological areas that are outside of typical routes for knowledge searching. In the case of combinations which enable inventors to synthesize devices across seemingly-unrelated technology fields, the radical nature of such activity suggests that the innovation synergies being realized may be *multiplicative* in nature. These activities could lead them to combine unexpected technology streams in their inventions. Unusual technological combinations generate multiplicative synergies by providing a bridge to novel revenue-generating opportunities. Such revenue-enhancement synergies may take firms into exotic arenas of activity, such as complementary products, new markets, new geographies or new technologies where their performance is improved by increasing sales to extant customers or serving new types of customers. The genesis of multiplicative-innovation synergies is in non-local search activities that pay off in launching products which are new to the firm (and sometimes new among competitors as well).

3.2.1. Sources of multiplicative synergies. Multiplicative-innovation synergies exploit less-familiar knowledge or increase (or recombine) the range of knowledge from which patentable inventions could be synthesized. We posit that creating such inventions—which will move researchers into technological areas that are outside of their knowledge comfort zones—offer greater financial improvements than do innovation processes that build primarily upon the combined firm's extant competencies (because the former type of invention can change the firm's future business model). The broad range of knowledge which inventors must master to make such innovative combinations would facilitate the patenting of more-radical inventions by the combined inventive team—an activity which improves firms' financial performance by providing rents that are available from the exploitation of resulting first-mover advantages through patents, royalties from licensing, and trade-secret advantages that are embedded in firms' products (Hill, 1992).

Performance improvements which exhibit increasing returns over time are typically propelled by learning—as in the example of synthesizing radical inventions that build on exotic technological antecedents or creating products that could *not* have been created before merged organizations were combined. Benefits include serving new customers, synthesizing new technological insights, or creating unexpected product-market combinations for business development.

In realizing innovation synergies, multiplicative benefits are more likely to occur when combining technologies where expertise has been curated by formerly-disparate inventors who can learn from exposure to each other's respective deep knowledge. Such benefits are less likely to be realized where transaction partners have not each developed their respective patenting methodologies. Multiplicative synergies improve firms' financial performance by increasing the range of domains where the combined entity can compete effectively.

3.2.2. Value created by multiplicative synergies. Multiplicative-innovation synergies are most beneficial to firms when the learning gained by combining researchers' respective knowledge competencies allows their firm to invent profoundly-novel solutions for customers—which increases customers' willingness to pay (which increases the revenues obtainable by commercializing firms' radical inventions) and may provide a temporary first-mover advantage (Adner and Kapoor, 2010; Kerin, Varadarajan, and Peterson, 1992; Lieberman and Montgomery, 1998). Increases in the range of knowledge integrated within the combined firm's patents are one indication that multiplicative-innovation synergies may have been realized—especially where there has been a pattern of synthesized inventions that draw from seemingly-unrelated technology fields. The successful fusion of formerly-unfamiliar technologies makes the nature of multiplicative-innovation synergies seem to be profoundly valuable—if they can be commercialized successfully. Higher financial performance is expected due to collecting rents from the benefits of learning processes underlying the realization of multiplicative-innovation synergies.

In summary, multiplicative synergies may be enjoyed from those innovations which increase the firm's scope of activities and related revenues by exploiting unusual knowledge combinations that may be suggested when integrating acquisitions, working within strategic alliances, or other external stimuli. Increasing returns can accrue from intangible assets (such as patents) from which the firm appropriates the benefits of exploratory learning—often because it also possesses the necessary complements needed to commercialize its innovations. Benefits from multiplicative synergies can be riskier to realize than additive synergies because offbeat ideas may have lesser commercial success, but the leveraging benefits of successfully integrating diverse inputs into the inventive process could provide greater returns than additive synergies can provide because of the leap forward in knowledge which such combinations could represent. The firm's performance could also be higher because of the temporary lack of competition that such devices may face in commercialization while temporary first-mover advantages can be exploited.

> *Hypothesis 1. Firms that realize multiplicative-innovation synergies will enjoy higher return-on-assets performance than firms that achieve additive-innovation synergies.*

3.3. Testing the effects of diversification

The source of beneficial-learning effects that we attribute to multiplicative-innovation synergies could, in fact, be evidence of the positive effects of technological diversification which occur where a firm competes in many lines of business. Broadly-diversified firms are exposed to more-diverse streams of technological knowledge than are narrowly-diversified ones; inventors may overcome their bounded rationality (Rosenkopf and Almeida, 2003; Song, Almeida, and Wu, 2003) and broaden the scope of technological streams where they search for ideas because their firm's activity in many unrelated businesses increases their exposure to new ideas for stimuli. Broadly-diversified firms who operate within diverse lines of business have been shown to reflect the breadth of their organization's strategic posture in the technological content of their patents (Miller, 2004; 2006), but does this strategic posture enhance financial performance?

