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DETERMINANTS OF MANUFACTURING-R&D CO-LOCATION

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ABSTRACT: The phenomenon of physical R&D-manufacturing co-location is interesting, because researchers have made very different observations regarding its prevalence. In some populations co-location of the two functions seems to be the norm; in others, an exception. However, we still do not have an explicit explanatory theory of co-location. In this paper, we look the reasons why manufacturing and R&D may have to be physically co-located. In a sample of 241 Finnish industrial firms, we find that the need for co-location varies drastically from company to company. We further find that product complexity, process complexity and industry clockspeed have an effect on co-location need.

KEY WORDS: Business location decisions, co-location, R&D, manufacturing, contingency theory

JEL CODES: D21, D23, F21, F23, L6, O32

Ketokivi, Mikko ja **Ali-Yrkkö**, Jyrki**. MITKÄ TEKIJÄT VAIKUTTAVAT SIIHEN, ETTÄ VALMISTUS JA T&K-TOIMINTA SIJOITTUVAT SAMOILLE ALUEILLE?** Helsinki, ETLA, Elinkeinoelämän Tutkimuslaitos, The Research Institute of the Finnish Economy, 2007, 28 s. (Keskusteluaiheita, Discussion Papers; ISSN 0781-6847; no. 1082).

TIIVISTELMÄ: Tuotanto ja t&k-toiminta näyttävät usein sijoittuvan samoille maantieteellisille alueille. Aina näin ei kuitenkaan ole. Tässä tutkimuksessa tarkastellaan sekä teoreettisesti että empiirisesti tekijöitä, jotka vaikuttavat tuotanto- ja t&k-toimintojen yhteissijoittumisen tarpeeseen. Aineisto koostuu 241 Suomessa toimivasta teollisuusyrityksestä. Tilastollisen analyysin tulosten mukaan t&k-ja tuotantotoiminnan yhteissijoittumisen tarve vaihtelee huomattavasti. Yhteissijoittumisen tarve lisääntyy, mitä monimutkaisempi yrityksen tuote tai tuotantoprosessi on. Myös jatkuva uusien tuotteiden valmistuksen aloittaminen ja vanhojen tuotteiden lopettaminen lisää yhteissijoittumisen tarvetta.

AVAINSANAT: sijaintitekijät, yhteissijainti, t&k, tuotekehitys, valmistus, tuotanto

JEL-KOODIT: D21, D23, F21, F23, L6, O32

1. Introduction

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. Empirical studies are scarce, but even more scarce are rigorous theoretical examinations of the topic at the proper level of analysis. 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 we pose in this paper is: When is co-location necessary for the effective coordination of R&D and manufacturing activities? Examination of this question necessarily implies a detailed micro-organizational analysis of the phenomenon.

This article is largely motivated by interesting yet almost opposing empirical observations regarding the co-location of R&D and manufacturing in extant research. In some contexts, co-location seems to be the norm rather than the exception: Ambos (2005), for instance, found that among his sample of large German industrial firms, 79% of research laboratories were co-located with production. Similar observations have been made with Japanese data (e.g., Kenney and Florida, 1994). In stark contrast, other research has led to completely opposite conclusions: R&D laboratories in Swedish and British industrial firms tend to be separated from production facilities (Håkanson and Nobel, 1993; Pearce, 1989). However, evidence regarding British firms appears mixed as Hood and Young (1979) in turn observed that foreign companies in the UK in the main co-located their R&D laboratories with production. Anecdotal case study evidence also suggests that the need for co-location can vary drastically from context to context (e.g., Clark and Wheelwright, 1993; Govindarajan and Gupta, 2001). Of course, it is difficult—and somewhat meaningless—ex post to construct theoretical interpretations about the need to co-locate based on past observations made by someone else. One of the primary reasons is that these empirical observations by and large only reflect what is, not what should be. The *need* for co-location is about what should be, not what *de facto* is. As Ambos (2005: 404) notes, "[co-location] may simply be a coincidence." Clearly, more primary theoretical and empirical research is needed.

To be sure, location decisions—both R&D and manufacturing—have received volumes of theoretical and empirical attention from economists (e.g., Mueller and Morgan, 1962; Pearce and Singh, 1992; Smith, [1776] 1991), researchers of industrial organization (e.g., Porter, 1986, 1990), as well as organizational and operations management researchers (e.g., Brush et al., 1999; Ferdows, 1989; Kuemmerle, 1999; Schmenner, 1982). However, what is missing from the literature is a theoretical account of the potential factors that may make co-location necessary. Extant theoretical explanations are not only cursory but also equivocal on the matter: while some researchers have argued that physical co-location of activities is central to coordination both within and across business functions, others have proposed that co-location is overrated in the sense that there are alternative and less expensive mechanisms for coordination (e.g., 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 commonplace (e.g., Howells, 1995; Rugman and Verbeke, 2001). The geographic dispersion of manufacturing activities within the firm, in turn, has been widespread for decades; for instance, year 2008 will mark the 100th anniversary of geographically dispersed production at General Motors.

