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Keskusteluaiheita – Discussion papers

No. 1051

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WHEN DOES CO-LOCATION OF MANUFACTURING AND R&D MATTER?

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Acknowledgements:
This paper has been prepared as part of the BRIE-ETLA collaboration (www.brie-etla.org). I would like to thank Jyrki Ali-Yrkkö, Christopher Palmberg, Petri Rouvinen, and Pekka Ylä-Anttila for comments on earlier drafts of this paper. I would also like to thank the six executives and managers who shared their expertise on co-location with me in the interviews. Some of the ideas regarding functional integration presented in this paper were developed in collaboration with my colleagues at the University of Minnesota and Helsinki University of Technology, and were presented at the Annual Meeting of the Academy of Management in Atlanta, August 2006. I would like to acknowledge here the contributions of Roger Schroeder and Virpi Turkulainen.

ISSN 0781-6847 03.11.2006

KETOKIVI, Mikko, **WHEN DOES CO-LOCATION OF MANUFACTURING AND R&D MATTER?** Helsinki: ETLA, Elinkeinoelämän Tutkimuslaitos, The Research Institute of the Finnish Economy, 2006, 22 p. (Keskusteluaiheita, Discussion Papers, ISSN 0781-6847; No. 1051).

ABSTRACT: While both manufacturing and R&D location decisions have received considerable theoretical and empirical attention from economists and organization scientists, theories and evidence regarding the "co-location" of the two are scarce. The goal of this article is to lay the theoretical foundation for R&D-manufacturing co-location. Theories of functional integration along with qualitative and preliminary quantitative empirical data are used to examine the question: When is co-location of R&D and manufacturing necessary?

Keywords: Location decisions, Co-location, Functional integration, Organization theory

JEL-codes: D21, L23, M11, O32, R32

1. INTRODUCTION

> Govindarajan and Gupta (2001, p. 86): "Texas Instruments' sophisticated high-speed telecommunications chip, TCM9055, was conceived in collaboration with engineers from Sweden, designed in France using software tools developed in the U.S., produced in Japan and the U.S., and tested in Taiwan."

> Clark and Wheelwright (1993, pp. 462-463): "Even though the phases in the new product development process of the baby heart monitor fell within the traditional definition each function's role in the project, the project was very problematic. Before arriving at a commercially viable product, the product had to undergo significant redesign. It took the organization a long time to move from product concept to market introduction of a viable commercial product. Because the design of the product and process were accomplished somewhat in isolation, the overall development of a completed design and manufacturing process was slow and required a great deal of rework, which ate up significant resources. Achieving an integrated product and process design requires a very different approach, one that brings design choices and process capabilities into contact with one another early enough so that the two can influence and shape one another in a timely and effective way."

Division of tasks and subsequent *coordination of these tasks* are fundamental to economic activity across levels of analysis; they are indeed relevant not only at macro- and micro-economic but also organizational and micro-organizational levels. Closely related to these two fundamental tasks are decisions regarding the geographic location of activities, because the physical location of activities has profound implications on coordination.

While manufacturing and R&D location decisions have both received a lot of attention in the extant literature, the determinants of *co-location* of the two—the location of both activities in the same geographic location—has attracted considerably less interest. The goal of this paper is to start filling this gap by examining the co-location of R&D and manufacturing activities, by looking at both external and internal (to the firm) drivers of co-location. The central question I pose in this paper is:

When is co-location necessary for the effective coordination of R&D and manufacturing activities?

While some researchers have argued that physical co-location of activities is central to coordination both within and across functions, others have proposed that co-location is "overrated" in the sense that there are alternative and less expensive mechanisms for coordination (Rafii, 1995), particularly after the advent of advanced information technologies, starting in effect already with the invention of the telegraph in the 1800s (Appold, 2005). As a result, geographic dispersion of R&D activities within the firm is more the norm than an exception (e.g., J. R. Howells, 1995; Rugman & Verbeke, 2001). The geographic dispersion of manufacturing activities within the firm, in turn, has been widespread for decades.

At the same time, information technology and other advances in coordination have not completely eliminated all interdependencies and the need for co-location. Conventional wisdom and some of the classical studies suggest that internationalization of R&D tends to—or at least did in the 1980s—follow the same path as internationalization of manufacturing (Pearce & Singh, 1992). In addition, just about any large manufacturing plant has an R&D organization with resident industrial engineers, product development teams, and the like. "Factories" have in many industries indeed developed into multifaceted and complex ”technology centers”. However, aside from a few conceptual frameworks and arguments, we have little formal theory and only a descriptive empirical understanding of how manufacturing and R&D location decisions are interdependent. The goal in this paper is to move us toward a theoretical understanding of co-location. This will be achieved through a micro-organizational analysis of R&D and manufacturing and their interdependencies.

To be sure, location decisions—both R&D and manufacturing—have received a lot of theoretical and empirical attention from economists (Mueller & Morgan, 1962; Pearce & Singh, 1992) as well as organizational scholars (Brush, Maritan, & Karnani, 1999; Ferdows, 1989; Kuemmerle, 1999; Schmenner, 1982). More recently, also co-location of various functional activities (R&D, marketing and manufacturing) has been addressed (Ekholm & Hakkala, 2006; Govindarajan & Gupta, 2001; van den Bulte & Moenaert, 1998). However, these arguments, many of them anecdotal, need to be supported by stronger theory development as well as rigorous empirical research.

With the rising concern in Finland and the Western Europe on general that manufacturing activities and jobs are being relocated to Eastern Europe and Asia, this article has economic, managerial and political relevance as well: What are the implications of this new geographic division of manufacturing tasks on R&D activities? Are decisions about the location of R&D activities subject to the same laws and regularities as manufacturing? Under what conditions must R&D and manufacturing be co-located?

1.1. “WHAT’S GOING ON OUT THERE?”

Nokia is still the world’s largest *manufacturer* of cellular phones. Where are its manufacturing activities located? Is it surprising that even though Nokia’s sales in Finland account for less than 1% of its total sales, it still keeps some 60,000 m^2 of production space (25% of its total) in Finland (Nokia, 2005)?

Intel, the world’s largest semiconductor chip manufacturer, in turn, has 77% of its manufacturing operations within the U.S. (this is actually higher than it was in 2002, when the corresponding figure was 70%). U.S. is also where the ”substantial majority” of Intel’s R&D takes place (Intel, 2002, 2005).

On a smaller scale, Vaisala, the Finnish developer and manufacturer of high-technology measurement systems and devices in meteorology, has 76% of its assets (including the vast majority of its manufacturing) located in the suburbs of Helsinki (Annual Report, 2005). In a similar vein, VTI Technologies, the Finnish developer and manufacturer of motion and pressure sensors, recently built an 80 M€ manufacturing facility in Helsinki, where its R&D is located as well. For a company with less than 100 M€ in annual sales, this is a huge investment in manufacturing, and in Finland.