A relationship between a firm's breadth of diversification and diverse content patterns in their focal patents' intellectual antecedents is plausible because complementary knowledge is valuable to acquiring firms; adding the technological knowledge of a related, target firm may help the resulting, combined firm's performance—provided that the added knowledge is not too similar to that of the acquiring firm. Sears and Hoetker (2014) suggested that if the technological-knowledge overlap between target- and acquiring-firm's knowledge were *low*, the combined firm's subsequent inventions would likely possess the type of attributes—novel prior-art citation patterns—which we associate with higher multiplicative-innovation synergies. Accordingly, we include tests for the effects of diversification posture in our analysis as an alternative explanation for differences in firms' performance patterns and test these null hypotheses. Hypothesis 2a argues that the patent-content patterns of interest may be due to diversification. Hypothesis 2b argues that highly-diversified firms having the patent-content patterns of interest will perform more highly.

> *Hypothesis 2a: Patents granted to highly-diversified firm will contain higher proportions of prior-art citations (in their patent report) from technology-class codes that are different from the technology-class codes in which their focal patents' claims have been granted.*

> *Hypothesis 2b: Highly-diversified firms whose focal patents contain higher proportions of prior-art citations (in their patent reports) from technology-class codes that are different from the technology-class codes in which their focal patents' claims have been granted will enjoy higher financial performance than do highly-diversified firms whose focal patents cited small proportions of prior art having technology-class codes that are different from the claims of their focal patents.*

In summary, our causal argument suggests that additive-innovation synergies are associated with incremental patterns of patent antecedents while multiplicative-innovation synergies are associated with radical patterns of prior-art citations vis-à-vis the technology class codes in which a patent's claims are granted. Higher financial performance will be associated with attainment of multiplicative-innovation synergies (which are indicated by the radical prior-art citation patterns of their focal patents). Because multiplicative-innovation synergies are associated with newly-connected personnel inventing together, high diversification is not expected to yield multiplicative synergies (but we tested for its effects).

4.0. Data, Methods, and Variables

Our panel of 1,236 electronics firms was drawn from 2,921 acquisitions of electronics firms occurring between 1998 and 2005 (Thomson Reuters' *Mergers and Acquisitions*, 2013). Of the 2,921 transactions, *COMPUSTAT* (2013) financial data was available for 2,183 firms (of which 1,140 had patents). Because the Thomson Reuters' electronics-industry sampling criterion was broader than that of other patent studies which have focused only on semiconductors, our panel also included firms who provided electronic-storage devices, communications equipment, computing equipment, and related software.

Patent content is a plausible way to identify aspects of the firm's synergy plan because patents enable firms to collect rents from the resource allocations of their growth plan. An invention's claims are assigned by patent examiners (Alcácer and Gittelman, 2006; Alcácer, Gittelman, and Sampat, 2009; Gittelman, 2008); coding systems represent the technology-class codes of those claims. We used the *Derwent* classification schema (which is available through *Web of Science*) for classifying technologies because of its parsimonious number of technology-class codes—as compared with the over-120,000 technology-class codes of the United States Patent and Trademark Office (USPTO) coding system.

4.1. Analyzing patent content

Using patent reports, we constructed a Euclidian distance score that compared focal patents' assigned technology-class codes (*core*) with those of their precedent patents (*core* and *non-core*); the *V-score* reflected the variability between the core and non-core codes. Distances from each focal patent's technology-class codes (core) and precedents (non-core) were computed by comparing the historical frequency of particular dyads of technology-class codes appearing together (*Derwent Innovations Index*, 2015). Appendix I describes the matrix of calculations for the

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Appendix I at the end

V-score. A firm's *V-scores* for each year of patents were summed and averaged to divide the sample into those having high *V-scores* and low *V-scores*, respectively, to test for pattern differences. Figure 1 shows performance differences for the *V-scores* of firms whose primary *Mergers*

Figure 1 here
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and Acquisitions-defined (2013) NAICS codes reflected electronics, communications services, and media services, respectively. For each industry panel, firms having higher-than-average *V-scores* also had higher returns on assets (ROA). We specified regression models only for the electronics panel to avoid confounding patterns from pooling panels of service firms with manufacturers.

Our *V-scores* reflected the content dispersion of focal patents' backward citation patterns and were lagged by two years because preliminary, univariate analysis indicated that *V-score* effects were not significant until then. We used *V-scores* because if patent evidence were measured simply, *e.g*., by counting increases in the number of post-acquisition patents that were produced (or by another method that captured additive synergy effects only), results could primarily reflect the effects of diversification which are typically associated with an acquisition; simple patent counts would not offer evidence that multiplicative, post-acquisition inventive activity had been harnessed by the resulting firm.