With the rising concern in Western economies that manufacturing activities and jobs are being relocated to Eastern Europe, Asia, as well as Latin America this article has economic 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? How should policy-makers take into account the proposition that co-location may be a necessity for some companies but not others?

1.1 Approaches to 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 and Feldman, 1996), whereas organizational researchers have focused not as much on locational as they have on industry- and especially firm-specific considerations (Brush et al., 1999) and even at a more micro-level, cross-functional interdependencies within the firm (Adler, 1995; Clark and Wheelwright, 1993). Our theory builds on the latter, organizational and micro-organizational analysis. However, we will contrast this approach with the macro-level approaches.

Toward this end, it is 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.

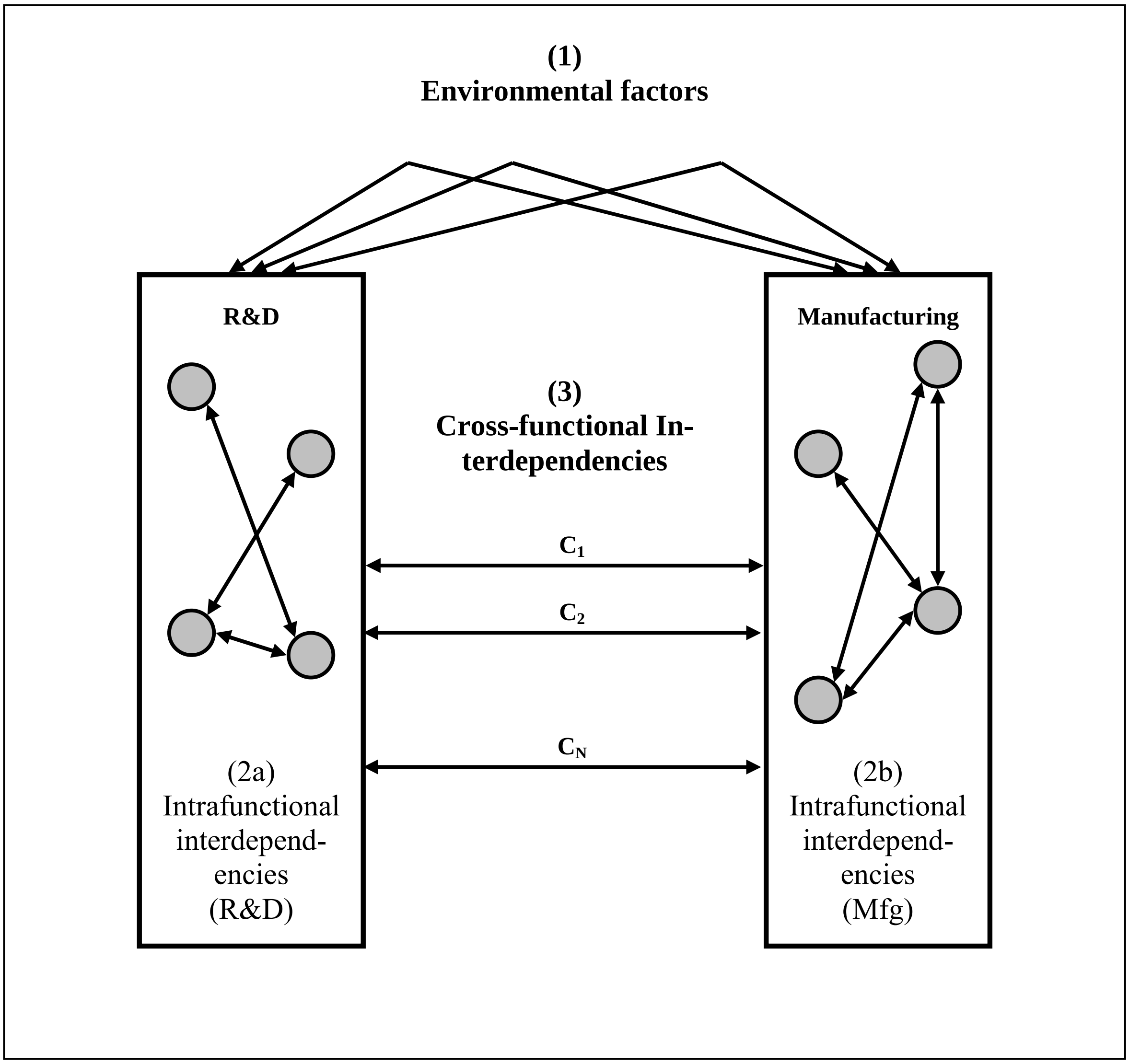
We can distinguish between three different approaches to the study of location decisions (Figure 1). All the approaches are indispensable, but they take a strikingly different approach to the phenomenon.

