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SOURCES OF CAPABILITIES, INTEGRATION AND TECHNOLOGY COMMERCIALIZATION

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In recent years, companies have increased their use of internal and external sources in pursuit of a competitive advantage through the effective and timely commercialization of new technology. Grounded in the resource-based view of the firm, this study examines the effect of a company's use of internal and external sources on multiple dimensions of successful technology commercialization (TC). The study also explores the moderating role of formal vs. informal integration mechanisms on these relationships. Applying a longitudinal design and data from 119 companies, the results show that internal human and technology-based manufacturing sources are positively associated with successful TC. Formal and informal integration mechanisms also significantly moderate the relationships observed between capability sources and TC.

Successful technology commercialization (TC) is important for survival in today's competitive markets (Cooper, 2000). Mitchell and Singh (1996: 170) view TC as 'the process of acquiring ideas, augmenting them with complementary knowledge, developing and manufacturing saleable goods, and selling the goods in a market.' This process begins with product conception; includes the product definition, design, prototyping and pretesting stages; and is consummated by effective product manufacturing and marketing. Successful TC allows the firm to satisfy its customers' needs in terms of the cost, speed, quality, and newness attributes of their technologies. However, TC requires strong and varied capabilities, especially in manufacturing (Ettlie, 1997; Siegel, Hansen, and Pellas, 1995). Manufacturing capabilities are grounded in the firm's people, skills, knowledge, processes, systems, and equipment. These capabilities can be assembled from different internal and external sources (Teece, Pisano and Shuen, 1997) and then deployed to create products and introduce them to the market in a timely manner.

Despite the growing use of internal and external sources of capabilities, researchers have not systematically documented the contributions of these sources to TC. This is especially the case with manufacturing sources. Consequently, most of the existing evidence is anecdotal (Eisenhardt and Tabrizi, 1995). Internal and external manufacturing sources have advantages and shortcomings that arise from their nature or the way they are managed (Barney, 1999). Though some shortcomings can be overcome through the effective integration of these sources into TC (Song, Souder, and Dyer, 1997), empirical evidence is sparse (Ragatz, Handfield, and Scannell, 1997). This gap in the literature reflects researchers' focus on the integration of the manufacturing unit, rather than the sources of capabilities in TC. Researchers have also studied the conditions that favor different sources (Williamson, 1999), emphasizing industry and competitive conditions (Combs and Ketchen,

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1999; Teece, 1986) but have failed to analyze how companies integrate their internal and external sources within TC. It is also not clear from the literature how formal and informal integration mechanisms influence the relationships between manufacturing sources and the various TC dimensions. Researchers have also selectively analyzed particular dimensions of TC while ignoring others, overlooking the potential trade-offs among these dimensions. This article attempts to address these gaps in the literature by considering multiple dimensions of TC.

The objectives of this study are twofold. First, it examines the effect of a firm's use of internal and external sources on TC. The study analyzes the impact of different manufacturing sources on TC but does not consider how these capabilities are assembled. Second, it explores the moderating effect of integration on the relationships between different manufacturing sources and various TC dimensions. Integration involves formal or informal mechanisms that coordinate the use of internal and external manufacturing sources within TC (Song *et al*., 1997). These sources determine the type, quality, and deftness of manufacturing capabilities. These capabilities indicate the firm's capacity to perform productive activities (Grant, 1998). The study considers the moderating effects of formal and informal integration mechanisms on internal or external manufacturing sources on TC.

This study makes three contributions to literature. First, it recognizes the multiplicity of manufacturing sources and their potential implications for TC. Second, it simultaneously considers TC as a multidimensional construct. Prior research has examined these dimensions separately, resulting in contradictory findings. Third, the study's research design provides insights into the effects of manufacturing sources on TC over time. Prior studies have used cross-sectional designs, making it difficult to evaluate the long-term effect of manufacturing sources on TC. We use a 3-year lag between TC dimensions and sources. We also rely on secondary data to capture TC and primary data to gauge sources, overcoming concerns about prior results that have used perceptual data.

The next section of the article reviews the literature, highlighting the importance and the multiple dimensions of TC. Drawing on the resource-based view (RBV), the article advances hypotheses on the relationships between manufacturing sources and integration mechanisms on TC. The article then presents a study that empirically tests these hypotheses, followed by a discussion of the findings and their managerial and scholarly implications.

THEORETICAL BACKGROUND AND HYPOTHESES

Successful TC is multifaceted. It refers to a firm's ability to: (1) develop and introduce a large number of product and process technologies (Zahra and Covin, 1993); (2) create radically new products (Zahra, 1996); (3) expedite the introduction of these new products to the market (Stevens, Burley, and Divine, 1999); and (4) create new knowledge (Leonard-Barton, 1995). We believe these dimensions should be considered simultaneously in order to understand the factors that influence TC.

Different TC dimensions play different roles in enabling the firm to develop a competitive advantage. The intensity of a firm's product introductions refers to the frequent introduction of products relative to the industry average or key rivals. New products help a company gain market leadership, and to achieve growth and profitability (Iansiti, 1995). They also enhance the company's understanding of its customers' needs and improve its responsiveness to the market (Day, 1999). Product radicalness signifies the newness or innovativeness of the products being introduced to the market (Rosenau, 2001). It enables the company to develop new markets or capture existing market share and thereby achieve growth. TC speed indicates a firm's ability to introduce new products or technologies more quickly than its competitors. This allows the firm to flank or attack its competitors, reduce costs, improve quality, absorb new technologies, expedite learning from customers (Eisenhardt, 1990; Iansiti, 1995), and improve new market performance (Calantone, Vickery, and Droge, 1995). The new knowledge created through TC also enables the firm to develop radically innovative products that transform the competitive landscape.

The RBV suggests that internal and external manufacturing sources, derived from human or technical assets and resources (Teece, 1986), can determine TC success. These sources give the firm the knowledge it needs to successfully pursue TC. This knowledge determines TC success. Though TC is the outcome of several organizational processes (e.g., strategic planning) and strategic choices (including manufacturing sources), and processes (e.g., strategic planning), different manufacturing sources significantly affect TC dimensions differently. As Figure 1 suggests, these effects will be moderated by integration, as discussed in the following paragraphs.

Capability sources and TC

Manufacturing plays a key role in determining a firm's competitive position (White, 1996).

Internal and external sources are the foundations of a firm's manufacturing capabilities (Grant, 1998). These capabilities evolve, reflecting shifts in technological trajectories, defined as the paths particular technologies follow over time (Dosi, 1982). These evolutionary paths depend on existing scientific knowledge and are fueled by a quest for improving a given technology's performance. As this technology enters a new phase, some companies experience a mismatch between their existing capabilities and the requirements for successful TC.

The RBV suggests that a company with strong manufacturing capabilities can enjoy an enduring competitive advantage and achieve superior performance (Stalk, Evans, and Shulman 1992). These capabilities enable the firm to develop new products and expedite their market introductions. However, external market factors sometimes constrain the supply of certain manufacturing sources (Dierickx and Cool, 1989). Some manufacturing sources are not tradable and must be built internally (Barney, 1999). Over time, some internal capabilities become rigid and limit TC success. Further, in dynamic markets, exclusive reliance on the internal sources of manufacturing capabilities have serious drawbacks. New products are increasingly complex (Leonard-Barton, 1995) and require multiple capabilities that few companies have internally.

Companies also selectively build certain manufacturing capabilities, leaving them vulnerable to market shifts. A firm's internal manufacturing capabilities might also be constrained by its prior investments, poor management, and internal process inefficiencies. Capabilities also develop at different rates and follow different evolutionary paths, creating significant difficulties in accumulating those capabilities needed for successful TC.