Finally, the Finnish mobile phone charger designer and manufacturer Salcomp has 90% of its manufacturing and 70% of its R&D personnel located in Shenzen, China (Annual Report, 2005).

All the companies described above have manufacturing and also invest in R&D, some more intensively than others. But for some reason, all of them have decided to co-locate R&D and manufacturing, at least to an extent. The purpose of this paper is to explore why this might be the case. The treatment of the topic in this paper is largely conceptual and theoretical, but it is also aimed at laying the foundation for more detailed and comprehensive large-sample empirical study. The theoretical treatment in this paper is, however, guided by a number of semi-structured interviews conducted in April-June 2006. Therefore, the theory is also in a sense induced from qualitative empirical observation.

2. DETERMINANTS OF LOCATION DECISIONS

While the research interests of economists and organization scholars have coincided in studying (co-)location decisions, economists have in the main been interested in the location-specific drivers, the ”locational pulls”, such as access to local technologies and know-how (e.g., Audretsch & Feldman, 1996), whereas organizational scholars have focused not as much on locational as they have on industry- and especially firm-specific considerations (Brush, Maritan, & Karnani, 1999) and even at a more micro-level, cross-functional interdependencies within the firm (Adler, 1995; Clark & Wheelwright, 1993).

In this paper, I incorporate the organizational drivers of location and co-location decisions by looking at within-organizational factors that may imply co-location. It is thus useful to distinguish between two types of determinants for location decisions: environmental and organizational. Environmental factors may further be divided into location-specific, industry-specific and market-specific; what they have in common, however, is that they are exogenous to the organization and often beyond the sphere of influence of organizational decision-making. Organizations *adapt* to these contingencies. These are also factors whose effects manifest themselves as tendencies in larger populations, even across national economies, although their effects on individual firms may vary (Kuemmerle, 1999).

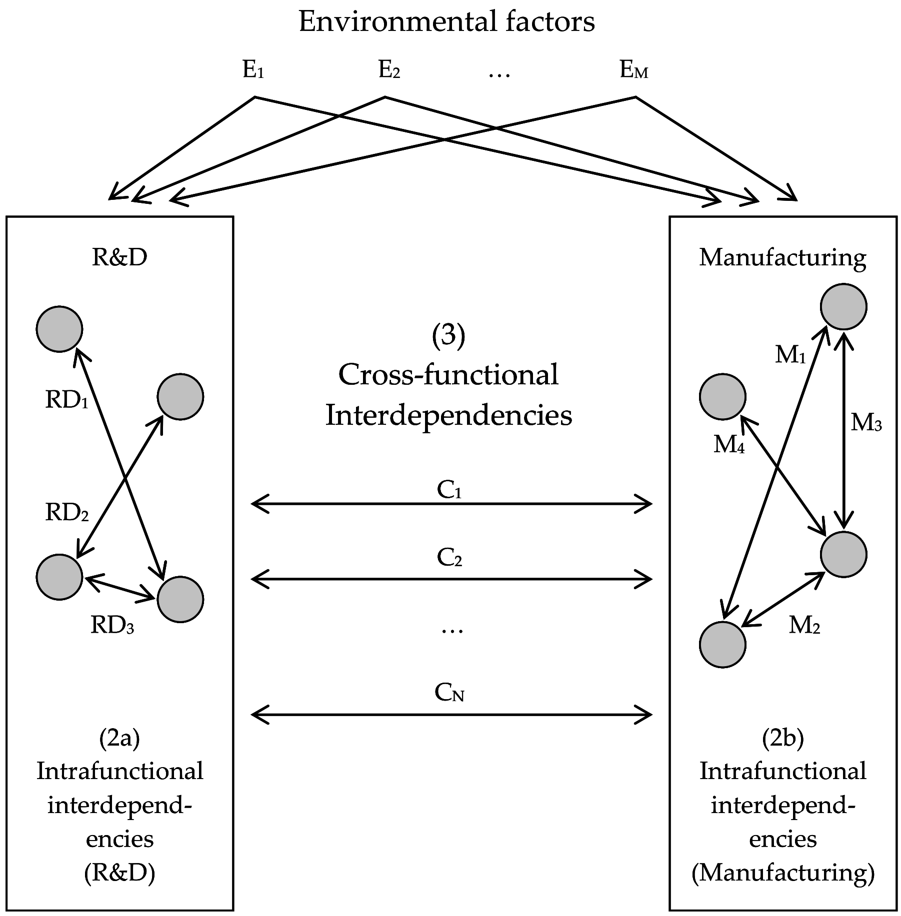
Organizational factors, in turn, are organization-specific and subject to both strategic and technological considerations, both of which are, at least in part, under the sphere of management influence. These are factors whose effects are more subtle and more difficult to ascertain empirically without conducting detailed micro-level analyses of organizational activities. At the same time, investigating these organizational factors is important, because Howells (1990), among others, has indeed argued that internal corporate considerations are more important than external, environmental factors in influencing the pattern of corporate R&D location. Helpman (2006) makes a similar argument regarding strategic firm behavior: firm-level examinations are required to understand the prevalent within-industry heterogeneity in location decisions. Finally, whether it is the organizational or environmental factors that matter, understanding managerial decision-making is the key to understanding co-location. After all, the decisions to co-locate or not co-locate R&D and manufacturing are ultimately made in corporate and business unit management teams; these micro-level activities lay at the foundation of all macro-level phenomena observed in micro- and macroeconomic studies. Failure to understand organizational decision-making means failure to understand co-location.

We can distinguish between three different approaches to the study of location decisions (Figure 1). All the approaches are indispensable, but they take a strikingly different approach to the phenomenon:

1. The External Drivers View,
2. The Intra-Functional Dependencies View, and
3. The Cross-Functional Dependencies View.

The three views will further be examined in turn.

Figure 1. Drivers of location decisions.



2.1. The External Drivers View

The proponents of this approach look at the various locational drivers or "locational pulls" for activities and functions. Locational drivers include factors such as low-cost labor, advanced local technology base or developed infrastructure. This is the view most often used by economists, and arguments often invoke the concept of *comparative advantage*. The external drivers are not, however, limited to economic factors, they also include political, and more recently, also sociological factors.

The external drivers view posits that decisions to locate activities are external to the organization and firms are trying to capitalize on the opportunities that the target location may offer. While these opportunities may offer first-mover advantages, they tend to become eventually available to competitors as well. The external drivers view is most often embraced by economists, however, organization scientists have also embraced this view as they have identified various locational drivers such as access to local technology base or low-cost labor at the level of individual organizations and their decision-making. It should be emphasized here that external drivers may operate at different levels of analysis: they may offer advantages to everyone (e.g., low-cost labor in China), they may be industry-specific (e.g., the technology base in the Silicon Valley) or even specific to a firm (e.g., co-location with an important customer). All these locational drivers are, however, external to the firm, and the task of the firm is to *adapt* and try to *exploit* these external opportunities.