1. The External Drivers View

2. The Intra-Functional Dependencies View

3. The Cross-Functional Dependencies View

Figure 1. Different views on location decisions



1.1.1 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 and even psychological factors. After all, in a classic study on manufacturing location decisions in the U.S., Mueller and Morgan (1962) discovered that by far the most common specific reason for location decisions was “personal reasons or chance,” not proximity to customers and suppliers or potential labor advantages.

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. In general, these opportunities may offer first-mover advantages, but are eventually available to competitors as well. While this view is most often embraced by economists, organization scientists have also invoked this view as by identifying 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 explicit explanatory theory of co-location, but to the extent that the two functions are subject to similar kinds of external drivers, co-location may obtain. This might be what Ambos (2005) meant by “co-incidental co-location.” There are, however, compelling theoretical arguments to suggest that the locational drivers or “pulls” for R&D and manufacturing do not necessarily coincide.

1.1.2 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 (Flaherty, 1986)? What is its strategic role compared to the other manufacturing plants the firm operates (Ferdows, 1997; Scherer, 1975)? 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. These within-function interdependencies can be examined in an inter-organizational context as well, a case in point being inter-organizational R&D collaboration (Powell et al., 1996).

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* (e.g., Lawrence and Lorsch, 1967; Nohria and Ghoshal, 1997) 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 (Blanc and Sierra, 1999; Gassmann and von Zedtwitz, 1999). However, much like in the external drivers view, the issue of co-location is only implicit. Again, there is no explanatory 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.

1.1.3 The Cross-Functional Dependencies View

The approach we have selected as our theoretical basis examines the implications that decisions regarding one function (e.g., manufacturing) have on decisions regarding another function (R&D). Indeed, studies examining the internationalization paths of manufacturing and R&D often focus on these cross-functional interdependences. Both economists and organization scientists have used this approach, although organization-level studies tend to dominate.

Organization scientists often base their arguments on a variant of structural contingency theory introduced by Lawrence and Lorsch (1967), who argued that fundamentally, managing the R&D-manufacturing interface is a question of organizational integration, specifically, functional integration. They also argued that to the extent that the functions are interdependent (high requisite integration), the more management has to focus on installing the proper integrative mechanisms to address the integration challenge. Physical co-location of R&D and manufacturing can be thought of as an alternative, because it is likely to enhance inter-functional communication and enable efficient joint problem solving between the functions when it is needed. Lawrence and Lorsch were, however, explicit about the fact that joint-problem-solving between functions may or may not be necessary: *requisite integration* varies from context to context (see also March and Simon, 1958).

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, while other more "light-weight" alternatives for coordination are available in the case of sequential interdependence (Thompson, 1967; Van de Ven et al., 1976). 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).

1.2 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 we mean by *tension* here is not to imply that the views are not compatible. They are not 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, not facts.

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, see Cyert and March, 1992), 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, internal and external, in making a particular location decision.

2. Organizational Determinants of Co-Location

We approach the co-location from the cross-functional interdependence point of view, therefore, the theoretical foundation of our argument is structural contingency theory. In the following, we will strengthen and elaborate the theoretical foundation underlying the cross-functional interdependencies view by discussing the factors that may increase the likelihood of physical R&D-manufacturing co-location. The goal is to develop a testable model for empirical analysis.

Firstly, complexity makes decision situations relatively more *ill-defined* (e.g., Simon, 1996), and product development and manufacturing decisions have a higher likelihood of being reciprocally interdependent in the sense that decisions regarding one cannot be made without considering the other. This is because complex tasks are difficult to break into smaller parts without significant residual interdependence (e.g., Galbraith, 1970). We would thus expect complexity in the new product development process to be correlated with the need for co-location. There are two relevant dimensions of complexity: product and process. Product complexity refers to the characteristics of the physical product being produced: an airplane is more complex than a toaster, because there are more interdependencies to consider.