Developing internal sources of manufacturing capabilities is also a time-consuming and costly process that may take years. Once assembled, these capabilities should be kept current. Organizational politics determine those capabilities to be upgraded, leading to inefficiencies. Overcoming these inefficiencies requires assembling capabilities from new internal or external sources.

External manufacturing sources enable the firm to develop needed capabilities quickly, leading to flexibility and reducing costs (Gil and de la Fe, 1999). Externally acquired capabilities do not always fit the firm's internal systems and processes

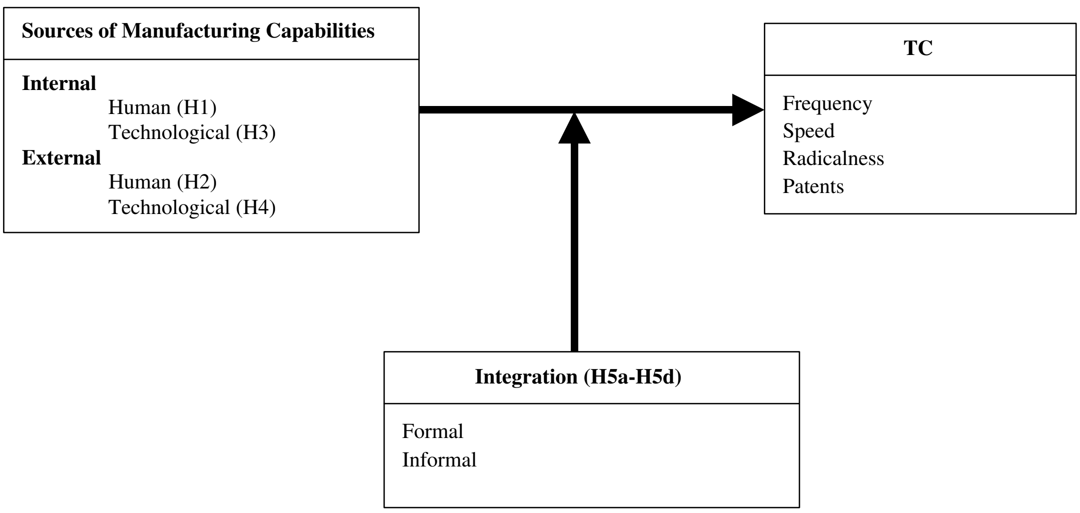

Figure 1. Integration as a moderator of the relationships between sources of manufacturing capabilities and technology commercialization (TC)

(Leonard-Barton, 1995), demanding the retraining of personnel or changing the flow of the production process. These changes can raise the cost of operations, create inefficiencies and slow down TC speed. Some external sources are also easier for outsiders to imitate. Excessive use of external sources can also reduce the investments in developing internal manufacturing capabilities, which can weaken a firm's competitive position (Lei, Hitt, and Bettis, 1996). These factors limit a firm's potential gains from using external sources. Given the advantages and shortcomings of the various sources of manufacturing, there is a need to document their effects on TC success.

Human resource (HR) sources

The HR component of internal manufacturing capabilities usually includes the knowledge, expertise, talents, creativity, and skills of a firm's manufacturing personnel (Cohen and Zysman, 1988; Davenport, 1992). The RBV posits that the unique skills and experiences of internally based manufacturing personnel can give the firm a competitive advantage (Lado and Wilson, 1994). This firm-specific, tacit knowledge takes years to develop (Nonaka and Takeuchi, 1995), making it difficult for others to copy those capabilities that embody this knowledge (Yeoh and Roth, 1999).

Following the RBV, a firm should maintain strong internal HR-based manufacturing capabilities in order to gain a competitive advantage. This can be achieved by recruiting (Ettlie and Vellenga, 1979) and maintaining a well-trained labor force and managers whose knowledge, skills, and experience serve as a source of innovation within manufacturing (Leonard-Barton, 1995). Recruitment also gives the firm access to current techniques and knowledge. New employees' skills are also honed through the experiences gained through learning by doing and the training the firm provides. These experiences also improve TC success by facilitating the development of innovative products (Yeoh and Roth, 1999). Ettlie and Vallenga (1979) have shown that new employees bring new skills and knowledge to the firm. This knowledge can expedite the speedy adoption of innovative technologies, which facilitates rapid product development and expedites TC. As manufacturing personnel gain experience, they become proficient in developing new products that expedite TC. These improvements also enhance the efficiency of the TC process, allowing the firm to reach the market quickly. Skilled manufacturing personnel also help the company by reducing costs, eliminating waste, and shortening the product development cycle. They also enhance the flexibility of a firm's manufacturing operations by adjusting its new product specifications and expediting TC cycles (Sanchez, 1995). Experienced and well-trained employees are also better equipped to implement changes in the internal processes, systems, and technologies needed for successful TC (Dertouzos *et al*., 1988). Therefore:

Hypothesis 1: Use of internal HR-based manufacturing sources leads to successful TC.

Some HR-based manufacturing capabilities are assembled from external sources (Figure 1) by joining strategic alliances, employing consultants and outside experts, or maintaining close ties with universities and other research centers (Ragatz *et al*., 1997). External sources fill serious voids in the firm's internal manufacturing sources (Teece, 1986), thereby promoting successful TC (Leonard-Barton, 1995).

The RBV holds that a firm's ability to develop innovative and different uses of external sources can become a source of competitive advantage. A company can deploy its external manufacturing sources in ways that expedite TC. Kamath and Liker (1994) note that the early involvement of suppliers and exploitation of their skills have helped several leading U.S. and Japanese companies succeed in TC. Suppliers also improve TC success by expanding the company's knowledge base (Quinn and Hilmer, 1994). Inputs from suppliers also enable the firm to focus TC activities on those sources that add value to new products while expediting TC (Dyer, 1996). Interactions with suppliers and other external groups also improve the manufacturing function's learning about the industry's best practices and applying them to TC, which would enhance the firm's knowledge base and TC speed. Therefore:

Hypothesis 2: Use of external HR-based manufacturing sources leads to successful TC.

Technology-based manufacturing sources

A key source of manufacturing capabilities is the firm's technological core, systems, assets, and resources (Figure 1). Japanese and Korean companies' success in TC has been attributed, in part, to the major improvements they have made in modernizing their manufacturing technologies and processes (Kodama, 1995). Companies that use modern manufacturing technologies are successful in TC (Dertouzos *et al.*, 1988). Modern technologies give the firm flexibility to manufacture different products and upgrade existing ones (Sanchez, 1995). They also foster other types of flexibility that expedite TC (Cohen and Zysman, 1988). The RBV proposes that companies that make effective use of modern technologies develop unique products and therefore gain a competitive advantage.

Modern manufacturing technologies also enable a firm to achieve economies of scope and increase the variety of their products while simultaneously reducing costs through economies of scale (Sanchez, 1995). These economies 'exist where multiple products can be more cheaply produced in combination than separately' (Jelinek and Goldhar, 1983: 29). New technologies also facilitate the rapid sharing of information in the TC process, which improves TC speed and efficiency. Following the RBV, innovative technologies are expected to promote successful TC. Therefore:

Hypothesis 3: Use of internal technical manufacturing sources leads to successful TC.

A firm can also use external sources to obtain modern manufacturing technologies (Lambe and Spekman, 1997), as noted in Figure 1. The RBV suggests that these technologies enable the firm to create differentiated products or lower costs. Sourcing can also reduce investing in the development of the company's internal manufacturing base. Using licensing and outsourcing arrangements gives the company access to highly specialized technologies or processes and standardized components. External sources can also reduce the costs and the time associated with TC, while encouraging suppliers to upgrade their technological base (Dyer, 1996). Similarly, outsourcing or licensing agreements give the firm access to several components or manufacturing processes, which would enhance TC success by exploiting the suppliers' technologies and knowledge (Bettis, Bradley, and Hamel, 1992). Therefore:

Hypothesis 4: Use of external technical manufacturing sources leads to successful TC.