4.2. Analyzing diversification

Since the *V-score* is a distance score, we created distance scores for testing the hypotheses which argued that breadth of diversification explains the dispersion of patent antecedents and ROA performance. North American Industrial Classification system (NAICS) industry codes were used to construct concentric diversification scores that were similar in spirit to Miller (2004)'s concentric-index measure of technology breadth. Our diversification index was

$$Diversification = \left[\frac{\sum_{1}^{i}|APRIME - ANAICS_i|}{APRIME} + \frac{\sum_{1}^{j}|APRIME - TNAICS_j|}{APRIME}\right]$$

where $i = 1, 2, \ldots, m$ refers to the acquiring firm's lines of business and $j = 1, 2, \ldots, n$ refers to the target firm's lines of business. *APRIME* is the NAICS code of the acquiring firm which is designated by Thomson Reuters' *Mergers and Acquisitions* database (2013) as being its primary line of business. ($ANAICS_i$ and *TNAICSj* refer to the other NAICS codes of the acquiring and target firms, respectively.) A high index indicated broad diversification. Univariate analysis of the *V-score* and the diversification index revealed no significant relationship with the *V-score*—which suggests that the diversification index is a good approximation of the breadth of diverse technology-class codes that one might expect to see in a focal patent's grant (but perhaps *not* in its antecedents).

4.3. Panel data and variables

In addition to regressing the *V-score* and diversification index on ROA, R&D spending and patent-productivity variables were tested as main effects on ROA. (Patent *productivity* is the number of patents divided by R&D spending.) Logarithm of sales (representing the effects of size), and leverage were specified as control variables (as well as the proportion of intangibles and employee productivity variables). A binary variable for the electronic components part of the electronics industry was added as a discriminator variable for comparability with results from earlier studies; many component makers in our panel were *not* also involved in making electronic equipment. Descriptive statistics are shown in Appendix II and correlations for each regression model are shown in Appendix III. Although some independent variables were correlated with each other, the variance inflation factor for each regression model was less than 2.0.

Appendix II and III at the end

4.4. Multivariate analysis

Regression models were specified for the third year through seventh year after acquisitions were consummated—testing for ROA. Observations began with the third post-acquisition year because Hitt, Hoskisson, and Ireland, (1990) suggested that the pattern of the firm's technological antecedents would spike immediately after an acquisition—flattening over time to show diminishing returns if the acquiring firm did not successfully combine the technology of the target firm with its own and realized only additive synergies.

Table 1 shows positive and significant *V-scores.* Patent productivity was positive (and significant) while R&D expenditures were always negative (and significant). Diversification was negative and significant. Coefficients for the patent-productivity and size were also positive and significant (indicating that larger firms enjoyed the additive benefits of scale economies).

Table 1 here

5.0. Discussion and Conclusions

Results suggest that that incremental novelty in patent content (which represents additive-innovation synergies) yields lower ROA. Higher novelty in patent content (which represents multiplicative-innovation synergies) enjoy higher ROA performance which supports Hypothesis 1. Results suggest that firms reap higher financial benefits where inventors learn from each other and search broadly to create inventions which incorporate technological knowledge from broadly-diverse streams. The consistently-negative signs of the diversification index suggested no support for Hypotheses 2a and 2b; the diversification index and *V-score* were negatively correlated and diversification had a negative coefficient in the specifications of Table 1. Post-acquisition performance improvements *cannot* be attributed to the combined firm's resulting diversification. The electronics firms in our panel who diversified broadly via acquisition did *not* produce inventions which reflected the broadest fusion of non-core technological knowledge. Highly-diversified firms did *not* bring more non-core technology-class codes to their focal patents than did the narrowly diversified firms. Results suggest that a highly-diversified firm may be awarded patents in many highly-diverse technological fields, but that the claims of their focal patents built upon a narrow array of *non-core* technologies; many of the highly-diversified firms in our panel were primarily exploiting their extant *core* knowledge—not stretching incrementally to master new knowledge areas. The highly-diversified firms realized innovation synergies that were additive in nature. Results suggest that firms whose patents have incorporated knowledge from a wide variety of *non-core* technological fields enjoyed superior returns and this result does *not* seem to be due to diversification; high post-acquisition *V-scores* were not found within firms with broad diversification postures.

More analysis is needed to verify the existence of multiplicative-innovation synergies and demonstrate their pattern of increasing returns (which are comingled with the decreasing returns of additive synergies in firms' performance). The characterization of synergies as offering additive and multiplicative benefits adds greater nuance to what is known about firms' ability to capture operating improvements by learning from outsiders through alliances or acquisitions. Multiplicative synergies accrue to inventions which could not have been created using only the knowledge of either party alone; they are enjoyed where combined research organizations work effectively together. Multiplicative-innovation synergies are difficult to capture because researchers must actively collaborate with each other in order to share their knowledge (Argyres, 1996; Henderson and Cockburn, 1994; Zhou 2011). High autonomy in exploring knowledge streams defeats the likelihood of realizing multiplicative-innovation synergies (Zaheer, Castañer, and Souder, 2013).

The measurement conundrum concerning how innovation synergies can be realized is not trivial because valuation presumably considers of all of a project's resources that could be discovered through the typical due-diligence process (and factors in the impact of all of previously-announced investments in knowledge creation). Transaction partners have already captured a portion of all previously-known potential synergies in any premium that was paid to them. Ways of stimulating combined-firm capacity for radical innovation capacity are needed in order to retain some of the potential synergies from combining resources for the surviving entity itself (Karim and Kaul, 2015).