Process complexity is clearly a separate dimension, both theoretically and empirically. Process complexity refers to the characteristics of the manufacturing process that produces the final product. While product and process complexity sometimes go hand in hand (e.g., Intel's microprocessors), this is not necessarily the case. A good example is basic metals production or oil refineries, where end products are rather simple and standardized (e.g., gasoline, sheet metal, copper tube) but manufacturing processes highly complex. Process complexity is also particularly relevant here, because in process-complex organizations R&D activities are obviously geared more toward process than product development. Extant literature on R&D is clearly biased toward new product development, however, this bias is theoretically puzzling: there is no compelling rationale to assume that R&D is aimed at new product development (NPD), NPD is only one option for R&D, along with a dozen other alternatives ranging from process development to development of organizational structures and supply chains (e.g., Sawhney et al., 2006).

Of course, products do matter. In particular, we hypothesize that in addition to product complexity, the rate of new product introduction, or industry clockspeed (Fine, 1998), makes co-location more likely: if new products are constantly being developed, manufacturing and R&D may be more dependent on one another in contrast with stable industries and commodity products. Increasing rate of change places a heavier burden on those managing the R&D-manufacturing interdependence.

We suspect that industry matters as well, because R&D-manufacturing interdependencies may be stronger in one industry than another. This is not because of product complexity and rate of change, the underlying reason for interdependence may in addition lie in the different roles of manufacturing and R&D in different industries. In some industries, manufacturing plants may indeed be a significant source of new ideas, technologies, even new products. In others, manufacturing plants have more of a perfunctory role as far as innovation is concerned. Indeed, Florida (1997) finds that industry differences are rather drastic: in U.S. biotechnology, only 5% of firms considered manufacturing as a significant source of new project ideas. In the automotive industry, the corresponding figure was 38%. We however suspect that in addition to this inter-industry variance, there is also intra-industry variance; but this intra-industry variance is likely captured by the other factors discussed above.

Hood and Young's (1979) results regarding manufacturing in the UK prompt us to consider ownership issues as well. It could be that domestic and foreign-owned companies view location decisions differently. It could be that foreign-owned companies have less knowledge of the local economy and infrastructure and are more likely to default to co-location. This could be one candidate explanation to Hood and Young's findings. These reasons are, however, conjecture on our part and outside the scope of our theorizing. But because ownership may be a factor, its effect has to be, at the very minimum, controlled.

Finally, 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 so-called high-tech industries (one operational definition for high-tech is R&D-intensity of 10% or higher). 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, we see no necessary relationship between R&D intensity and the need for co-location: R&D and manufacturing can be strongly interdependent even when the size of the R&D function is relatively small. They key theoretical variable is interdependence of the two functions, which may have little to do with R&D intensity. This view is consistent with Florida (1997), who found that, with proper third factors controlled, R&D spending is unrelated to manufacturing-R&D cooperation. As expected, the size of the R&D budget does increase the intensity of cooperation with the research community external to the organization

(Florida, 1997: 93), but this has nothing to do with interdependencies with the manufacturing function.

Table 1. Hypothesized determinants of co-location

No	Co-location of R&D and Manufacturing	Yes
Low	Product complexity	High
Low	Process complexity	High
Low	Uncertainty	High
Low	Industry clockspeed	High
N/A	R&D intensity	N/A

3. Empirical Analysis

We examine the effects of the factors discussed above in a sample of 241 manufacturing firms. The data used in this paper were collected in Finland using a written survey conducted in July-August 2006. The sampling was done as follows:

1. First, the overall sampling frame was identified. This included 1827 firms drawn from Finland's total of 12,475 firms (stratified by sector and company size) with more than 10 employees in 2005. All firms are incorporated in Finland, although they may be subsidiaries of foreign firms.
2. A successful contact was made with 1,650 firms, of which 653 (40%) responded.
3. For obvious reasons, only companies that engage in both manufacturing and R&D were included in the dataset. Out of 350 manufacturing firms among those contacted, 241 firms provided all necessary data required in this study. Thus, our final dataset contains these 241 firms. Summary statistics for the data are presented in Table 2.

Table 2. Descriptive statistics of the sample

	Mean	S.D.	1	2	3	4	5	6	7
1. Colocation	2.62	1.14	1.00						
2. Product complexity	3.05	1.05	0.03	1.00					
3. Process complexity	2.15	1.06	0.25	-0.07	1.00				
4. Clockspeed	2.42	1.16	-0.01	0.06	-0.49	1.00			
5. R&D-intensity	4.93	7.13	-0.08	0.16	-0.29	0.14	1.00		
6. Number of employees	1310	4850	-0.26	0.19	-0.25	0.21	0.05	1.00	
7. Foreign ownership (dummy)	0.24	0.43	-0.16	0.03	-0.01	0.01	0.14	0.02	1.00

The informants who provided the data were most commonly the CEO in small- and medium-sized companies and a corporate-level technology manager in larger firms. This effectively makes the firm the unit of analysis. This may bias the results a little bit for large multidivisional firms, where the divisions may differ somewhat from one another. However, in our sample there are only very few large multidivisional firms; the average company size in terms of number of employees is only 1,300.