The external drivers view considers co-location of R&D and manufacturing only indirectly. There is no formal theory of co-location, but to the extent that the two functions are subject to similar kinds of external drivers, co-location may obtain. There are, however, compelling theoretical arguments to suggest that the locational drivers or "pulls" for R&D and manufacturing do not necessarily coincide.

2.2. The Intra-Functional Dependencies View

This approach considers the implications of existing R&D or manufacturing locations within the firm on new location decisions *within the same* function. For instance, how does a new manufacturing facility fit into the existing network of manufacturing facilities within the firm? What is its strategic role compared to the other manufacturing plants the firm operates? One of the themes in this stream of research is also the centralization vs. decentralization of manufacturing and R&D activities within the firm. Both economists and organization scientists have used this approach, although organization-level studies tend to dominate.

A very common approach in the operations management and operations strategy literature is to examine within-firm networks of manufacturing plants. In this view, the specific location and task of a given manufacturing facility can only be understood as part of a larger network of manufacturing plants. Each plant within the business unit or the corporation has a specific strategic charter, strongly interdependent with charters of other plants. This is not say that all plant charters are alike, they may or may not be. A firm may be *internally differentiated* in the sense that plant charters are very different from one another and each plant is specialized and unique in terms of technology, size, markets served, etc. Then there are industrial firms where plant charters are almost identical and all plants have very similar manufacturing tasks. This is often the case with predominantly single-product companies with global markets (e.g., Intel).

A similar intra-functional "school of thought" can be identified in R&D location research, where researchers have examined the distribution and diffusion of R&D activities within the firm.

Much like in the external drivers view, co-location is only implicit. Again, there is no formal theory of co-location, but in the intra-functional dependencies view co-location may result if the intra-functional dependencies within the two functions are somehow similar.

2.3. The Cross-Functional Dependencies View

This approach examines the implications of, say, manufacturing locations on decisions regarding R&D location. Studies examining the internationalization paths of manufacturing and R&D often focus on cross-functional interdependence. Both economists and organization scientists have used this approach, although organization-level studies tend to dominate.

Organizational factors in particular cause R&D and manufacturing to be interdependent: decision regarding one cannot be made without considering the other. These functional interdependencies are often either of *sequential* or *reciprocal* variety, to use Thompson's (1967) interdependence typology. In the former one function is dependent on the other for information, materials, or technology, while in the latter the two are mutually co-dependent and joint problem-solving is required. Now, physical co-location of the two functions is one way to manage reciprocal interdependencies in particular, although there are other viable and perhaps more "light-weight" alternatives for coordination as well. Activities such as new product development (NPD) and the associated new product introduction (NPI) are prime examples of situations where reciprocal interdependencies likely exist and where effective cross-functional coordination is required (Adler, 1995). These will be further examined in this paper as a special case.

2.4. Tensions and Tradeoffs between the Three Views

What makes the study of determinants of (co-)location decisions particularly interesting and relevant is the proposition that there are tradeoffs or tensions between the three views. What I mean by *tension* here is not to imply that the views are conflicting views. They aren't in conflict with one another per se, because they address different aspects of the same phenomenon. But they may lead to different kinds of predictions and managerial prescriptions regarding co-location. For instance, if the management team wanted to optimize on external drivers, it might opt not to co-locate R&D and manufacturing. Functional interdependencies, in turn, might imply co-location.

This potential tension has been identified, although empirical treatments of the issue appear scarce. Specifically, we have some—at least indirect—empirical evidence that tensions may indeed exist. Audretsch and Feldman (1996) provide empirical evidence of this at the industry level by observing that in the U.S. the factors explaining the dispersion of R&D activities are quite different from the factors that explain dispersion of manufacturing activities. Mariani (2002, p. 31), in turn, has explicitly argued that "in developing innovations a tradeoff exists between the benefits of spreading research close to production, and the advantages of concentrating it in the areas with technological external economies". In a similar vein, Blanc and Sierra (1999, p. 187) argue that "the multinational firm's external organization should not be constituted to the detriment of its organizational coherence; it should, on the contrary, be completed by the implementation of relations of proximity internal to the firm." Whether *complementarity* between the internal and external drivers and organization is possible is, however, debatable; it seems that companies that prefer co-locating their R&D and manufacturing operations to manage functional interdependencies may indeed be forced to make a tradeoff in that they are simultaneously giving up potential benefits of external economies such as R&D spillovers. But these should be considered working hypotheses at this point.

To clarify, the tension identified here is distinct from the better-known argument for sub-optimality in location decisions. Assuming bounded rationality (defined in here in accordance with the *behavioral theory of the firm*), we can argue that managers cannot de facto make optimal location decisions: "In many industries, firms cannot optimally choose locations because the required resources are either difficult to observe or not well understood" (Appold, 2005, p. 20). However, the position taken here is different, although compatible with the sub-optimality argument: because of the fundamental tensions and incommensurabilities, even relaxing the bounded rationality assumption would not imply optimal decision-making across the three views. No amount of data collection and analysis will lead to optimality, because the three views are to an extent competing explanations. Appold (2005) further makes an important theoretical point—building on sociological institutionalism—by arguing that sometimes the external drivers of location decisions are likely to be sociological, not economic or political.

In sum, we have a reason to believe that the three views are not commensurate with one another in that optimizing on one set of factors leads to sub-optimal choices with another set of factors. This makes the study of all three sets of factors particularly important, not only from an academic but also practical point of view: after all, a top management team will in the end have to consider all sets of factors in making a particular location decision.

2.5. CALL FOR THEORETICAL AND EMPIRICAL RESEARCH ON CO-LOCATION

More theoretical and empirical work on co-location is clearly warranted, and the organizational factors and cross-functional aspects in particular should receive more attention.

One can argue that the cross-functional dependencies view is the only approach that *explicitly* addresses co-location of manufacturing and R&D: in the other two, co-location is ancillary and if observed, merely the result of spuriousness: we observe co-location because both types of location decisions have similar drivers. Only the cross-functional dependencies view addresses theoretically the direct interdependence and causality between location decisions. At the same time, whether explanatory accounts are of spurious or causal variety, all three views can illuminate the phenomenon of co-location. Specifically, we are more likely to observe co-location of R&D and manufacturing when

1. The external drivers (E_i) of location decisions for the two functions coincide;
2. The patterns of intra-functional interdependencies within the functions (M_i, RD_i) are similar;
3. The cross-functional dependencies (C_i) are of *reciprocal* variety.