The moderating effect of integration

Integration is the process by which the firm coordinates and deploys its different manufacturing sources in order to achieve successful TC (Grant, 1991). It includes the approaches, systems, and processes management uses to involve the firm's manufacturing staff in the TC process (Song *et al.*, 1997). This process centers on the deployment and use of the different internal and external manufacturing sources within TC. Integration is a conceptually distinct process from other internal manufacturing-related decisions (e.g., machine selection), activities or, capabilities that influence TC success. These variables typically fall under the input side of the manufacturing process, are functionally based, and relate to production activities. They also demand specialized knowledge bases.

Iansiti and Clark (1994) propose that the integration of internal and external sources is positively associated with successful TC. However, some companies that excel in developing their manufacturing sources and creating important capabilities fail in TC because of ineffective integration. Manufacturing integration promotes and cultivates cross-functional skills while understanding the TC task(s), considering when and how to involve the manufacturing staff, and selecting effective ways to harmonize the work of different functions associated with TC. This process requires political savvy and strong communication, and is usually grounded in a firm's culture and the trust that prevails among its units and employees. Integration corresponds to the transformation (throughput) of the firm's sources within its manufacturing operations.

Some companies succeed in obtaining manufacturing resources from internal and external sources but fail to gain the full benefits of these inputs because they do not effectively integrate their manufacturing sources into TC (Ettlie, 1988). Organizational culture, politics, lack of experience, and poor management may cause this failure to integrate different manufacturing sources into TC. Thus, the abundance of manufacturing resources does not guarantee that the firm will excel in, or practice, effective manufacturing integration (Hitt, Hoskisson, and Nixon, 1993). Conversely, other companies with limited internal sources have maximized their financial gains from TC through effective integration (Song *et al.*, 1997). Still, companies with developed internal manufacturing sources may tightly integrate the various functions within their operations, improving the efficient use of the resources employed to develop capabilities. These capabilities are multifaceted and some may not relate directly to TC. The effect of this dynamic interplay between resources and integration within the manufacturing unit becomes evident in the long run (5 years or longer), rather than within this study's time frame. Consequently, in this study, internal sources and integration are treated as independent constructs because of our focus on the use of different manufacturing *sources*, rather than their creation.[1]

Figure 1 suggests that the contribution of manufacturing integration to the success of TC will be greater when integration is high, rather than when it is low (e.g., Ettlie, 1995; Ettlie and Reza, 1992). Effective integration starts at the earliest stages (Eisenhardt and Tabrizi, 1995) and continues through the entire TC process. The early integration of manufacturing sources into the TC process is important because a large percentage of manufacturing costs (Whitney, 1988), and the features and quality of new products are determined early in the design stage. Integration also reduces slack within the TC process (Stalk and Hout, 1990) and provides the manufacturing staff with information that improves capacity planning and machine layout decisions (Leonard-Barton, 1992), ensuring TC success. Integration also improves learning (Iansiti and West, 1997) and makes the overlapping of the different internal and external manufacturing sources within TC possible, expediting TC.

When integration of manufacturing sources in TC is high, the alignment of different internal and external sources with product specifications will be stronger than when integration is low (Kahn, 1996). This ensures a problem-free transfer of new product designs into manufacturing, promoting efficient and speedy TC. When integration is high, the manufacturing staff can also contribute to successful TC by: developing ideas for new products using existing and untapped capabilities, serving as a learning laboratory for the TC team (Iansiti, 1995), and reducing costs while improving manufacturability (Gerwin, 1993).

Integration also improves coordination among the various groups involved in the TC process. It increases intergroup interactions (Kahn, 1996) and encourages joint problem solving and ownership and cross-learning, leading to successful TC (Ettlie, 1995). Collaboration facilitates the learning of tacit knowledge, which is firm specific. This learning can increase the firm's innovation, expedite new product development, and enhance the radicalness of the firm's new products. Integration also synchronizes external and internal manufacturing sources (Leonard-Barton, 1995), improving the firm's ability to customize its externally acquired components in ways that differentiate its products from those of the competition. Customization allows the firm to create unique technologies that are hard for rivals to imitate. Therefore:

Hypothesis 5a: The effect of internal HR sources on TC success is significantly higher when integration is high rather than when it is low.

Hypothesis 5b: The effect of external HR sources on TC success is significantly higher when integration is high rather than when it is low.

Hypothesis 5c: The effect of internal manufacturing technology sources on TC success is significantly higher when integration is high rather than when it is low.

Hypothesis 5d: The effect of external manufacturing technology sources on TC success is significantly higher when integration is high rather than when it is low.

METHOD

Sample

To test the hypotheses, data were collected using two mail surveys (conducted in 1996 and 1999), which were supplemented and validated with secondary data. Initially, we identified the names of 600 established companies. Defined at the 4-digit SICs, 20 U.S.-based industries were chosen because of their differences in manufacturing

[1] The RBV supports the separation of these two constructs (Teece *et al*., 1997). Prior researchers (Ettlie and Reza, 1992; Leonard-Barton, 1995; Song *et al*., 1997) also discussed these concepts as separate constructs, which is consistent with this study's position. Further, as reported later, the simple correlations among measures of integration and sources of capabilities were modest, with the highest simple correlation being 0.24. Further, we ran an orthogonal factor analysis with the measures of integration and internal sources to establish the distinctiveness of these variables. The multiple measures, as reported later, emerged as separate factors, suggesting that integration and internal sources were two different constructs.

technologies, innovation rates, and profitability. These variations were desirable in order to provide a valid test of the hypotheses.

Two criteria were used in developing the sample. First, to avoid problems arising from 'liability of newness,' a company had to be at least 5 years old. New companies may not have access to many external sources and often possess few internal resources, thereby constraining their TC efforts. These companies usually do not have significant experiences in all phases of TC, possibly limiting their gains from TC. Second, given that the need for integration increases as the firm's size grows, a company also had to have at least five employees in order to minimize the effects of extremely small company size. Larger companies often have multiple product lines, use multiple external sources and maintain a specialized labor force, making integration necessary. Very small firms may not face these issues or have the resources or the established relationships necessary to gain access to external manufacturing sources.

Names and addresses of companies and their senior executives were obtained from multiple sources including *Lexis-Nexis*, companies' annual reports, and *Business Week 1000*. Surveys were mailed to each company's chief executive officer (CEO) or highest-ranking official, who were the most knowledgeable about his/her firms' manufacturing operations (Gerwin, 1993; Hitt and Ireland, 1985) and innovation (Hitt *et al*., 1996). In the 1996 survey, two mailings were used. Of the 600 surveys mailed out, 23 were undeliverable. Completed responses were received from 149 companies, for a response rate of 25.82 percent. This response rate compared favorably with those achieved in similar studies (e.g., Gupta and Somers, 1996). The 1999 survey consisted of a single-page questionnaire that targeted those companies that responded to the 1996 survey. Three mailings, combined with follow-up calls and e-mails, yielded 97 completed responses.

Sample representation

We established the representativeness of the sample by comparing responding and non-responding companies based on their age, size (full-time employees), and sales volume. t-Tests showed that the two groups did not differ significantly in these variables. The χ^2 test also revealed that industry type and response to the survey were not significantly associated. A χ^2 test of the association between company location (by state) and response to the survey was not significant. Finally, t-tests compared early respondents to the 1996 survey (those that sent their questionnaire in within the first 2 weeks) and later respondents (those that sent their replies within the third week or later). Early and later respondents did not differ in their age, size (employees), or responses to the study's variables. These analyses supported the representativeness of the sample. Similar analyses for the 1999 survey showed no significant differences by company age, size, or location.