3.1 Variables

We operationalized the key concepts by having our informants evaluate various statements using four-point rating scale (1=strongly disagree, 2=predominantly disagree, 3=predominantly agree, 4=strongly agree).

1. **Co-location need:** "The majority of our research and product development has to be physically co-located with manufacturing activities." It is important to note that this question probes the *need* for co-location, not the actual state of affairs about co-location: need can exist without *de facto* co-location, and de facto co-location does not imply necessary need.
2. **Product complexity**: "Our products are so complex that they require constant R&D-manufacturing interaction." This question probes not only the complexity of the product, but in particular, the extent to which this complexity induces R&D-manufacturing interdependence. Not all kinds of complexity imply interdependence.
3. **Process complexity**: "Our R&D focuses mainly on process not product development." This question examines the extent to which R&D efforts are geared towards process development.
4. **Clockspeed**: "Every year, we launch new products or product models and ramp down the production of old products or models."
5. **R&D intensity**: the ratio of the number of R&D employees to the total number of employees (%) is calculated.

It is interesting to note that with respect to the distribution of answers concerning the need of co-location, there is high variability: 31% of the respondents strongly agreed, 25% predominantly agreed, 21% predominantly disagreed and 23% strongly disagreed with the statement. This is in line with past observations regarding *de facto* co-location: there is large variance between firms. This observation is also reassuring, because the primary goal of our analyses is to explain variance in this variable. There is indeed a lot of variance to be explained.

In addition, based on the discussions in the theory section, we used the following control variables:

1. **Company size**: the logarithm of the number of employees.
2. **Industry controls**: dummy variables to control for industry heterogeneity.
3. **Foreign-owned**: a dummy indicating whether the company in question is foreign-owned or domestic.

These variables are strictly speaking theoretically irrelevant, because the explanations for their potential effects are beyond the scope of our (structural contingency) argument. At the same time, because their effects may be reflected in the theoretically relevant dependent variable, their effects must be controlled. One exception here is the industry variable, which is in a sense both control and a theoretically relevant variable: industry effects may reflect underlying structural contingencies. However, because we have not measured these theoretically relevant characteristics (we have only observed industry dummies), this makes industry, from a theoretical point of view, a control variable.

3.2 Analysis

Because we have an ordinal, not continuous, dependent variable, we use an ordered (cumulative) logit model (e.g., Clogg and Shihadeh, 1994) to estimate relationship between co-location and the theoretically hypothesized drivers. To control the potential industry-specific factors of co-location, industry dummies are included in the model.

The results of the ordered logit model are presented in Table 3. Values for the industry dummies are omitted for presentation clarity; after all, industry is a control variable.

Table 3. Results of the ordered logit models (industry controls omitted)

	Estimate	Standard error	
Product complexity	0.237	0.123	*
Process complexity	0.544	0.145	**
Clockspeed	0.256	0.129	*
R&D intensity	0.001	0.020	
Size (log of #employees)	-0.284	0.081	**
Foreign ownership (0=domestic, 1=foreign)	-0.658	0.296	*
N		241	
Log likelihood		-305.9	
Likelihood ratio		52.45	
Overall model significance		0.0001	
Concordance index		39.5%	

** $p<0.01$; * $p<0.05$.

The estimation provides us with four main findings. First, as hypothesized, product complexity matters in the need for co-location between R&D and manufacturing functions. The coefficient of product complexity has a positive and statistically significant impact on co-location (p-value=0.05). Second, there is a significant (p-value=0.01) positive relationship between process complexity and co-location, implying that more complex manufacturing processes are, on average, associated with co-location need. Third, the coefficient of clockspeed has the expected positive sign and it is statistically significant at the 0.05 level. This confirms the hypothesis that co-location is more crucial in rapidly changing industries where new products are introduced more often. Fourth, the coefficient for R&D intensity is not statistically significant: there is no empirical evidence that innovative firms feel a stronger need for co-location. Of course, we fully recognize that if the hypothesis is that a coefficient is zero, failing to reject the null hypothesis does not constitute a rigorous statistical test. At the same time, our data is consistent with the idea that there are more important factors than R&D intensity.