The focus in the remainder of this article will be on (3), although research on (1) and (2) should not be overlooked. In order to develop an explicit understanding of R&D and manufacturing co-location drivers from the intra-functional dependencies view, I suggest the following research design:

1. Break down both manufacturing and R&D into smaller constituent parts (Section 3 of this article). Treating either one as being somehow monolithic is inappropriate, because both functions contain drastically different kinds of activities and give rise to different kinds of cross-functional interdependence.
2. Map the key interdependencies between the various sub-parts or sub-activities of manufacturing and R&D (Section 4 of this article). What is the source and nature of these inter-

dependencies? There are different types of interdependence, some of which are more intensive and more difficult to manage than others (Thompson, 1967).
3. Gain qualitative in-depth empirical insight from interviews with both manufacturing and R&D management, and explorative quantitative analyses using secondary databases (Sections 4, 5, and 6 of this article).

Because the cross-functional dependencies view is the only perspective that explicitly addresses co-location and where a promising extant theoretical base exists, it may prove to be the best candidate for explicit in-depth studies of co-location. This is not to say that the two other views are irrelevant, but it seems to be the case that they may not hold as much promise in shedding light on co-location. Of course, all three are highly relevant in studies of R&D and manufacturing location decisions and should receive their fair share of theoretical and empirical attention.

This paper lays the foundation for the development of measurement instruments that can subsequently be used in large-scale surveys and help draw statistical generalizations regarding co-location.

3. DISSECTION OF R&D AND MANUFACTURING

3.1. MANUFACTURING

There are many ways one might dissect the manufacturing function into its constituent parts for analysis. However, distinguishing between *routine* vs. *non-routine* activities appears most useful as the primary dimension, because it has direct implications to the need for cross-functional cooperation: routine activities are those activities performed without explicit need for problem-solving, while non-routine activities often involve at least some crossing of functional boundaries.

Routine manufacturing includes activities that can be performed independently from other activities and other functions, and there are typically standard procedures for executing these activities. These activities can usually be run as parts of a ”closed system” (Thompson, 1967) in that routine manufacturing activities can be assigned to the manufacturing function and executed fully within the manufacturing function, without cross-functional dependencies. These routines include the following activities, the most routinized activities first:
1. Production activity control (PAC): finite scheduling of individual workstations and the execution of detailed production steps;
2. Production planning;
3. Inventory management (managing work-in-process [WIP] inventory);
4. Routine technology management (e.g., maintenance of equipment);
5. Supply chain management (inbound and outbound logistics).

Non-routine activities, in turn, are those where manufacturing has an important role (perhaps even the most important functional role), but may not be able to operate independently of other functions and perhaps the strategic decision-maker (business unit and corporate management). These are, with the least routinized activities listed last:
6. Implementing engineering change orders (ECO) to existing products;

7. Continuous improvement and development of manufacturing processes and technologies;
8. Non-routine technology management (major maintenance and equipment break-downs, capacity additions, changes in plant layout);
9. Ramp-up of new products (and ramp-down of old ones);
10. Supplier selection (for raw materials, technology).

These are activities that require cross-functional cooperation and sometimes business-level management (strategic) intervention. In some cases co-locating at least some R&D personnel, either temporarily or semi-permanently, with manufacturing activities is also necessary in order to complete these activities.

In summary, have a continuum of manufacturing-related activities, ranging from the most routinized PAC to the highly non-routine activities of production ramp-ups and supplier selection. We further observe that the proportion of non-routine activities in a high-tech manufacturing operation can be substantial.

3.2. R&D

The primary dimension for dissecting R&D is to separate the R from the D, that is, basic research from the applied research, or development of new products. Basic research encompasses the development of entirely new generations of technologies that have no direct and explicit link to existing technologies or products. While integration of R with D is an important issue (Iansiti, 1998), I do not consider it crucial as far as the issue of co-location. The focus in this paper will be on the more applied development activities, because they have a more direct link to manufacturing activities discussed above (the non-routine activities in particular) and thus co-location.

For the purposes of my argument, the standard phases of a new product development process can be used to dissect the parts of R&D relevant here, for example:

1. Exploration, developing the conceptual model (in this phase, the product being developed only exists as an idea).
2. Development, developing the detailed functionality of the product (involves prototype production).
3. Implementation, finalizing the design and ramping up production.

This breakdown that follows the product development *process* is useful for my purposes, because the R&D-manufacturing co-dependence often strongly depends on the specific phase of the development project, with less co-dependence in the early phases (e.g., Adler, 1995). At the same time, it is now generally accepted that none of the phases, even the early ones, are totally free of R&D-manufacturing co-dependence (Clark & Wheelwright, 1993).

4. MAPPING THE INTERDEPENDENCIES

Mapping interdependencies is ultimately a process of theoretical abstraction and theory development, but these abstractions can (and should) be made in an empirical context. In this

Figure 2: The interdependency framework at a general level.

			R&D		
			Research	Development	
				Product	Process
Manufacturing	Routine	Production Planning and Control			
		Continuous Improvement			
	Non-routine	Managing Discontinuities			

Figure 3. The interdependency framework at a more fine-grained level.

			Product Development					
			Exploration	Development		Implementation		
			Conceptual model	Functional model	Prototype	Pilot series	0 series	Ramp-up
Manufacturing	Routine	Production Activity Control						
		Production Planning						
		Inventory Management						
		Routine Technology Management						
		Supply Chain Management						
		Continuous Improvement						
		Engineering Change Orders						
		Nonroutine Technology Management						
		Ramp-up and Ramp-down						
	Non-Routine	Supplier Selection						

section, a general framework of R&D-manufacturing interdependencies will be developed, based on both theoretical considerations as well as insight gained from the electronics and pharmaceutical industries. The purpose of this section is to argue and demonstrate that the interdependencies (and co-location) must always be guided by both industry- and firm-specific considerations. The interdependency framework at a general level is depicted in Figure 2.

This framework can further be examined at a more fine-grained level, for instance, by breaking the manufacturing function into its smaller constituent parts (on the routine–nonroutine continuum) and by focusing on the R&D dimension on, for instance, the micro-structure of new product development (see Figure 3).

In the following, these interdependencies are further elaborated in two empirical contexts: pharmaceuticals and electronics.

4.1. R&D-Manufacturing Interdependencies: Case Pharmaceuticals[1]

Looks can be deceiving: while the actual mass production of pharmaceuticals has been considered to be a fairly straightforward process and production costs themselves may be next-to-negligible (see, however, Pisano, 1997, Ch 5, for a slightly different view), the process of new product introduction and development is not only extremely complex and uncertain but also heavily regulated. The NPI process in pharmaceuticals, straightforward fabrication notwithstanding, can indeed be much more complex and risky than in other industries. Pisano (1997, pp. 84-86) further argues that production has become a more important source of competitive advantage in that process development has an important role not only in reducing manufacturing costs, but also in achieving faster product development and enhanced product innovation. The purpose of this section is to elaborate on the pharmaceutical NPI process from an interfunctional dependence view.