Effectively-integrated firms can amplify their knowledge of unknown technologies more constructively than individual researchers could do because they offer greater potential catalysts for innovation. Because multiplicative-innovation synergies are stimulated by working with capabilities beyond those mastered internally, firms typically seek external stimuli to learn about diverse knowledge and gain needed capabilities, knowledge and expertise (Harrigan, 1988; Hitt, *et al.*, 1991; Kogut, 1988; 1991; Sears and Hoetker, 2014; Winter, 2003). Successful synergies from cross-fertilization and knowledge-sharing activities are not guaranteed. Results suggest that special post-acquisition efforts should be made to encourage research organizations to understand each other's technologies—even if the applicability of such knowledge is not immediately apparent. The novelty of inventions offering multiplicative-innovation synergies is important because they could shift an industry's evolutionary path to emphasize greater convergence of heretofore divergent technological streams (Mowery and Rosenberg, 1998; Nelson and Winter, 1982).

Scientists and engineers who are most effective at assimilating exotic technological knowledge into their inventions have a superior ability to see potential applications for their own products in different or unfamiliar technologies—as well as the skills to share their insights with colleagues more effectively. Because they have a well-developed absorptive capacity, the inventive processes within such firms are a source of competitive advantage that will be pursued after making technological acquisitions—in order to gain complementary assets or otherwise replenish their own stocks of knowledge with the stimulus of new researchers' insights. Their ability to infuse inventions with unexpected technological content will persist long after their newly-combined organization has been integrated and knowledge that was once novel and exotic becomes assimilated through the learning of other researchers. Multiplicative-innovation synergies have the potential to improve performance in revolutionary ways—*albeit* when combined with the moderating tempering of organizational insights about customer demand.

Evidence is accumulating that the *quality* of post-acquisition innovations increases in technology acquisitions (Cloodt, Hagedoorn and Van Kranenburg, 2006; Makri, Hitt, and Lane, 2010; Sears and Hoetker, 2014)—which means that post-acquisition inventions garner a greater number of prior-art citations from inventors who build on them, as well greater royalty streams to earn back the acquisition premiums that may have been paid to acquire technology (Hoetker and Agarwal, 2007; Nair, Mathew, and Ng, 2011; Sherry and Teece, 2004; Stuart, 2000). Acquisitions for technology are presumed to increase the range of knowledge which inventors can utilize within their patentable inventions, but the benefits of external stimuli should not be left to chance.

Patents are an important way for firms to appropriate rents from the resources invested in R&D (Breschi, Malerba, and Orsenigo, 2000; Coff and Lee, 2003; Coff, 2010; Cohen, 2010; Veuglers and Cassiman, 1999). Even allowing for potential R&D-substitution effects—in cases where acquirers rely heavily upon the inventors of their transaction partners to perform innovation tasks for their benefit (Cassiman, Colombo, Garrone, and Veuglers, 2005; Hitt, Hoskisson, Ireland, and Harrison, 1991)—there is evidence that exposure to interfirm knowledge, especially complementary knowledge, is valuable for several reasons, such as hold-up and pre-emption, as well as for collecting rents through licensing, incorporating into firms' products, and realizing economies from offering more-complete product offerings to extant customers (Ziedonis, 2004; Grimpe and Hussinger, 2014). Possession of complementary assets enhances the realization of increasing returns which are fundamental to multiplicative-innovation synergies as a source of learning-based benefits (Arthur, 1996).

The unforeseen benefits of combining inventive organizations—the improvements that that investors did not already anticipate (and price)—stimulate additional learning efforts which can build upon the combined organization's radical innovations, create important gateway patents for extracting rents, and form new ways of using the combined firm's extant knowledge. Multiplicative-innovation synergies can arise from potentially-serendipitous interactions among researchers and their success at inventing after these collaborations reinforces their willingness to search more aggressively beyond an organization's 'comfort zone' in mastering the non-core knowledge that could better solve their customers' problems.

The next big conglomerate wave may soon be upon us**—**as acquisition sprees by technology firms like Google and Cisco transform electronics pioneers into technology conglomerates. Results suggest that successful attainment of multiplicative-innovation synergies will be an important means of earning the required performance improvements that will be needed to amortize premiums that will be paid. Research teams should seek external collaborations in order to stimulate opportunities to realize multiplicative-innovation synergies when knowledge from remote technological arenas can be applied to patented inventions.