The overall predictive value of the model—above and beyond tests of statistical significance—can be assessed by looking at the *concordance index*, the percentage of observations for which the model predicts the correct value for the dependent variable (Agresti, 2002: 229). Predicted values are based on the estimated category probabilities in the cumulative logit model: the predicted category for a given observation is the category with the highest estimated probability given the values of the independent variable. Our model correctly predicts the observed category in 39.5% of the cases (pure guessing, of course, would have a 25% concordance index). In conclusion, we submit that the predictive power of the model is satisfactory, given that the model is rather simple. We must also keep in mind that both independent and dependent variables likely contain measurement error, which attenuates predictive power. Therefore, potential lack of predictive power may be due to imperfect measurement, not flawed theory.

In terms of the control variables, we observe that the larger the firm, the less likely the need for co-location. Also, foreign-owned companies are less likely to exhibit co-location need. These observations are atheoretical however, because we did not present any *a priori* hypotheses. Hence, we do not wish to present any *ad hoc* interpretations. These observations do however suggest that there may be contingencies associated with the phenomenon that our theory and models have not incorporated. This presents one opportunity for future research.

3.3 Robustness tests

There are a number of reasons why robustness tests are required to establish stability of the estimates. First and foremost, the measurements likely contain measurement error, and because the psychometric measurements are single-item scales, measurement error is indeed a cause for concern. Measurement error in the independent variables in particular may present a problem, because it is known to lead to biased parameter estimation (e.g. Kennedy, 2003).

3.3.1 Robustness test 1

In the first robustness test, we estimated the regression model as a latent-variable regression model using a structural equation model. Instead of including the independent variables directly in the model, we modeled them as latent variables with manifest indicators. Now, our measurement instruments are single-item scales, therefore, explicit estimation of measurement error is not possible. Instead, we followed Anderson and Gerbing (1988: 415) and fixed the error variance such that item reliabilities are what they are typically in these kinds of measurement instruments (around 0.70). This procedure effectively modifies the regression input correlation matrix to adjust for unreliability (Ping, 1996). Fixing reliabilities to 0.70 is admittedly an arbitrary choice, however, it does enable an examination of what the effects of measurement error in the independent variables could be. In addition, we suspect that in terms of potential estimation bias, fixing reliabilities to 0.70 is certainly a better option than fixing them to 1.0, which is the implicit assumption in conventional regression analysis.

The substantive results of the latent-variable regression are almost identical. Process complexity and clockspeed have the same kinds of effects as in the ordered logit model. The control variable effects are also identical. The only different result concerns the product complexity measure, which is no longer significant. However, we have to bear in mind that this latent-variable regression treats the dependent variables as continuous. We were forced to make this assumption as we are not aware of a latent-variables regression approach to ordinal dependent variables.

In terms of variance explained, the latent-variable regression model explains 35% of the variance in co-location need, 13 percentage points of which is due to the theoretically interesting variables. Given that the reliability of the dependent variable may be somewhere around 0.70 (and maximum R^2 thus around 70%), this model has fairly high explanatory power. This is consistent with our conclusions based on the concordance index of the cumulative logit model.

We also estimated a conventional regression model using OLS estimation. The results of this analysis are similar to the original analysis. As far as the statistical significance and sign of coefficient estimates, substantive conclusions are identical.

3.3.2 Robustness test 2

Are our results an artifact of the ordered logit model? To test this, we ran a binominal logit model where the dataset include only those firms (N=127) that either strongly agree or strongly disagree the co-location statement. The dependent variable equals one if the firm strongly agree the co-location statement and zero if it strongly disagree. The majority of the results of this new estimation echo our previous findings. The coefficients of product complexity and process are again positive and statistically significant. The coefficient of clockspeed remains positive, but is no longer statistically significant. Again, the larger the firm, the less likely the co-location.

3.3.3 Robustness test 3

A standard ordered logit model assumes that regression coefficients are equal across all levels of the outcome variable. If this assumption does not hold, estimates are potentially misleading. To take into account the potential bias caused by the violation of the assumption we test the parallel regression assumption of the ordinal regression model. We use Wald tests to see whether our variables meet the parallel lines assumption (Williams, 2006). The null hypothesis states that regression coefficients are equal across all levels of the outcome variable.

A global Wald test result (χ^2 = 16.9 with d.f. of 32, and p = .98) indicates that there is no significant difference for the corresponding regression coefficients across the response categories, suggesting that the model assumption of parallel lines is not violated.

In sum, robustness tests indicate that measurement error may have caused some instability in estimation. However, we can safely conclude that process complexity is a strong determinant of co-location. As far as clockspeed and product complexity, the results are in the main supportive, but some concerns with measurement remain. This presents another opportunity for further research on the topic.