There are a number of idiosyncrasies that make the pharmaceutical industry particularly interesting from the R&D-manufacturing interdependence point of view. Firstly, the pharmaceutical industry in characterized by tremendous uncertainty regarding new products, technologies and markets. Pisano (1997, p. 100) offers an example:

> [C]onsider the development of a 16-megabyte DRAM chip. Process developers in this context do not have to worry that product designers will one day rush into their laboratories and proclaim that they accidentally came up with a 1-gigabyte chip (which would dramatically reduce the capacity requirements for chips per year). Similarly, they need not figure out how to quadruple capacity if product designers come up with only a 4-megabyte design. In the pharmaceutical context, process development must be extremely responsive to capacity requirements that can change drastically. Given that this information becomes available only late in the game (relative to when process development needs to be finished), fast response is absolutely critical to keeping the project on time.

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[1] This section is based on review of existing literature, as well as interviews with two R&D experts in the pharmaceutical industry: Leif Hildén, Vice President, Product Development, Fermion Oy (part of Orion Group), and a Head of Special Projects, Global Strategic Marketing, in a large international pharmaceutical company, whose name and affiliation are confidential.

Because of this uncertainty, we might hypothesize that the probability of critical R&D-manufacturing interdependence is higher (Ketokivi, Schroeder, & Turkulainen, 2006; Thompson, 1967).

Secondly, the industry is heavily regulated by National Agency for Medicines [Lääkelaitos] in Finland, European Agency for the Evaluation of Medicinal Products (EMEA) in Europe, and Food and Drug Administration (FDA) in the U.S. Even minor changes not only to the product but also to the production process are very cumbersome and time-consuming to implement, and always require approval. Autonomous continuous improvement within the manufacturing organization is often limited to activities such as adding production capacity or improving production cycle times. Both the product and production process must be frozen at the time of new product introduction, and even small changes, such as shifting to a different supplier on a standard raw material, require approval.

Thirdly, R&D activities involve significant amounts of production for animal tests, human clinical trials, etc. (sometimes dubbed the ”clinical supply process”). In contrast with industries such as metalworking and electronics where the production of prototypes is limited to a few or perhaps a few dozen individual products, pharmaceutical companies may produce millions of doses of the drug in the R&D process. Later phases of clinical trials in particular—which involve head-to-head comparisons of the drug against placebos or existing drugs in a large sample of patients—use large quantities of the new drug, and can easily cost millions. Thus, the R&D process may be an important source of manufacturing competence development for new generations of products: R&D and manufacturing use in part exactly the same technology, which is, for instance, an explicit requirement enforced by FDA in the U.S. (Pisano, 1997, p. 98).

Fourthly, many important decisions regarding production are made at the development phase: (a) many of the important aspects of upstream supply chain management in particular are determined within R&D, because the exact raw materials must be specified; (b) R&D typically determines in detail the technical specifications and tolerances required for the production process; (c) the production site is determined during the development process, because knowledge about the designated production environment is taken into account in the development process. R&D is thus at least in part production-site specific and the production process is in a sense frozen during the clinical trials, sometimes even during pre-clinical development. This associated with the uncertainty described above makes the R&D-manufacturing linkage especially critical.

Finally, Quality assurance (QA) is a critical and legally required function in the development of pharmaceuticals. QA is a function separate from manufacturing, but it has to maintain close connection to both R&D and manufacturing. It follows that wherever there is production, there must also be laboratories.

Pharmaceutical companies (unlike some other industries) engage in basic research, where new molecules are built and different *routes of synthesis* are identified. This part of R&D (”the R part”) is usually completely independent of daily manufacturing operations and can thus be managed as a separate entity. Here, the proximity to various locational advantages is of paramount importance, and research is often located near universities: it is more important to be co-located with potential sources and catalysts of innovation than close to those who will apply the results of the innovation process. This does not, however, mean that research is altogether independent of manufacturing: the decision on which synthesis route to pursue is influenced by foreseeable costs of manufacturing. If this interdependence is not carefully managed, the potential cost disadvantages of the selected synthesis route may not be identified in time.

A second consideration in locating basic research is the need for a ”critical mass” of scientists and the associated economies of scale and scope; fragmentation and decentralization of basic research into small dispersed units is often neither scientifically nor economically feasible. From the point of view of locating manufacturing activities, this centralization of research activity presents few problems: because the locational pulls for manufacturing activities are not crucial in advanced pharmaceuticals in particular (see section 4.1.1 below), locating manufacturing activities close to R&D does not require considerable tradeoffs from the point of view of manufacturing. In this sense, manufacturing can ”follow the locational pulls of R&D.”

4.1.1. THE FUTURE OF PHARMACEUTICALS

At a very general level, we can distinguish between three types of pharmaceutical industry:
1. Cost-competitiveness-driven manufacture and sale of standard pharmaceuticals for which patent protection has expired. Competitive advantage arises from economics of scale and scope in manufacturing as well as comparative cost advantages (e.g., labor).
2. Research-intensive patent-protected pharmaceuticals, where patents and first-mover advantages are of strategic import.
3. New pharmaceutical industry: gene technology, advanced biotechnology, nanotechnology. Sources of competitive advantage are today still unknown for the most part.

Whereas the functional interdependencies in (1) and (2) are fairly well known, (3) is a question mark. Yet, (3) is the only one which is growing fast, the other two categories have more or less been saturated. What will be the source of competitive advantage? What will be the role of patented production technology? Is it going to be a critical success factor in the future (today, most pharmaceutical companies buy their production technology from specialized equipment manufacturers)?

4.2. R&D-MANUFACTURING INTERDEPENDENCIES: CASE HIGH-TECH ELECTRONICS[2]

Many of the contemporary examples of R&D-manufacturing interdependence build on examples from R&D-intensive electronics industries: Intel, Microsoft, Nokia, RCA, and Sony. It is often argued that the rate of change and unpredictability of these industries makes the R&D-manufacturing interface so difficult to manage. I believe this to be a misattribution, at least to an extent: the fundamental reason for the challenge lies in the reciprocal interdependence between R&D and manufacturing in these industries. Hence, the question is not as much ”How do we do things as rapidly as possible?”, rather, it is ”How are we managing the

[2] This section is based on review of existing literature, as well as interviews with four experts in the electronics industry: Hannu Järvelin, Vice President, Delivery Operations, Nokia Networks; Kimmo Perälä, Team Leader, R&D, Aspocomp Oy; Sami Ruotsalainen, Manager—New Technology Platforms, Suunto; and a Chairman of the Board of a high-tech electronics company, whose name and affiliation are confidential.

crucial interdependencies?” This is why management of the R&D-manufacturing interface is equally relevant to companies such as Boeing, which designs a new generation of aircraft only once every 15-20 years. As one of the interviewees put it: ”If something fails in the new product introduction process, it is coordination”. Coordination can fail in environments of both rapid and slow change.