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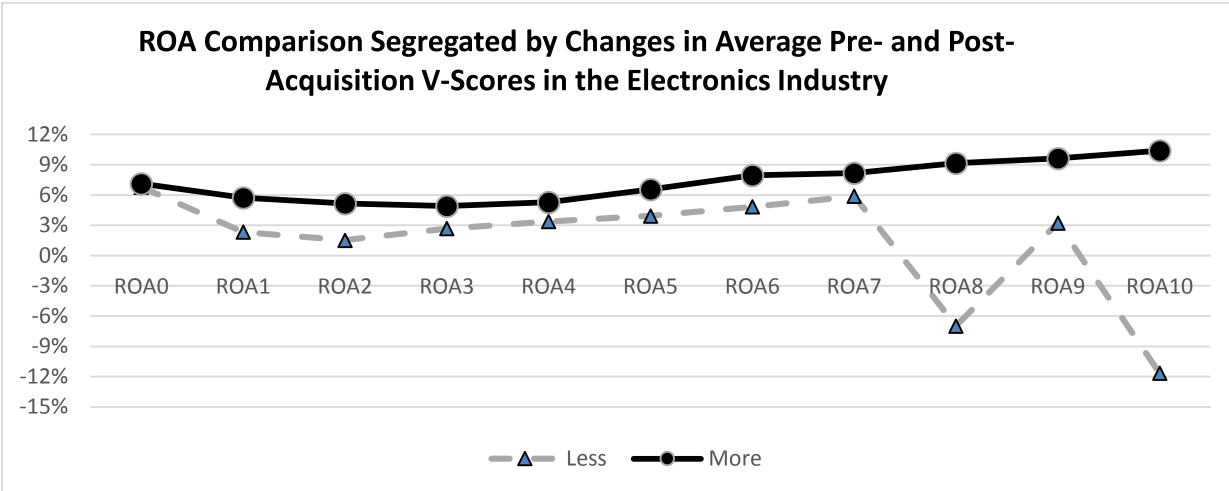
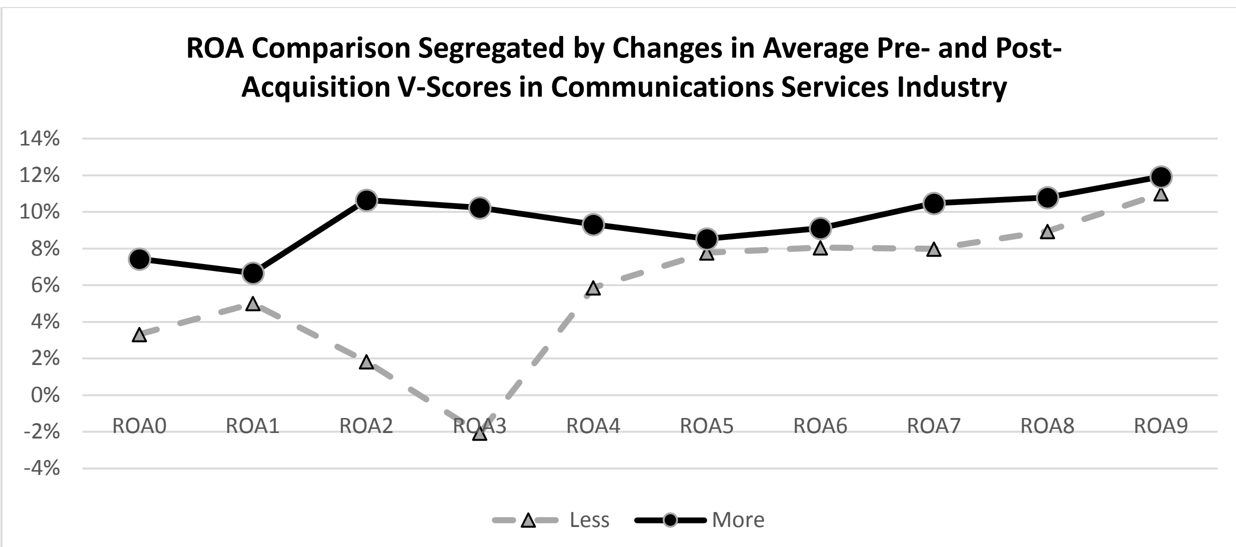
Figure 1
Average Post-Acquisition Return on Assets Comparison in Three Industries