4. Discussion and Conclusion

Firm- and technology-specific characteristics clearly have implications to the need to co-locate R&D and manufacturing activities. This basic result not only complements the extant industry- and country-level analyses, but also offers a solid contingency-theoretic explanation to the phenomenon: product complexity, process complexity and rate of change impose different kinds of information-processing and problem-solving needs and thus inter-functional interdependence. Sometimes these interdependencies are so strong that physical co-location of the two functions is the most efficient mode of coordination.

Structural contingency theory is perhaps the most widely used theoretical basis for organizational research (Scott, 2003). Our theory and empirical results further expand the scope of structural contingency theory to cover structuring of geographically dispersed operations. Of course, contingency-type theorizing in the study of geographically dispersed activities is nothing new (e.g., Nohria and Ghoshal, 1997; Prahalad and Doz, 1987), however, applying contingency theory to co-location is a novel idea. At the same time, because organizational design is ultimately a function of information-processing requirements (Egelhoff, 1988; Galbraith, 1972), much like the cross-functional integration challenge (Lawrence and Lorsch, 1967), contingency theory seems to be a good candidate to aid theoretical inquiry. It is further reassuring that the conventional task-environmental contingencies—complexity and dynamism in their various forms—are the prevalent factors in explaining the co-location need.

The power of the structural contingency argument is strengthened by the fact that we observe high variance in both the independent (contingency) variables as well as the dependent variable in our model. Not only is the contingency-theoretic explanation important from a theoretical point of view, it also explains why we *de facto* empirically observe a high degree of variability in the co-location need.

We observe that R&D intensity does not matter as far as co-location is concerned; indeed the parameter estimate is virtually zero. This is consistent with previous findings. However, in addition to making an observation consistent with extant empirical research, we also have a theoretical interpretation to this: co-location need is not a function of the size of the R&D organization, it is a function of the interdependence between R&D and manufacturing. Interdependence may exist even at low levels of R&D intensity. Much more important than the size of the R&D budget are technological considerations such as product and process complexity.

4.1 Managerial Implications

While extant empirical evidence on co-location may be relevant to economic policy, it is not very relevant to actual decision-making in organizations. It is of course interesting to observe that British, Swedish, German and Japanese companies differ on average in their propensity to co-locate, or that automotive industries are different from biotechnology. However, executives in the auto industry probably do not care very much about what happens in biotechnology, they are likely much more interested in intra-industry variance as well as their own position vis-à-vis the competition. Of course, macro-level examinations are important and relevant, in particular if they lead to a more refined theoretical understanding of the phenomenon. Their managerial relevance is however suspect. If we wish to engage in managerially relevant research, we must theorize at the proper level of aggregation, which in this case is the organization, not industry or country. In fact, even more detailed micro-organizational analysis at the level of an individual product line or a product development project might be appropriate (Adler, 1995).

At any rate, the results of our model are indeed relevant to organizational decision-makers as well, because our theory operates at the level directly relevant and observable to strategic decision-making. Take product complexity for instance: based on our model, we may conclude that manufacturers of high-technology electronics consumer products can alleviate the co-location need by tackling those aspects of product complexity that create interdependencies. Toward this end, modular product designs have emerged (Baldwin and Clark, 2000), designs that enable the division of a complex tasks into smaller, by and large self-contained tasks (e.g., the cell phone battery). This effectively eliminates reciprocal interdependence and turns it into a more "lightweight" sequential or pooled interdependence, to use Thompson's (1967) interdependence terminology. This sequential or pooled interdependence can then be managed by plans, schedules and standards, without the need for extensive problem-solving; similar interdependence and coordination logic can be applied to inter-firm coordination of activities (Grandori, 1997). To be sure, product modularity is a widely used product architecture in many industries: consumer electronics, automobiles, and elevators are good examples.

We suspect that process complexity may be a somewhat different issue from the managerial point of view. It is relevant to managerial decision-making, but management's options may be more limited than in the product complexity case. A case in point, Intel still manufactures the vast majority of its products in the United States, where the bulk of its R&D is located. Ramp-up of new production also occurs in the United States (e.g., NAND flash memory production ramped up in 2006 as a joint venture with Micron). We do not think this co-location is a coincidence. We further suspect that this need for co-location is not going to change drastically in the near future: when R&D efforts are heavily concentrated on the development of process technology, or joint-development of product and process technology, the most obvious location for R&D activities and personnel is in the vicinity of the manufacturing plant.

4.2 Policy Implications

Many Western economies are concerned with the phenomenon of manufacturing operations relocating to low-cost countries. One response from policymakers has been the argument that Western economies should increase their R&D efforts and concentrate on the development and manufacture of innovative high-technology products. Indeed the so-called Lisbon Strategy initiative by European Union calls for EU member states and the European Commission to work towards an increase in R&D spending to a total of 3% of Gross Domestic Product. Advocates of this position hope, among other things, that concentrating on the design and manufacture of highly complex products would prevent massive off-shoring of manufacturing activities.