There is overwhelming evidence that with new product generations in particular, product design and development decisions should not be made without close coordination with manufacturing. Early involvement of manufacturing in decisions regarding product architecture and design is essential, as early as the concept development phase. Equally compelling is the idea that if manufacturing and R&D personnel are not physically co-located, decision-making and cooperation will not be as efficient. Finally, if R&D is geographically centralized while manufacturing is decentralized, the new product introduction (NPI) process may be delayed.

However, to say that co-location is a necessity would be an oversimplification, for at least three reasons. First, the benefits of co-location must be weighed against the losses in efficiency due to not being able to exploit locational factors to their fullest. Second, while the dispersion of manufacturing activities is often categorically better than centralization, we cannot say the same about R&D: a ”critical mass” of R&D activity and personnel is often required for successful R&D; having small groups of R&D personnel scattered around the world would not only be very expensive but also likely very unproductive. Third, we again have to distinguish between different types of interdependence. Specifically, if we look at the NPI as a process, we observe that the type of interfunctional interdependence varies as a function of time: at early phases interdependence may be reciprocal, but once the most important decisions regarding product design are completed, only sequential interdependence remains, and product developers no longer need manufacturing input to get their work done. Also, minor changes to existing products can often be performed such that product development or the product engineers can simply issue an engineering change order to change the design, knowing that it can readily be implemented in manufacturing.

4.2.1. The Stage-Gate Model of new product development

The majority of electronics companies use some variant of the so-called stage-gate (SG) model to structure their new product development activities. In the model, the NPD process is structured in a linear fashion around a set of ”stages” (activities such as product architecture development) and ”gates” at which certain key decisions are made (e.g., detailed design approval).

There is a time and a place for SG, and the reasons behind this are closely related to the topic at hand. SG works best when the NPD process can be divided into specific phases that can be completed in sequence. In essence, it assumes sequential interdependence. Many NPD processes can be structured in such linear fashion, but others cannot.

SG has been successfully implemented also in environments of high R&D-manufacturing reciprocal interdependence. The key insight here is that the SG should not be viewed as a way of assigning different people to different tasks, but rather, as a way of organizing activities. To clarify, if the NPD project is handed off to a new group of people at each gate, it will likely fail if reciprocal interdependence is prevalent: the product design team cannot simply sign off at the detailed design approval gate and ”throw the blueprints over the wall” to manufacturing. Instead, successful applications of SG in high-reciprocal-interdependence environments call for continuity in participation in an NPD project. As one executive interviewed put it: ”We have the same people on board from start to finish. All key decisions are made within the inter-functional team.”

Many companies have also observed that NPI is an iterative process: one cannot go through a set of gates in a linear fashion, closing every gate once and for all once it has been passed. This is a strong indication that NPI, with new and radical product development efforts in particular, is first and foremost a process of problem-solving and discovery, not a rational linear process that can be pre-planned and scheduled. Problem-solving efforts in turn are greatly facilitated if the problem-solvers are co-located, either on a temporary or more permanent basis. We are more likely to find companies choosing co-location of R&D and manufacturing activities when extensive problem-solving and joint-decision making between functions is required.

4.2.2. The importance of the supply chain

When we look at the management of the NPI process in electronics companies who assemble final products (e.g., Nokia, Samsung, Sony), we have to take a broader look at manufacturing, one that spans the organizational boundaries. After all, the vast majority of manufacturing work that goes into the production of a consumer electronics product is performed outside the walls of the final assembler; sometimes even final assembly is outsourced. This highlights another important question, particularly relevant to companies located toward the ”downstream” of the supply chain: How do we manage the interdependencies between our R&D and *our suppliers'* production? Of course, we can also look at the same question from the point of view of the supplier: How do we manage the interdependencies between our R&D and manufacturing vis-à-vis our customer? To be sure, the manufacturing location decisions of Perlos, the manufacturer of components and sub-assemblies to cellular phones, are strongly influenced by the location of the final assembly of its main customer Nokia.

5. THEORETICAL SYNTHESIS: DETERMINANTS OF CO-LOCATION

As a synthesis of the preceding discussion, Table 1 depicts the hypothesized causal determinants of co-location of R&D and manufacturing.

Table 1: Determinants of co-location.

No	Co-location of R&D and Manufacturing	Yes
Low	Product complexity	High
Low	Process complexity	High
Sequential	Functional interdependence	Reciprocal
Low	Uncertainty	High
Low	Industry clockspeed	High
Yes	Other integrative mechanisms	No
?	R&D intensity	?

The reasoning associated with each hypothesis is as follows:

1. Complexity makes decision situations relatively more *ill-defined*, and problem-solving efforts more likely reciprocally interdependent. Complex tasks are difficult to break into smaller parts without significant residual interdependence.
2. The degree of reciprocal interdependence is strongly linked to co-location. While information can easily be transferred across the globe in a split-second (thus making management of sequential interdependence easier in a geographically dispersed setting), solving problems in this same manner is much more challenging.
3. Uncertainty has similar effects as does complexity: with increasing uncertainty, the ability to divide tasks into self-contained sub-tasks is difficult. Instead, there is always residual interdependence between tasks. With high uncertainty, managers may not even know ex ante what the tasks are and how they should be divided among organizational sub-units.
4. Industry clockspeed is the rate at which new products and product generations are introduced. Although I have argued that rate of change is not the fundamental reason for the co-location need (reciprocal interdependence is), increasing rate of change places a heavier burden on those managing interdependence.
5. If co-location can be avoided using other, less expensive, mechanisms of coordination, these options should be exhausted first. If plans, schedules, information systems, centralization of decision-making, or other mechanisms work, co-location may not be as essential, and activities can be located based on external drivers, ”locational pulls”.
6. The effect of R&D intensity remains a question mark, but is worth observing, because one might be tempted to think that co-location applies only to high-tech industries. Of course, if a firm has no R&D, this discussion is irrelevant. However, while it is true that R&D intensity is related to the size of the R&D function, I see no direct relationship between R&D intensity and the need for co-location. Although anecdotal evidence is always inconclusive, it is interesting to observe that among the companies listed as examples in section 1.1 (Nokia, Intel, Vaisala, Salcomp), the R&D intensity varies quite a bit, the R&D-to-sales ratios ranging from Intel’s 13.3% to Salcomp’s 2.6% (Intel and Salcomp’s 2005 Annual Reports). The theoretical explanation here is that reciprocal interdependence is not necessarily a function of R&D intensity: Salcomp and Intel may indeed be subject to similar kinds of functional interdependence.