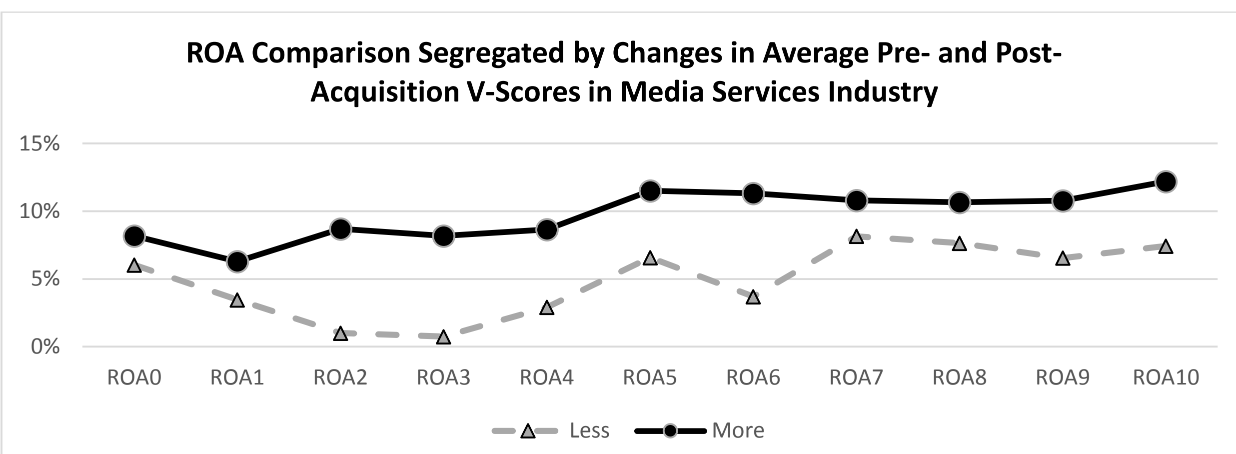


Table 1
Post-Acquisition Patent Effect on ROA

	1 3 years	2 4 years	3 5 years	4 6 years	5 7 years
Intercept	**-0.21327**	**-0.17711**	**-0.16071**	**-0.09953**	**-0.14566**
	0.02020	0.02214	0.01923	0.02252	0.02533
	***	***	***	***	***
Backward Patent Score$_{t-2}$	**0.00066**	**0.00058**	**0.00096**	**0.00054**	**0.00878**
	0.00029	0.00032	0.00027	0.00032	0.00034
	*	*	**	*	**
R&D Expenses/ Sales$_{t-2}$	**-0.01612**	**-0.01036**	**-0.02675**	**-0.05416**	**-0.09146**
	0.00281	0.00146	0.00329	0.00925	0.00381
	***	***	***	***	***
Number of Patents/ R&D Expenses$_t$	**0.00894**	**0.00989**	**0.00939**	**0.00925**	**0.01128**
	0.00301	0.00348	0.00309	0.00296	0.00716
	**	**	**	**	NS
Diversification Index	**-0.00132**	**-0.00121**	**-0.00164**	**-0.00173**	**-0.00820**
	0.00067	0.00069	0.00058	0.00062	0.00308
	*	†	**	**	**
Logarithm of Total Revenues$_t$	**0.07997**	**0.07214**	**0.06680**	**0.05771**	**0.06283**
	0.00515	0.00539	0.00468	0.00515	0.00537
	***	***	***	***	***

	3 years	4 years	5 years	6 years	7 years
Long-Term Debt/ Total Assets$_t$	**-0.04360**	**-0.03576**	**-0.03817**	**-0.03535**	**--**
	0.02716	0.02748	0.02392	0.02687	
	NS	NS	NS	NS	
Intangibles/ Total Assets$_t$	**--**	**-0.02178**	**--**	**--**	**--**
		0.02663			
		NS			
Sales/ Number of Employees$_t$	**--**	**--**	**--**	**--**	**0.04668**
					0.02120
					*
Components (binary variable)	**0.03181**	**0.02827**	**0.01671**	**0.00967**	**0.02628**
	0.00910	0.00956	0.00830	0.00915	0.01021
	**	**	*	NS	*
Adjusted R^2	**0.3497**	**0.3301**	**0.3731**	**0.2624**	**0.6629**
Number of Observations	657	632	610	570	454
Significance	*** < .0001, ** = .01, * = .05, † = .10				

Appendix I

Mathematical Notation for Calculating Backward-Dispersion Patent-Citation Scores

Calculations of *V-scores* for a focal patent were made in a spreadsheet matrix that juxtaposed each Derwent technology-class code (i_n, o_m) awarded to the focal patent with itself and all other cited Derwent technology-class codes in order to generate the dyad frequencies (p_j) appearing as probabilities in the cells that were created by the intersection of the matrix rows—which represented all *core*- as well as *non-core* Derwent Codes appearing in the backward-cited (or antecedent) patents—with the matrix columns which represented only the Derwent technology-class codes that were awarded to the focal patent. The dyad frequencies (p_j) are the probability of the intersecting Derwent Codes occurring together in a particular year (and were obtained by searching the *Derwent International Patents* website). The dyad frequencies in each row were averaged to create the average probabilities (a_i, a_o).

The frequency with which the Derwent technology class code in each row was cited (f_k) was divided by the total count of codes cited (F) to create its frequency factor (ff_k), which was multiplied by the row's average probability (a_i, a_o) to produce a weighting (W_k). The weightings were summed to produce a *Core Score* (W_i) reflecting the focal patent's granted claims and *Non-Core Score* (W_o) reflecting all other possible technology-class codes. These were combined to produce a *Raw Innovation Score* (R) which is equal to the *Core*- and *Non-Core Scores* (ΣW_k). The *Raw Score* (R) was multiplied by the ratio of *non-core* frequency counts (Σf_o) to *core* frequency counts (Σf_i) to create the focal patent's *V-score*.