Our empirical results however challenge this policy, because in light of our analysis an increase in R&D intensity does not necessarily lead to an increase in manufacturing of high-technology products in the same economy. The need to co-locate manufacturing and R&D does not appear to be a function of R&D intensity, hence, increasing R&D intensity may not lead to desired ends. Interestingly, in its mid-term review of the Lisbon Strategy, the EU Council (2005) was quite critical of the initiative, highlighting its "shortcomings and obvious delays" (p. 2) in terms of growth and employment goals set in the initiative. However, The Council still maintains the 3% R&D goal for year 2010 (p. 4).

Others have suggested that the future global division of labor could be based on business function in that Western economies could concentrate on R&D and production activities could be carried out through off-shoring. Various parts of the world could thus specialize in different business functions. Our results however challenge this scenario as well: R&D and manufacturing are conceptually separate, but in a significant number of cases inseparable in practice. This kind of a “global-level functional integration challenge” could well be way too complex and expensive to manage. This is because in many industrial contexts manufacturing units are no longer just “factories,” rather, they have developed into highly complex technology centers where production and development activities are closely intertwined in everyday activities. Our results suggest that policy-makers should consider these interdependencies when they contemplate policy actions.

4.3 Future Research

There are always multiple avenues for new research on a given topic. In this case, we think the most fruitful both from theoretical and managerial point of view is a more detailed examination of manufacturing and R&D activities. After all, manufacturing and R&D are both merely rubrics that comprise a wide variety of activities. Manufacturing contains a variety of tasks from the mundane and routinized daily production activity control to highly non-routine activities of new production ramp-up and supplier selection. R&D in turn consists in both basic research on emerging technologies that is completely detached from existing products and technologies, as well as highly focused product development aimed directly at generating new sales in the near future. If we wanted to get a more refined picture of the R&D-manufacturing interdependencies, we should look at the phenomenon and interdependencies at a more fine-grained level. One way to do this would be to examine the interdependencies of different kinds of manufacturing “sub-activities” with different kinds of product development “sub-activities.” We submit that this is also managerially the most relevant level of analysis, because it specifically addresses the questions that management has to manage on a daily basis: managers tackle the functional integration challenge in specific cells of the interdependence grid depicted in Table 4.

Table 4. A more detailed view of interdependence

<table>
<tr><td colspan="3" rowspan="3"></td><td colspan="3">R&D</td></tr>
<tr><td rowspan="2">Research</td><td colspan="2">Development</td></tr>
<tr><td>Product</td><td>Process</td></tr>
<tr><td rowspan="3">Manufacturing</td><td rowspan="2">Routine</td><td>Production Planning and Control</td><td></td><td></td><td></td></tr>
<tr><td>Continuous Improvement</td><td></td><td></td><td></td></tr>
<tr><td>Non-routine</td><td>Managing Discontinuities</td><td></td><td></td><td></td></tr>
</table>

Another possibility for future research would be to engage in a more general empirical treatment of functional interdependencies and thus potential substitutes for co-location. To be sure, there are many other mechanisms for coordination that are available to management, both within (Van de Ven et al., 1976) and across (Grandori, 1997) organizational boundaries. To the extent that these mechanisms can be used to tackle functional task interdependence, need for co-location may be alleviated. For instance, enterprise resource planning (ERP) systems are perhaps one of the most important coordination tools today, tools that enable efficient transfer and processing of complex information in a geographically dispersed setting. Because co-locating manufacturing and R&D may force the organization to make significant tradeoffs in terms of exploiting locational advantages, co-location may turn out to be a rather costly option for coordination. If requisite coordination can be achieved with less expensive arrangements, the firm may be able to avoid co-location.

4.4 Conclusion

Kuemmerle (1999: 192, emphasis added) noted that "the process of globalization of R&D is an extremely complex one that is driven by a large number of *company-specific* variables and that rewards more research attention." We have answered this call for research attention by examining company-specific technological factors that may affect the need to co-locate R&D and manufacturing activities. We find that product and process complexity as well as rate of new product introduction all have a hypothesized effect on co-location need. We also find that R&D intensity *per se* is ancillary to the co-location phenomenon The hypotheses are based on classical structural contingency theory of organizations, in particular the variant that addresses organizational solutions to information-processing needs and different types of functional interdependencies. We find that this general theory about organizations can indeed be used to advance our understanding of location decisions, and we suspect, has a lot to offer in future research as well. Our study marks one of the first attempts to address the phenomenon of co-location using a rigorous and theory-driven hypothetico-deductive research design.

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