Testing for source bias

We safeguarded against source bias by collecting data from secondary and primary sources. Data for three of the four dependent variables as well as company age, size, and industry type came from different secondary sources. Further, we conducted the 'single factor' test on the 1996 survey data, as done in some prior research (Simonin, 1999). A principal component factor analysis of responses to all survey items yielded 12 factors with eigenvalues of 1.0 or higher. The analysis produced 12 factors rather than one, indicating that source bias was not a serious concern (Podsakoff and Organ, 1986).

Testing for inter-rater agreement

In 1996, a second copy of the questionnaire was sent to the vice presidents for manufacturing operations (or equivalent) in each of the 149 responding companies. Completed responses were received from 67 manufacturing managers. These responses served to establish inter-rater reliability. We matched the data already received from their CEOs (or highest-ranking executives) with the responses of manufacturing managers, as done in prior studies (Hitt *et al*., 1996; Zahra and Covin, 1993). We repeated this process in 1999, generating responses from two managers from 56 companies. Responses by the second executive were correlated with those of their firm's CEOs (or highest-ranking executive) on the study's variables using the 1996 ($r = 0.65$, $n = 67$, $p < 0.001$) and the 1999 ($r = 0.67$, $n = 59$, $p < 0.001$) surveys. This indicated a significant inter-rater reliability on the study's key variables. Data collected from the first (primary) respondents were used in the analyses. Finally, where possible, secondary data were collected and correlated with the survey-based measures, a commonly accepted practice (e.g., Zahra, 1996). This analysis showed positive and significant associations, supporting the validity of the measures. The results of this procedure are described next.

Measures

The dependent variables were measured and averaged over the 1997–99 period. The independent and control variables were measured over the preceding 3-year period.

Dependent variables

We collected data for four TC measures: the number of new products, number of radical new products, number of patents, and TC speed. Data for the first three measures were gathered from secondary sources, whereas the data for TC speed came from the 1999 survey.

Number of new products We measured this variable by the number of announcements of new product introductions each firm made over the 1997–99 period (e.g., Singh and Mitchell, 1996). The number of announcements came from *Lexis-Nexis,* a comprehensive research database (e.g., Anand and Khanna, 2000; Mitchell and Singh, 1996). We counted each product introduction only once, even if it appeared in multiple announcements.

Radical new products Given the high risks, costs, and rewards of radical new products (Cooper, 2000), we reclassified product announcements into radical vs. incremental (Chaney and Devinney, 1992; Devinney, 1992). Following past research (e.g., Kotabe and Swan, 1995), three MBA students independently reviewed all announcements related to a given product introduction and rated it based on its radicalness (Cooper, 2000). Given that strong disagreements persisted on the classification of 13 announcements, they were excluded from the analyses. We coded radically new products as 1 and incremental products as zero.

Number of patents We counted the number of a firm's patents, using data from the U.S. Patent Office. Data were available for 103 firms. Patents are an important measure of a company's innovation (Narin, Noma, and Perry, 1987), hence the knowledge created through TC. However, patent counts did not separate significant from incremental innovations. Also, some patents did not generate new products (DeCarolis and Deeds, 1999).

TC speed Data for this measure came from the 1999 survey. Following the literature (Buzzell and Gale, 1987), the survey asked managers, 'Once your company has developed a new product, how long on average does it take your company to introduce it to the market?' Respondents provided data in months. We validated this measure in two ways. First, using *Lexis-Nexis* we found references to the length of time it took some companies in the sample to develop and introduce new products. Where information existed for more than one new product, we averaged the figures and used this average in the analysis. We correlated the information from secondary sources with the figures gathered by the 1999 survey ($r = 0.71$, $n = 39$, $p < 0.001$). Second, we correlated a statement in the 1999 survey with the figures that managers reported (in months) about the speed of their new product introductions. The statement was, 'Compared to its key competitors, our company has a shorter product development cycle' (1 = strongly disagree vs. 5 = strongly agree). The correlation was positive and significant ($r = 0.81$, $n = 97$, $p < 0.001$).

Independent variable

We measured internal and external manufacturing sources, as follows:

Internal sources We measured internal manufacturing sources by eight items that were extracted from the literature (e.g., Hitt and Ireland, 1985; Lee and Na, 1994). A varimax factor solution (with an orthogonal rotation) yielded two significant factors, each with an eigenvalue above 1.0. As Table 1 shows, the two factors explained 56.03 percent of variance. The first factor (five items, $\alpha = 0.73$) indicated the existence of strong internal manufacturing-related HR skills among a firm's management and employees (Snell and Dean, 1992). The second factor (three items, $\alpha = 0.67$) showed the use of external consultants and temporary employees.

External sources Fourteen items, also extracted from the literature (e.g., Dyer, 1996; Lambe and

Table 1. Factor analysis of manufacturing human sources

Items	Factor 1	Factor 2
This company...		
• ... has a highly skilled production labor force	**0.78**	0.31
• ... offers extensive training to its employees in modern manufacturing techniques	**0.70**	0.27
• ... has increased hiring of new production workers	**0.65**	0.37
• ... has increased hiring of first-line production supervisors	**0.61**	0.19
• ... has reduced the size of its manufacturing labor force (*r*)	**−0.57**	0.24
• ... has increased the use of temporary employees in its manufacturing operations	0.25	**0.79**
• ... has used outside consultants in its new product development activities	0.31	**0.74**
• ... has used outside consultants in its manufacturing operations	0.23	**0.61**
Eigenvalue	2.43	1.95
% of variance explained	31.09	24.94
Cumulative % of variance explained	31.09	56.03

Spekman, 1997), showed the extent of a firm's use of external manufacturing sources. An orthogonal factor analysis (with a varimax rotation) of these items yielded three significant factors. As Table 2 shows, each factor had an eigenvalue above 1.0. The three factors explained 66.11 percent of variance.

The first factor (five items, $\alpha = 0.74$) showed the existence of strong internal manufacturing technological resources and facilities (Dertouzos *et al*., 1988). The second (five items, $\alpha = 0.70$) captured the use of joint ventures and alliances in manufacturing (Kotabe and Swan, 1995). The third factor (four items, $\alpha = 0.68$) showed a firm's use of outsourcing and licensing (Quinn and Hilmer, 1994).

Moderator variable

We measured integration in TC by 11 items that were extracted from the literature (Eisenhardt and Tabrizi, 1995; Ettlie, 1995; Gerwin, 1993; Kahn, 1996; Kahn and McDonough, 1997; Ettlie and Reza, 1992). An orthogonal factor analysis with a varimax rotation yielded the three factors presented in Table 3. These three factors explained 70.21 percent of variance.

The first factor (five items, $\alpha = 0.82$) captured the formal coordination between manufacturing and other functional units in TC (Rauscher and Smith, 1995). The second (three items, $\alpha = 0.73$) indicated the involvement of manufacturing in TC (Leonard-Barton, 1992). The third factor (three items, $\alpha = 0.73$) showed the existence of informal manufacturing coordination (Kahn, 1996; Kahn and McDonough, 1997).

Control variables

We controlled for a company's size, age, industry, and past performance, as follows.

Company size The analysis controlled for a company's size because of its potential impact on new product introductions (Yeoh and Roth, 1999) and access to external sources (Mosakowski, 1991). Company size was measured by the company's full-time employees (e.g.,Yeoh and Roth, 1999).