$V = R \times [\, \Sigma f_o / \Sigma f_i \,]$ = *V-score*, the *Raw Innovation Score* times the ratio of the count of *outside-the-core* technology-class codes divided by the ratio of the count of *inside-the-core* technology-class codes

where

i_n = *Core* technology-class codes of backward citations for Patent where the number of *Core* codes = 1, 2, 3, …, n

o_m = *Non-core* technology-class codes of backward citations for Patent where number of *Non-Core* codes = 1, 2, 3, …, m

f_k = Frequency with which a *Core* technology-class code$_i$ (or *Non-Core* technology class code$_o$) occurred in backward citations of Patent, which is the count of each technology-class code appearing in its backward citations where $k = 1, 2, ..., n, n+1, ... , n+m$

$F = \Sigma f_k = [\Sigma f_i + \Sigma f_o]$ = the sum of the count of all technology-class codes

$ff_k = f_k / F$ = the frequency factor for one technology-class code

Assume an $n \times (n + m)$ matrix for searching probability p_j that dyads occur in technology class codes of a focal patent's backward citations for $i_n \times i_n$, $i_n \times o_m$ and $o_m \times o_m$ where $j = n \times (n + m)$ and p_j is the dyad weighting for a particular *core* technology-class code$_i$ or *non-core* technology-class code$_o$ appearing with itself or another backward-cited technology-class code defined as $i_1, \ldots, i_n \times i_1, \ldots, i_n, o_1, \ldots, o_m$. (Twenty reference tables were created to reflect the annual dyad probability with which each combination of technology-class codes occurred together in a patent for each year.) Thus,

$a_i, a_o = [\Sigma p_j / i_n]$= Average dyad weighting for each *inside-the-core* technology-class code $(i_1 + \cdots + i_n)$ and for each *outside-the-core* (or *non-core*) technology-class code $(o_1 + \cdots + o_m)$, the sum of each row of weightings divided by the number of core technology-class codes that there are.

$W_k = a_i, a_o \times ff_k$ = the weighted score for a *core* technology-class code$_i$ or for a *non-core* technology-class code$_o$

$R = \Sigma W_k$ = *Raw Innovation Score*, the sum of all weighted scores = $\Sigma W_i + \Sigma W_o$

Appendix II
Descriptive Statistics

	Variable	Obs.	Mean	Standard Deviation	Minimum	Maximum
1	Backward1	837	35.4889	17.9128	0.05	240.602
2	Backward2	783	37.2585	19.0746	0.05	197.422
3	Backward3	744	39.2573	21.8800	0.05	255.405
4	Backward4	710	40.6777	23.7791	0.05	308.960
5	Backward5	660	41.6551	22.6169	0.05	240.602
6	R&D/ Sales1	1011	0.57477	6.14406	0	164.765
7	R&D/ Sales2	942	0.34442	2.19773	0	39.0741
8	R&D/ Sales3	884	0.43338	3.28421	0	67.2753
9	R&D/ Sales4	839	0.32353	2.12113	0	39.0741
10	R&D/ Sales5	795	0.50013	7.58944	0	211.016
11	#Patents/ R&D3	697	0.65812	1.30427	0	14.7368
12	#Patents/ R&D4	674	0.60198	1.11071	0.00166	14.6032
13	#Patents/ R&D5	625	0.56827	1.36512	0	22.2222
14	#Patents/ R&D6	569	0.43925	0.84313	0.00223	11.7742
15	#Patents/ R&D7	494	0.33337	0.57387	0.00018	9.38462
16	Diversification	1236	1.0841	1.40524	0	9.78019
17	LogSales3	1014	2.6449	1.01161	-0.7235	5.07322
18	LogSales4	955	2.69538	1.00064	-0.7235	5.07322
19	LogSales5	904	2.74687	1.00472	-1.1938	5.10048
20	LogSales6	858	2.80352	0.9935	-1.1938	5.10464
21	LogSales7	807	2.85549	0.98871	-0.5467	5.10464
22	LT Debt/ Total Assets3	936	0.11848	0.15875	0	0.96844
23	LT Debt/ Total Assets4	844	0.11696	0.1604	0	0.91754
24	LT Debt/ Total Assets5	835	0.11294	0.15795	0	0.91754
25	LT Debt/ Total Assets6	792	0.10476	0.15128	0	0.86465
26	Intangibles/ Assets4	844	0.17507	0.1749	0	0.85556
27	Sales/ Total Employees7	729	0.32098	0.21661	0.00536	2.30995
28	Components (binary)	1236	0.56472	0.49599	0	1

Appendix III

Correlations for Specification 1

OBS.	**1**	**6**	**11**	**16**	**17**	**22**
6	**-0.0319**					
	0.3884					
	732					
11	**-0.0272**	**-0.022**				
	0.4881	0.5772				
	651	*643*				
16	**-0.0482**	**-0.0008**	**-0.1021**			
	0.1635	0.9801	0.007			
	837	*1,011*	*697*			
17	**-0.0648**	**-0.2224**	**-0.0208**	**0.35106**		
	0.0754	<.0001	0.5831	<.0001		
	753	*876*	*697*	*1014*		
22	**0.0086**	**-0.0472**	**-0.0167**	**-0.0362**	**0.11647**	
	0.8212	0.1625	0.6714	0.2692	0.0004	
	694	*878*	*648*	*936*	*933*	
28	**0.0562**	**-0.0528**	**0.10311**	**-0.2524**	**0.03398**	**0.02463**
	0.1042	0.0937	0.0064	<.0001	0.2797	0.4516
	837	*1,011*	*697*	*1,236*	*1,014*	*936*