These causal effects are not proposed as deterministic, rather, they should be taken as tendencies: companies with high reciprocal interdependence in the NPI process are *more likely* to co-locate.

These causal effects are not presented as facts either, they are presented as working hypotheses. The strength of these tendencies can be examined through a more detailed statistical study of a large sample of organizations. Further, the purpose of this table is not to propose that product complexity, for instance, is either high or low. All the dimensions should be thought of as continua: the likelihood of co-location increases as product complexity increases. Again, the rate of increase should be determined using statistical analysis of a large sample; theory does not enable a precise a priori specification of the strength of these tendencies.

6. PRELIMINARY EMPIRICAL LARGE-SAMPLE OBSERVATIONS

The *High Performance Manufacturing (HPM)* group is an international team of academic researchers who have studied manufacturing activities at the organizational level for almost two decades. Detailed data on manufacturing activities and their links to marketing and R&D have been collected since 1989. The data is collected using written surveys, where 10-15 different experts within each organization answer questions about manufacturing and its links to strategy, the operating environment and other business functions. I will use the data collected in 1997 (164 industrial organizations in 5 countries: Germany, Italy, Japan, U.K., U.S.) and 2003-2005 (218 industrial organizations in 6 countries: Finland, Germany, Japan, Korea, Sweden, U.S.) to gain preliminary insight into the co-location phenomenon. The industries studied in both rounds of data collection were the metalworking and electronics industries.

While the HPM data does not directly address co-location, it does address the fundamental theoretical foundation underlying co-location, the concept of *functional integration*. More details on the HPM data can be found in Schroeder and Flynn (2001).

In the functional integration part of the survey, representatives of different functions were asked to answer questions regarding

1. The importance of functional integration in the organization.
2. The amount of cross-functional cooperation taking place inside the organization.
3. The difficulty of achieving functional integration.
4. The extent of functional integration achieved within the organization.

These data were collected by presenting the informants with a number of statements, which they rated on a Likert Scale. Various statistical tools from the psychometrics literature were used to examine the reliability and validity of these measures. I will forgo detailed discussion of these tools and analyses (some of these tools are documented in Ketokivi & Castañer, 2004).

Central tendencies are always important. It might serve us well to calculate the averages and identify the general trends in the population. However, while central tendencies are important and serve their purpose, I will argue that it is indeed the *tails* of the distributions that are more interesting as far as the topic at hand is concerned. The most interesting and relevant cells in Table 2 are highlighted by a gray background. I will elaborate on each of the four questions in the following.

6.1. THE IMPORTANCE OF FUNCTIONAL INTEGRATION

HPM data suggests that on the average achieving functional integration is very important, if not crucial. But there is a non-trivial proportion of organizations, where other functions do not know, and simply do not *need* to know about manufacturing. Now, this does not mean that such organizations are dysfunctional. On the contrary, a manufacturing company where functions can operate independently of one another can be highly efficient. These companies are also likely to locate their R&D and manufacturing activities based on locational factors.

At the same time, we must bear in mind that the organization may not always be the right level of analysis: there is at times drastic variance across the NPI projects within a firm, depending on the nature of the project. The same firm likely engages both in revolutionary design changes as well as minor adjustments of existing ones. Organization-level studies should indeed be complemented by even more micro-level analyses, where the unit of analysis is the new product development project.

Table 2. Descriptive statistics on functional integration in the *HPM data*.

Dimension	Statement	Dataset		Distribution of responses						
IMPORTANCE OF FUNCTIONAL INTEGRATION	"Marketing and Finance know a great deal about manufacturing"	1997	n=465		Strongly disagree	Disagree	Neutral	Agree	Strongly agree	
					8.4%	31.4%	32.7%	24.5%	3.0%	
	"Other functions do not need to know about manufacturing"	2004	n=526	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
				39.2%	41.8%	8.9%	4.4%	2.9%	1.9%	1.0%
AMOUNT OF CROSS-FUNCTIONAL COOPERATION	"Functions communicate frequently with each other"	1997	n=2007		Strongly disagree	Disagree	Neutral	Agree	Strongly agree	
					4.9%	16.7%	22.3%	43.0%	13.1%	
	"Our functions work interactively with one another"	2004	n=524	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
				0.2%	1.5%	6.9%	7.3%	26.7%	46.0%	11.5%
DIFFICULTY OF ACHIEVING FUNCTIONAL INTEGRATION	"Departments are in constant conflict with each other"	1997	n=1991		Strongly disagree	Disagree	Neutral	Agree	Strongly agree	
					17.4%	32.6%	28.9%	16.4%	4.7%	
	"Problems between functions are easily solved"	2004	n=522	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
				0.4%	2.5%	11.9%	13.0%	35.8%	31.0%	5.4%
EXTENT OF FUNCTIONAL INTEGRATION ACHIEVED	"The functions of our firm are well integrated"	1997	n=463		Strongly disagree	Disagree	Neutral	Agree	Strongly agree	
					0%	12%	32%	46%	9%	
	"The functions of our firm are well integrated"	2004	n=520	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
				0.2%	1.0%	8.1%	6.5%	32.3%	45.2%	6.7%

6.2. Amount of Cross-functional Cooperation

As Table 2 demonstrates, companies engage in cross-functional cooperation in drastically varying degrees. For some organizations it is crucial, for others, it is not. Again, that a company does not engage in cross-functional cooperation should not be viewed as negative: perhaps they do not need to spend time and effort coordinating their functions, and are thus more efficient. Maybe they do not have to work interactively with one another, which could be the case when reciprocal interdependence is absent. Again, these companies are more likely candidates to separate their R&D and manufacturing geographically as well and enjoy the benefits of locational advantages for both.

6.3. Difficulty of Achieving Integration

Some companies struggle with functional integration, others do not. It would be very easy to attribute this to others having better management practices; smarter people, simply put. While this may be a plausible explanation, there is a compelling competing explanation: the difficulty is a manifestation of the requirements of the operating environment. Managing reciprocal interdependence is more difficult. Conflict can be political, but it can also be caused by ambiguity and lack of information. As far as co-location is concerned, those who struggle with achieving integration may find co-location essential.

6.4. Extent of Functional Integration Achieved

This is perhaps the most complex of the four to interpret. First of all, the right tail of the distribution is heavy, most companies tend to report success in functional integration. While this may be in part exaggeration and reflect social desirability in replying to questions such as this, it also tells us that integration is essential for many companies. The previous three points also showed that many companies are taking the necessary actions to achieve integration.

The left tail of the distribution is thin but non-trivial. The first question that arises is: Is the degree of functional integration achieved related to the importance of functional integration? It is interesting to observe that this correlation is 0.002, non-existent. Therefore, we cannot conclude that when integration is called for, organizations integrate. Now, the correlation between the difficulty of achieving integration and degree of integration achieved is, as we would expect, strong and negative (-0.551, $p<0.001$): the more difficult integration is, the more likely it is to fail. Again, difficulties arise from managing reciprocal interdependence.