Company age The analysis also controlled for age because established companies had more access to external sources (Mosakowski, 1991) and engaged in frequent new product introductions and patenting (Deeds and Hill, 1996). Age was measured by the number of years a company has existed.

Industry type The study controlled also for industry type, which could determine the companies' technological opportunities (Ali, Kalwani, and Kovenock, 1993; Klevornick *et al*., 1995). Abundant technological opportunities might encourage companies to develop a large number of new products. Industries also varied in the payoff from speedy TC (Ali *et al*., 1993). They also differed in the extent of their use of internal vs. external sources (Teece, 1986); frequency of radically new products (Kotabe and Swan, 1995); and TC speed (Schoonhoven, Eisenhardt, and Lyman, 1990).

Industries were defined at the 4-digit SIC level. To control for industry type, an industry's average score on a given variable was subtracted from a

Table 2. Factor analysis manufacturing technological sources

Items	Factor 1	Factor 2	Factor 3
This company			
• ... has first-rate manufacturing facilities	**0.83**	0.26	0.38
• ... uses up-to-date technologies in its manufacturing operations	**0.80**	0.37	0.22
• ... relies on proprietary production (process) technologies	**0.77**	0.29	−0.29
• ... relies on internally developed process technologies	**0.74**	0.41	−0.16
• ... relies on proprietary product technologies	**0.71**	−0.09	0.12
• ... uses joint ventures to acquire innovative manufacturing technologies	0.40	**0.74**	0.27
• ... uses alliances with other companies to acquire new manufacturing technologies	−0.37	**0.69**	0.10
• ... uses joint ventures for new product development	0.29	**0.66**	0.08
• ... uses joint ventures to gain knowledge about new manufacturing systems and methods	0.21	**0.61**	0.17
• ... uses alliances with other companies to gain knowledge about new manufacturing methods	0.25	**0.57**	0.23
• ... has contracted out a major part of its manufacturing/production activities	0.23	0.30	**0.70**
• ... has contacted out some of its new product development activities	−0.33	0.21	**0.61**
• ... licenses product technologies from other companies	0.28	0.06	**0.55**
• ... licenses process technologies from other companies	0.34	0.21	**0.53**
Eigenvalue	3.81	2.80	1.92
% of variance explained	29.53	21.70	14.88
Cumulative % of variance explained	29.53	51.23	66.11

firm's score, and the difference was then divided by the industry's score (e.g., Zahra and Covin, 1993). Industries (and 4-digit SICs) studied were: fabricated metals (3442, 3443, 3465), industrial machinery and equipment (3556, 3559), computers (3571, 3572, 3575), electronics and electric equipment (3621, 3652, 3663), transportation equipment (3711, 3721, 3724, 3728), and instruments and related products (3812, 3825, 3826, 3842, 3845).

Past company performance A company's past financial performance was expected to increase the slack resources available for TC. When slack resources were abundant, companies were expected to develop radically new products and introduce them quickly to the market (Eisenhardt and Tabrizi, 1995), modernize their manufacturing base, attract qualified employees, spend more on employee training, and use different manufacturing sources. Slack resources were expected to promote radical innovation (Yeoh and Roth, 1999). The 3-year return on assets (ROA) was used as a control variable.

ANALYSIS

Table 4 presents the means, standard deviations, and intercorrelations for the study's variables. These figures were based on data from 119 firms. Given that the need for integration increases with size, companies with less than 100 employees ($n = 19$) were excluded. Missing data further reduced the sample to 119. Table 4 suggests that the correlations among the dependent and independent variables were consistent with expectations. Regression diagnostics also revealed a lack of serious multicollinearity among the variables.

We used hierarchical multiple regression analysis to test the hypotheses. In step 1, the control

Table 3. Factor analysis of manufacturing integration

Items	Factor 1	Factor 2	Factor 3
This company tightly coordinates:			
The activities of its R&D, production and marketing units	0.81	0.33	−0.09
The activities of its production and marketing units	0.78	0.29	0.05
The activities of all its operations	0.75	−0.21	0.01
The activities of its R&D and marketing units	0.71	0.39	−0.08
The activities of its R&D and production units	0.69	0.42	0.03
This company has increased the involvement of the following groups in the new product (technology) development:			
The production unit	0.37	0.79	−0.18
The marketing unit	0.32	0.70	−0.22
This company:			
Encourages free exchange of operating and financial information	0.09	0.51	0.44
Encourages bypassing of formal communication channels, as needed	0.12	−0.07	0.70
Stresses informal relationships for getting things done	0.33	−0.09	0.67
Maintains open communication channels in its operations	−0.15	0.19	0.61
Eigenvalue	3.2	1.99	1.60
% of variance explained	33.09	20.58	16.54
Cumulative % of variance explained	33.09	53.67	70.21

Table 4. Correlation matrix[a]

	Variables	χ	S.D.	01	02	03	04	05	06	07	08	09	10	11	12	13	14
01	Number of new products	2.13	4.17														
02	Number of radical products	0.61	0.98	21													
03	Patents	1.83	2.19	23	34												
04	TC speed	18.94	15.70	14	19	13											
05	Internal human resources	3.20	1.09	27	23	25	29										
06	External human resources	2.67	1.65	−13	−13	−11	09	14									
07	Internal manufacturing	3.31	1.35	25	29	−03	31	07	07								
08	Outsourcing & licensing	3.16	1.43	21	−19	−08	19	03	18	23							
09	Alliances & joint ventures	3.22	1.31	24	−25	10	21	26	29	26	23						
10	Formal involvement	3.07	1.76	20	09	07	21	−09	−04	19	18	19					
11	Formal coordination	3.05	1.61	19	23	04	27	−07	15	18	26	13	24				
12	Informal coordination	2.91	1.71	18	16	02	23	19	−27	−15	20	25	20	13			
13	Venture size (employees)	548.31	2392.17	14	−09	18	−07	16	15	18	07	23	12	20	−10		
14	Company age (years)	26.91	17.16	−07	−09	24	−03	10	12	−12	21	11	07	08	−04	11	
15	Past performance (ROA)	7.95	11.81	−04	−06	13	08	13	09	14	05	18	18	13	−05	09	−04

[a] $N = 119$ except for TC speed, where $N = 97$, and Patents, where $N = 103$; correlations are to the two decimal points and derived based on scores adjusted for industry average. Scores for the following variables are logged: number of products, radical products, patents, venture size, and past performance. For $N = 119$, r has to be 0.164 or higher to be significant ($p < 0.05$). For $N = 97$, r has to be 0.173 to be significant ($p < 0.05$).

variables were entered into the regression equation. Step 2 included both the control and independent variables. In step 3, we added interaction terms to the previous model. We created these interaction terms by multiplying each moderator by the manufacturing sources. The significance of changes in R^2 between successive steps (e.g., first vs. second) was also evaluated, as reported in Tables 5–8.

Hypotheses 1–4

The analyses showed that use of internal HR manufacturing sources was positively and significantly related to the number of new products (Table 5), radicalness of new products (Table 6), patents (Table 7), and TC speed (Table 8). These results supported Hypothesis 1.

External HR manufacturing sources were also positively and significantly related to the number of new products (Table 5) and TC speed (Table 8). These two results supported Hypothesis 2. However, external HR sources were negatively related to the number of patents (Table 7) and radicalness of new products (Table 6), which contradicted Hypothesis 2. Thus, the results partially supported Hypothesis 2.

The use of internal technological sources (measured by the 'internal proprietary manufacturing technologies') was positively and significantly related to the number of new products (Table 5), radical new products (Table 6), patents (Table 7), and TC speed (Table 8). These results supported Hypothesis 3.