Correlations for Specification 2

OBS.	2	7	12	16	18	23	26
7	**-0.0127**						
	0.7426						
	675						
12	**-0.0178**	**-0.0504**					
	0.6584	0.2071					
	623	*628*					
16	**-0.0369**	**0.03045**	**-0.112**				
	0.3023	0.3506	0.0036				
	783	*942*	*674*				
18	**-0.0852**	**-0.2502**	**-0.0742**	**0.35977**			
	0.0235	<.0001	0.0542	<.0001			
	707	*827*	*674*	*955*			
23	**-0.0024**	**-0.05**	**-0.0275**	**-0.0138**	**0.10527**		
	0.9504	0.1499	0.4896	0.6825	0.0018		
	653	*830*	*635*	*882*	*878*		
26	**0.0659**	**-0.0457**	**-0.0472**	**0.0687**	**0.0493**	**0.1171**	
	0.0921	0.1979	0.3823	0.0458	0.1532	0.0007	
	653	*795*	*884*	*844*	*840*	*844*	
28	**0.0832**	**-0.0771**	**0.08312**	**-0.2524**	**0.03965**	**-0.0177**	**-0.2133**
	0.0198	0.0179	0.031	<.0001	0.2209	0.5995	<.0001
	783	*942*	*674*	*1,236*	*955*	*882*	*884*

Correlations for Specification 3

OBS.	**3**	**8**	**13**	**16**	**19**	**24**
8	**-0.0066**					
	0.8677					
	643					
13	**-0.0224**	**-0.0192**				
	0.5896	0.6448				
	584	*581*				
16	**-0.057**	**0.00146**	**-0.0836**			
	0.1204	0.9654	0.0368			
	744	*884*	*625*			
19	**-0.086**	**-0.2534**	**-0.1099**	**0.35339**		
	0.0258	<.0001	0.006	<.0001		
	673	*787*	*623*	*904*		
24	**0.06925**	**-0.0571**	**-0.0289**	**-0.0029**	**0.09984**	
	0.0847	0.1092	0.4848	0.9334	0.004	
	621	*789*	*586*	*835*	*830*	
28	**0.1003**	**-0.044**	**0.07951**	**-0.2524**	**0.03325**	**-0.033**
	0.0062	0.1909	0.0469	<.0001	0.318	0.3411
	744	*884*	*625*	*1,236*	*904*	*835*

Correlations for Specification 4

OBS.	**4**	**9**	**14**	**16**	**20**	**25**
9	**-0.0407**					
	0.3118					
	620					
14	**0.00093**	**0.04387**				
	0.983	0.3125				
	533	*532*				
16	**-0.057**	**0.02223**	**-0.1035**			
	0.1292	0.5201	0.0135			
	710	*839*	*569*			
20	**-0.06**	**-0.2131**	**-0.085**	**0.35602**		
	0.1307	<.0001	0.043	<.0001		
	637	*755*	*567*	*858*		
25	**0.07552**	**-0.0486**	**-0.0247**	**0.05**	**0.16044**	
	0.0659	0.1819	0.5693	0.1597	<.0001	
	594	*757*	*533*	*792*	*787*	
28	**0.12938**	**-0.0802**	**0.03907**	**-0.2524**	**0.00217**	**-0.017**
	0.0005	0.0202	0.3522	<.0001	0.9494	0.6321
	710	*839*	*569*	*1,236*	*858*	*792*

Correlations for Specification 5

OBS.	**5**	**10**	**15**	**16**	**21**	**27**
10	**-0.038**					
	0.3642					
	572					
15	**-0.0667**	**-0.0064**				
	0.1526	0.8902				
	462	*465*				
16	**-0.0675**	**-0.0265**	**-0.1132**			
	0.083	0.4553	0.0118			
	660	*795*	*494*			
21	**-0.0442**	**-0.1911**	**-0.0866**	**0.36064**		
	0.2849	<.0001	0.0548	<.0001		
	587	*713*	*493*	*807*		
27	**0.05951**	**-0.0773**	**-0.0696**	**0.13726**	**0.22193**	
	0.1669	0.0404	0.1371	0.0002	<.0001	
	541	*704*	*458*	*729*	*729*	
28	**0.06627**	**-0.0557**	**0.02063**	**-0.2524**	**-0.0287**	**-0.1727**
	0.0889	0.1165	0.6473	<.0001	0.4151	<.0001
	660	*795*	*494*	*1,236*	*807*	*729*

Coefficient
Significance
Observations