6.5. Cross-country Differences

Comparing countries to one another is always interesting. Analysis of cross-country differences results, however, in a rather familiar conclusion observed in these kinds of studies: while there are some statistically significant differences between countries, what is much more prevalent and relevant is the observation of high variance within each country. Country effects are statistically significant, but account for less than 5% of total variance. In sum, there is no ″typical″ Finnish organization that could be compared to a ″typical″ Japanese organization, at least as far as the topic of functional integration is concerned.

On the other hand this was to be expected: reciprocal interdependence, product complexity, environmental uncertainty, and the other variables under scrutiny, are all issues of technology and rational aspects of the organization—they are not aspects of culture or institutions, or perhaps issues of policy. The theory recognizes no country-level factors or variables operating on these variables. Of course, if we were interested in the cultural or institutional aspects of the organization, we might observe more drastic differences. But this data confirms the maxim that technology knows no national boundaries: the functional integration challenge is fundamentally the same in Finland, Korea and the U.S. Similarly, prescriptions regarding co-location would not differ from country to country, but of course, they would vary quite a bit from company to company.

7. CONCLUSION

If we wish to understand co-location of R&D and manufacturing, we must understand managerial decision-making. For this reason, the need for co-location must be analyzed and understood at the organizational and perhaps even sub-organizational (e.g., an individual product development project) levels. The need for co-location, and functional integration in general, arises from the requirements of the operating environment as well as the characteristics of the product or service developed. However, the need for functional integration and thus the pressure for co-location varies from company to company, depending on a number of factors discussed in this article.

This has been the first step in laying the foundation for rigorous theory-driven empirical study of co-location. The next step would be to craft a measurement instrument explicitly directed at addressing the need for co-location, actual degree of co-location, environmental characteristics, product characteristics, as well as measures of performance, and examine the hypotheses presented in this article in more detail. The ultimate measure of performance is of course financial performance, but clearly more proximate measures are needed to examine the causal path from functional integration to financial performance.

As a final note, although the interviews conducted as part of this study were exploratory, it is noteworthy to mention that the external drivers or ”locational pulls” were rarely mentioned when the interviewees described the location decisions of R&D and manufacturing in their own context. In the words of one interviewee: ”90% of it is about internal interdependencies and coordination issues, 10% location-specific drivers”. While it would be foolish to suggest this figure as a universal truth, it is not at all foolish to submit it as an interesting hypothesis worthy of further theoretical and empirical scrutiny.

REFERENCES

Adler, P. S. (1995). Interdepartmental interdependence and coordination: The case of the design/manufacturing interface. *Organization Science, 6*(2), 147-167.

Appold, S. J. (2005). Location patterns of US industrial research: Mimetic isomorphism and the emergence of geographic charisma. *Regional Studies, 39*(1), 17-39.

Audretsch, D. B., & Feldman, M. P. (1996). R&D spillovers and the geography of innovation and production. *American Economic Review, 86*(3), 630-640.

Blanc, H., & Sierra, C. (1999). The internationalization of R&D by multinationals: A trade-off between external and internal proximity. *Cambridge Journal of Economics, 23*, 187-206.

Brush, T. H., Maritan, C. A., & Karnani, A. (1999). The plant location decision in multinational manufacturing firms: An empirical analysis of international business and manufacturing strategy perspectives. *Production and Operations Management, 8*(2), 109-131.

Clark, K. B., & Wheelwright, S. C. (1993). *Managing New Product and Process Development*. New York: Free Press.

Ekholm, K., & Hakkala, K. (2006). Location of R&D and high-tech production by vertically integrated multinationals. *Economic Journal, forthcoming*.

Ferdows, K. (1989). Mapping international factory networks. In K. Ferdows (Ed.), *Managing International Manufacturing* (pp. 3-21). Amsterdam: Elsevier Science Publishers.

Govindarajan, V., & Gupta, A. K. (2001). *The Quest for Global Dominance*. San Francisco: Jossey-Bass.

Helpman, E. (2006). Trade, FDI, and the Organization of Firms. *NBER Working Paper Series, National Bureau of Economic Research*.

Howells, J. (1990). The location and organization of research and development: New horizons. *Research Policy, 19*(2), 133-146.

Howells, J. R. (1995). Going global: The use of ICT networks in research and development. *Research Policy, 24*(2), 169-184.

Iansiti, M. (1998). *Technology Integration*. Boston: Harvard Business School Press.

Intel. (2002). *10-K form*: filed with the Securities and Exchange Commission of the United States.

Intel. (2005). *10-K form*: filed with the Securities and Exchange Commission of the United States.

Ketokivi, M., & Castañer, X. (2004). Strategic planning as an integrative device. *Administrative Science Quarterly, 49*(3), 337-365.

Ketokivi, M., Schroeder, R. G., & Turkulainen, V. (2006). *Operations management and contingency theory: A new look at an old theory.* Paper presented at the Academy of Management Annual Meeting, Atlanta, GA.

Kuemmerle, W. (1999). The drivers of foreign direct investment into research and development: An empirical investigation. *Journal of International Business Studies, 30*(1), 1-12.

Mariani, M. (2002). Next to production or to technological clusters? The economics and management of R&D location. *Journal of Management and Governance, 6*, 131-152.

Mueller, E., & Morgan, J. N. (1962). Location decisions of manufacturers. *American Economic Review, 52*(2), 204-217.

Nokia. (2005). *20-F form*: filed with the Securities and Exchange Commission of the United States.

Pearce, R., & Singh, S. (1992). *Globalizing Research and Development*. London: Macmillan.

Pisano, G. P. (1997). *The Development Factory: Unlocking the Potential of Process Innovation*. Boston, MA: Harvard Business School Press.

Rafii, F. (1995). How important is physical collocation to product development success? *Business Horizons, 38*(1), 78-84.

Rugman, A. M., & Verbeke, A. (2001). Subsidiary-specific advantages in multinational enterprises. *Strategic Management Journal, 22*(3), 237-250.

Schmenner, R. W. (1982). *Making Business Location Decisions*. Englewood Cliffs, N.J.: Prentice Hall.

Schroeder, R. G., & Flynn, B. B. (Eds.). (2001). *High Performance Manufacturing: Global Perspectives*. New York: Wiley.

Thompson, J. D. (1967). *Organizations in Action: Social Science Bases of Administrative Theory*. New York: McGraw-Hill.

van den Bulte, C., & Moenaert, R. K. (1998). The effects of R&D team co-location on communication patterns among R&D, marketing, and manufacturing. *Management Science, 44*(11), S1-S18.

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