Focusing on external technological sources, outsourcing and alliances were positively and significantly related to new product radicalness and TC speed. These results supported Hypothesis 4. Outsourcing was significantly but negatively associated with product radicalness (Table 6) and patents (Table 7), contradicting Hypothesis 4. The use of alliances and joint ventures had positive but nonsignificant signs with patents (Table 7) and TC radicalness (Table 8), also contradicting Hypothesis 4. The results partially supported Hypothesis 4.

Hypothesis 5

The results supported the moderating effect of integration, as indicated by the data from steps 3.1 through 3.3 in Tables 5–8. In all cases, adding the moderators significantly improved the results from step 2 ($p < 0.05$). Also, 14 of the 15 moderating relationships were significant ($p < 0.05$) for the number of new products. Twelve of the 15 moderators were significant at $p < 0.05$ and one at $p < 0.10$ with TC radicalness. Twelve moderators (out of 15) were also significant ($p < 0.05$) in the case of patents.

Hypothesis 5a suggested that the effect of internal HR sources on TC will be significantly higher under higher than lower integration. The results (Tables 5–8) strongly supported this prediction. All interaction terms for manufacturing involvement, formal coordination and informal coordination with internal HR sources were statistically significant with the number new products, radically new products, patents, and TC speed.

Hypothesis 5b suggested that the effect of external HR sources on TC will be significantly higher under higher than lower integration. The results (Tables 5–8) partially supported Hypothesis 5b. The three interaction terms for involvement, formal coordination and informal coordination with external HR sources were significant with the number of new products. For TC radicalness, the interaction of involvement with external HR sources was significant at $p < 0.05$, whereas the interaction term for informal coordination was marginally significant ($p < 0.10$). The interaction term for formal coordination was not significant. The results for patents (Table 7) also showed that only the interaction term for formal coordination and external HR was significant ($p < 0.05$). The interaction terms for involvement and informal coordination were not significant. For speed, two of the three interactions were significant, the exception being the interaction term for informal coordination (Table 8).

Hypothesis 5c posited that the effect of internal manufacturing sources on TC would be significantly higher when integration was high than low. The results (Tables 5–8) uniformly supported this prediction. Whether the dependent variable was the number of products, radical products, patents, or TC speed, the interaction terms for involvement, formal coordination, and informal coordination were significant.

Hypothesis 5d suggested that the effect of external manufacturing sources on TC would be significantly higher when integration was high rather than low. The results supported this prediction. Tables 5–8 showed that 19 of the 24 interaction terms for involvement, formal coordination, and informal coordination were positive and significant, validating our expectations. Nonsignificant interactions included alliances and joint ventures with informal coordination (Tables 5 and 6), and informal coordination and outsourcing (Table 7) with patents. For speed (Table 8), the four interaction terms for involvement and formal coordination were significant, but the two interaction terms for informal coordination were not. Thus, with 79.2 percent of the interaction terms being positive and significant, Hypothesis 5d was supported.

Table 5. Effect of manufacturing sources on number of new products ($N = 119$)

Variables	Step 1	Step 2	Step 3.1	Step 3.2	Step 3.3
Constant	2.09*	1.81*	1.47*	1.99**	1.91**
Step 1					
Company size	0.34**	0.29*	0.27*	0.37**	0.33*
Company age	0.10	−0.11	−0.07	−0.05	−0.09
Industry type (high technology = 1)	0.14@	0.17@	0.15@	0.14@	0.19*
Past performance (ROA)	0.04	0.09	0.03	0.01	0.07
Step 2					
Internal HR		0.23*	0.26*	0.22*	0.29*
External HR		−0.09	−0.08	−0.01	−0.09
Internal proprietary manufacturing technologies		0.43***	0.47***	0.39**	0.33**
Outsourcing & licensing		0.21*	0.26*	0.31*	0.23*
Alliances & joint ventures		0.33**	0.23*	0.25*	0.18*
Formal involvement		0.09	0.13	0.12	0.11
Formal coordination		0.13	0.06	0.11	0.11
Informal coordination		0.08	0.11	0.11	0.09
Step 3					
Involvement ∗ Internal HR [step 3.1]			0.37**		
Involvement ∗ External HR			0.25*		
Involvement ∗ Internal prop. manufacturing technologies			0.19*		
Involvement ∗ Outsourcing & licensing			0.25*		
Involvement ∗ Alliances & joint ventures			0.21*		
Formal coordination ∗ Internal HR [step 3.2]				0.23*	
Formal coordination ∗ External HR				0.27**	
Formal coordination ∗ Internal prop. manufacturing technologies				0.22*	
Formal coordination ∗ Outsourcing & licensing				0.21*	
Formal coordination ∗ Alliances & joint ventures				0.39**	
Informal coordination ∗ Internal HR [step 3.3]					0.29*
Informal coordination ∗ External HR					0.20*
Informal coordination ∗ Internal prop. manufacturing technologies					0.23*
Informal coordination ∗ Outsourcing & licensing					0.19*
Informal coordination ∗ Alliances & joint ventures					0.02
F-value =	2.09*	2.97**	4.59***	5.61***	4.53***
Adjusted R^2 =	0.08	0.21	0.29	0.30	0.28
Change in R^2 =		0.13	0.09	0.09	0.07
Partial F (change in R^2) =		2.24*	2.17*	2.59*	1.86*

@$p < 0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Table 6. Effect of manufacturing sources on number of radically new products ($N = 117$)

Variables	Step 1	Step 2	Step 3.1	Step 3.2	Step 3.3
Constant	1.03	1.19*	1.53*	1.60*	1.71*
Step 1					
Company size	−0.02	−0.03	−0.05	0.09	−0.13
Company age	−0.09	−0.02	−0.03	−0.05	−0.04
Industry type (high technology = 1)	0.14@	0.18*	0.15@	0.14@	0.19*
Past performance (ROA)	0.04	0.04	0.03	0.05	0.06
Step 2					
Internal HR		0.51***	0.46***	0.22*	0.29*
External HR		−0.09	−0.08	−0.03	−0.09
Internal proprietary manufacturing technologies		0.43***	0.56***	0.41***	0.24*
Outsourcing & licensing		0.19*	0.23*	0.31*	0.34**
Alliances & joint ventures		0.34**	0.21*	0.20*	0.27*
Formal involvement		0.11	0.13	0.09	0.07
Formal coordination		0.05	0.06	0.03	0.09
Informal coordination		0.06	0.10	0.14@	0.10
Step 3					
Involvement ∗ Internal HR [step 3.1]			0.59***		
Involvement ∗ External HR			0.20*		
Involvement ∗ Internal prop. manufacturing technologies			0.37*		
Involvement ∗ Outsourcing & licensing			0.21*		
Involvement ∗ Alliances & joint ventures			0.19*		
Formal coordination ∗ Internal HR [step 3.2]				0.26*	
Formal coordination ∗ External HR				0.09	
Formal coordination ∗ Internal prop. manufacturing technologies				0.19*	
Formal coordination ∗ Outsourcing & licensing				0.27*	
Formal coordination ∗ Alliances & joint ventures				0.23*	
Informal coordination ∗ Internal HR [step 3.3]					0.21*
Informal coordination ∗ External HR					0.14@
Informal coordination ∗ Internal prop. manufacturing technologies					0.25*
Informal coordination ∗ Outsourcing & licensing					0.23*
Informal coordination ∗ Alliances & joint ventures					0.09
F-value =	2.13**	3.04**	4.59***	3.93***	4.08***
Adjusted R^2 =	0.07	0.21	0.29	0.27	0.28
Change in R^2 =		0.14	0.08	0.06	0.07
Partial F (change in R^2) =		2.39*	2.23*	1.78*	1.97*

@$p<0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Control variables

Tables 5–8 also showed that company size was positively related to the number of new products ($p < 0.05$), but negatively associated with patents ($p < 0.05$). Company age was negatively associated with both TC radicalness and speed (both at $p < 0.05$). Competing in a high-technology industry was positively associated with patents ($p < 0.05$), but marginally ($p < 0.10$) and positively associated with the number of products, product radicalness, and TC speed ($p < 0.10$).

Table 7. Effect of manufacturing sources on number of patents ($N = 103$)

Variables	Step 1	Step 2	Step 3.1	Step 3.2	Step 3.3
Constant	2.31*	3.45**	4.07**	4.61**	4.72**
Step 1					
Company size	−0.22*	−0.23*	−0.25*	−0.26*	−0.23*
Company age	0.03	0.12	0.13	0.07	0.04
Industry type (high technology = 1)	0.19*	0.18*	0.19*	0.18*	0.19*
Past performance (ROA)	0.10	0.11	0.13	0.08	0.03
Step 2					
Internal HR		0.34**	0.36**	0.31**	0.23*
External HR		−0.01	−0.02	−0.03	−0.09
Internal proprietary manufacturing technologies		0.27*	0.31*	0.34**	0.31*
Outsourcing & licensing		−0.03	−0.03	−0.01	−0.04
Alliances & joint ventures		0.23*	0.21*	0.20*	0.24*
Formal involvement		0.09	0.02	0.03	0.05
Formal coordination		0.03	0.04	0.06	0.03
Informal coordination		0.07	0.06	0.05	0.02
Step 3					
Involvement ∗ Internal HR [step 3.1]			0.47***		
Involvement ∗ External HR			−0.09		
Involvement ∗ Internal prop. manufacturing technologies			0.26*		
Involvement ∗ Outsourcing & licensing			0.21*		
Involvement ∗ Alliances & joint ventures			0.18*		
Formal coordination ∗ Internal HR [step 3.2]				0.26*	
Formal coordination ∗ External HR				0.29*	
Formal coordination ∗ Internal prop. manufacturing technologies				0.19*	
Formal coordination ∗ Outsourcing & licensing				0.28*	
Formal coordination ∗ Alliances & joint ventures				0.19*	
Informal coordination ∗ Internal HR [step 3.3]					0.24*
Informal coordination ∗ External HR					0.03
Informal coordination ∗ Internal prop. manufacturing technologies					0.29*
Informal coordination ∗ Outsourcing & licensing					0.01
Informal coordination ∗ Alliances & joint ventures					0.20*
F-value =	1.94*	2.81**	3.76***	3.94***	3.29***
Adjusted R^2 =	0.09	0.20	0.28	0.28	0.24
Change in R^2 =		0.13	0.08	0.08	0.04
Partial F (change in R^2) =		1.92*	2.15*	2.15*	1.03

$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$

DISCUSSION

Increasingly, companies use internal and external sources to assemble the capabilities required for successful TC. This study shows that a company's internal and external sources significantly influence its TC and that integration strengthens the contributions of the manufacturing sources to TC. This section discusses the study's key findings.

Capability sources and TC

The results show that internal HR manufacturing sources positively influence TC by providing the

Table 8. Effect of manufacturing sources on TC speed ($N = 97$)

Variables	Step 1	Step 2	Step 3.1	Step 3.2	Step 3.3
Constant	0.41	0.97*	1.33*	1.59*	1.71*
Step 1					
Company size	−0.11	−0.09	−0.13	−0.18*	−0.11
Company age	−0.19*	−0.19*	−0.21*	−0.23*	−0.20*
Industry type (high technology = 1)	0.07	0.07	0.09	0.11	0.06
Past performance (ROA)	0.04	0.09	0.03	0.04	0.05
Step 2					
Internal HR		0.26*	0.36**	0.31**	0.25*
External HR		0.19*	0.20*	0.18*	0.19*
Internal proprietary manufacturing technologies		0.23*	0.31*	0.27*	0.27*
Outsourcing & licensing		0.37**	0.31*	0.29*	0.24*
Alliances & joint ventures		0.22*	0.21*	0.20*	0.21*
Formal involvement		0.15@	0.12	0.11	0.08
Formal coordination		0.12	0.09	0.07	0.01
Informal coordination		0.07	0.06	0.03	0.09
Step 3					
Involvement ∗ Internal HR [step 3.1]			0.38**		
Involvement ∗ External HR			0.29*		
Involvement ∗ Internal prop. manufacturing technologies			0.20*		
Involvement ∗ Outsourcing & licensing			0.25*		
Involvement ∗ Alliances & joint ventures			0.23*		
Formal coordination ∗ Internal HR [step 3.2]				0.21*	
Formal coordination ∗ External HR				0.25*	
Formal coordination ∗ Internal prop. manufacturing technologies				0.29*	
Formal coordination ∗ Outsourcing & licensing				0.23*	
Formal coordination ∗ Alliances & joint ventures				0.18*	
Informal coordination ∗ Internal HR [step 3.3]					0.35**
Informal coordination ∗ External HR					−0.08
Informal coordination ∗ Internal prop. manufacturing technologies					0.21*
Informal coordination ∗ Outsourcing & licensing					−0.12
Informal coordination ∗ Alliances & joint ventures					−0.03
F-value =	1.05	2.11*	2.87***	2.53***	2.43**
Adjusted R^2 =	0.04	0.17*	0.25	0.28	0.23
Change in R^2 =		0.13	0.08	0.11	0.06
Partial F (change in R^2) =		1.57	1.77*	2.44**	1.23

@$p < 0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

company with the knowledge needed for successful TC. The results suggest that strong internal technical manufacturing capabilities lead to successful TC. Given these significant results, investments in and the development of internal HR and technical manufacturing sources should be a managerial priority.

The analyses also highlight the importance of, and challenges associated with, using external HR manufacturing sources. These sources significantly improve the number of new products and TC speed. Likewise, outsourcing and alliances facilitate new product introductions and speedy TC. However, the results also show that firms might have to trade off the radicalness of their new products and patents as they intensify their product introductions and the speed of these introductions, especially when using external sources. Specifically, external HR sources are negatively associated with TC radicalness and patents. The data also indicate that outsourcing is negatively related to new product radicalness and patents. Given that the number of patents and new product radicalness capture a firm's ability to develop new knowledge, the negative coefficients observed in this study signal a serious loss of proprietary knowledge because of a company's reliance on external sources. Outsourcing and other external sources adversely influence the development of tacit and firm-specific knowledge necessary for radical innovation that yields new knowledge. In contrast, frequent new product introductions and speedy TC can be achieved through incremental product and process innovation. However, it takes time to acquire, assimilate, and deploy external knowledge. Transforming a firm from imitation to radical innovation also takes years to occur. Radical innovation and new knowledge creation also require considerable learning by doing to develop requisite knowledge. External sources may not yield tacit knowledge, either because acquired items are standard components or are sold without suppliers' sharing their knowledge with the firm. Tacit knowledge is not easily transferred in formal market transactions and substantial effort is needed to assimilate this knowledge (Zahra and George, 2002).

Integration of capability sources

Integration emerges as a strong and significant moderator of the relationship between manufacturing sources and TC. Thus, the effect of the manufacturing sources on different TC dimensions is higher and significant when integration is high. Three key points are evident from the results. First, both formal and informal integration is important but the contributions of formal integration are clearly identifiable in this research. Informal coordination adds significantly to the explanatory power in the regressions in two out of four cases (number of new products and radically new products). 19 and 18 of the 20 interaction terms for involvement and formal coordination, respectively, are significant. Conversely, 12 of the 20 interactions for informal coordination are significant. Formal coordination yields greater synergies between internal and external capability sources, which promotes TC.

Second, the moderating effects of integration are also stronger for internal human and technological sources than external human and technological sources. All 12 interaction terms for internal and external HR sources are positive and significant. Companies that develop internal HR and manufacturing sources gain significantly in TC, especially when integration of manufacturing sources in TC is high. These firms can combine different resources and skills that increase the firm's combinative knowledge that creates radically new products and patents and achieves speedy TC. Integration of internal sources also yields the resource combinations and proprietary knowledge that facilitate successful TC.

Third, informal integration mechanisms do not help in assimilating external sources to the extent they do internal sources. 7 of the 12 interactions for external HR and 19 out of 24 interactions for external technological sources are positive and significant, showing that integration of internal and external sources can be beneficial in terms of TC. Some organizational cultures promote the sharing of knowledge among the firm's units regarding internal sources. Common and well-understood routines that permeate organizational units also facilitate communication, generating combinative knowledge and fostering learning by doing.

There are several factors that limit the role of informal integration in assimilating external sources. These sources often embody tacit and different knowledge bases that are not easily comprehended by the recipient firm. The use of multiple external sources also constrains a firm's ability to decipher and understand the knowledge embedded in these sources. Informal integration also necessitates trust based on shared experiences and goals. The suppliers of some external sources do not fully understand or share the recipient firm's goals, complicating the integration of different sources. Informal, and often post hoc, integration may not suffice to overcome these critical shortcomings. For example, though informal coordination may facilitate the sharing of sensitive information in alliances and joint ventures, it may not suffice to integrate the knowledge gained from these transactions into the TC process.

The above observations highlight the limits of transaction cost and RBV explanations of the differential use of internal and external sources (Steensma and Corley, 2001). Transaction cost and RBV analyses usually ignore the role of a firm's absorptive capacity in assimilating external sources of knowledge (Zahra and George, 2002). Reliance on economic criteria to make sourcing decisions also obscures the need for adaptation and learning in order to benefit from externally acquired products, components, or knowledge. Sourcing decisions should also recognize the importance and costs of organizational learning and the evolution of capabilities as an outcome of the various phases of the TC process.

Limitations

The above discussion urges caution in interpreting our results. Even though the sample represents its target population, it does not cover all U.S. manufacturing industries and the results may not apply to all sectors of the economy. The study has also examined the relationships between manufacturing sources and integration with TC, ignoring other functions. The focus on the extent rather than the process of integration is another shortcoming. Finally, the study did not probe a company's motivations for using different manufacturing sources. Still, the results make several contributions to the field, as discussed below.

Contributions to the literature

Empirically, this article recognizes and measures four dimensions of TC. Prior research has examined selected dimensions of TC, possibly overlooking the trade-offs that might exist among these dimensions. In contrast, this study provides a richer understanding of the relationships among these dimensions while setting the stage for exploring their influence on a firm's competitive advantage and performance. Another contribution is linking internal and external manufacturing sources to the four TC dimensions and developing measures of several internal and external manufacturing sources as well as informal integration. A third contribution is using multiple data sources to gauge the study's various constructs, while using a 3-year lag between the independent and dependent variables. This overcomes a limitation of prior research that has employed cross-sectional designs and used data gathered from a single respondent.

The article also contributes to theory development. It examines manufacturing integration within TC, which is different from the integration of the manufacturing function or unit into the firm's planning or strategy formulation process. Focusing on integration moves us closer to where it can significantly influence a firm's financial performance. Similarly, studying internal and external manufacturing sources has implications for conducting thoughtful analyses of a firm's boundary decisions and the locus of its productive activities, which is a fundamental issue in the study of strategy (Williamson, 1999). Further, though the concept of integration has commanded great interest in the literature, this study has analyzed the various formal and informal mechanisms that a firm can use to integrate various sources of knowledge with its TC process. The results inform future theory development on the efficiency of formal vs. informal integration mechanisms, especially in terms of their impact on TC.

The article also highlights knowledge creation as an important dimension of TC, thereby connecting research on manufacturing capabilities with the knowledge-based view of the firm (Grant, 1998). Concerns have been raised about the boundaries and potential contributions of the RBV (Priem and Butler, 2001; Barney, 2001). Even though the article offers a test of the propositions of the RBV within the TC and manufacturing arena, its results show a need to go beyond this perspective and investigate the role of knowledge in creating dynamic capabilities that foster successful TC. In particular, the article links TC dimensions with the growing literature on the knowledge-based theory of the firm. This article departs from the literature by suggesting that decisions related to TC and sourcing decisions should incorporate criteria that consider their potential effect on knowledge creation and exploitation. TC is a knowledge-intensive process that requires managers to consider internal or external resources based on their potential effects on a firm's knowledge base (Lee, Lee, and Pennings, 2001).

Managerial implications

The results also highlight the importance of having strong internal manufacturing sources for successful TC. This requires patient investments to acquire new skills and upgrade existing ones. Strategic audits should also enable executives to identify the firm's internal resources and explore ways to develop the manufacturing capabilities that improve TC success.

Managers need also to develop strong HR-based manufacturing skills that ensure successful TC. Internal HR sources improve learning by doing, yielding the tacit knowledge essential for TC. The strategic value of internal HR sources is further highlighted by the weak and negative associations observed between external HR manufacturing sources and some of the TC measures. Excessive use of external HR manufacturing sources may also cause companies to lose opportunities to develop the proprietary and tacit knowledge needed to introduce radically new products. While the use of external sources is a competitive necessity today, managers should identify the critical resources and capabilities that should be developed internally.

Integration also significantly influences the number and radicalness of a firm's new products. It improves the contributions of the internal technical and HR manufacturing sources to TC and offsets some of the shortcomings of the external sources of technical and HR sources. Importantly, formal coordination is more important for TC success than informal coordination. Managers can establish the mechanisms that encourage the involvement of the firm's manufacturing activities within TC by using specialized and cross-functional task forces that combine and coordinate the use of different manufacturing sources.

Implications for future research

Our analyses indicate that different internal and external manufacturing sources significantly differentially influence TC dimensions. The four TC dimensions analyzed in this article offer different but complementary paths to various types of competitive advantages. The specific links between these four dimensions of TC and different sources of competitive advantages should be explored in future studies. Research on this issue can capture the complementarities (or trade-offs) that might exist among different TC dimensions. A formal meta-analysis of TC dimensions can also clarify the relationships among TC, integration, and company performance.

The distinction between internal and external sources is a thorny issue. With recent changes in the way firms assemble their diverse capabilities, we need to revise existing definitions of internal vs. external sources. The complexity of the transactions involved and ownership systems that might exist in today's business environments suggest that a new classification of these sources would be beneficial. Once such distinctions are made, researchers can examine the systems and processes employed to integrate internal and external sources and the factors that influence such integration. Future research can also identify industry and firm-related factors that influence the integration of internal and external sources of manufacturing capabilities. Finally, the processes by which this integration occurs within TC should be examined. Toward this end, the domain and measurement of integration should be clarified and the contextual variables that influence the associations between integration and TC should be investigated.

CONCLUSION

Technology commercialization is an important means for gaining market share, satisfying customers' needs and achieving profitability. Our results show that a company's internal human and technological sources are important for successful TC. Further, some external sources (both human and technological) are conducive to successful TC. The contributions of internal and external manufacturing sources, in particular, to TC increase significantly with the use of formal integration. The pay-off from informal coordination in enhancing TC success is higher with internal than with external technological sources. The results invite future empirical research into the effect of integration of manufacturing sources on TC.

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