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Abstract

This paper analyses the effectiveness of knowledge transfer between research and development (R&D) and intra-firm production units. Specifically, two distinct network structures are compared: the lead factory concept and traditional networks of R&D and production. Based on an analytical two-stage decision model for prototype and serial production, we highlight relevant factors that determine the relative advantages and disadvantages of the lead factory concept in comparison to a traditional network structure. In particular, the lead factory concept is more efficient than the traditional network if there are a high number of production plants, the adaptation costs for implementing the transferred prototype from the lead factory to the plant are low, the manufacturing costs for the prototype are high, and the manufacturing processes are not highly specific or knowledge intensive.

Keywords: Operations Management; Manufacturing; Lead Factory; Knowledge transfer; Cost Benefit Analysis

JEL Classification: D21, D83, M11, L60

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1. Introduction

Today, large industrial companies operate a network of geographically distributed research and development departments (R&D) and manufacturing units to add the benefits of location-based advantages to their preexisting firm-specific advantages. Managers of such R&D and manufacturing networks must solve one of the most intriguing dilemmas in the field of business administration: They have to organize these networks to achieve operational efficiency and at the same time must be able to reconfigure the operations of these networks to adapt to new circumstances and explore new opportunities [e.g. 1].

The extent to which a company can overcome the friction between exploration (R&D) and exploitation (production) crucially depends on the company's ability to create, transfer, and apply relevant knowledge; however, the transfer of knowledge within a company's internationally distributed network is highly challenging. Although the effectiveness of knowledge transfer within production networks depends on many factors, the organization of the network structure plays one of the most import roles.

Traditionally, R&D and manufacturing networks have been structured as follows: Headquarters and R&D have typically been located in the same regional area, whereas production plants have been spread across the globe. One of the key characteristics of this kind of traditional network is a spatial and structural separation of exploitation and exploration [2]. The R&D department contributes exploration activities, and the geographically dispersed production plants focus exclusively on exploitation [3].

Over the last years, a new form of organizing intra-firm R&D and manufacturing networks has begun to emerge, which has been motivated by the contemporary viewpoint that subsidiaries differ in their tasks and capabilities [4]. Various researchers have shown that plants within an intra-firm network can be allocated to different strategic roles. Enright and Subramanian [5] provide a comprehensive overview, wherein they identify the common concept of a production plant that is strategically important and serves as the central knowledge hub of the network. A widely accepted denotation for this special type of production plant is the lead factory.

Following Ferdow's definition of lead factories, the task of such a central plant is to create new processes, products, and technologies for the entire company [6]. In contrast to the traditional network structure, the lead factory is the sole plant that interacts with the R&D

department. The lead factory supports the R&D department in the development of new products and processes, and produces the prototype. The most important task of the lead factory is the generation and transfer of knowledge.

Many studies have described the core concept of the lead factory and have explored its activities and responsibilities; however, current research to date has failed to explain the reason why such a special plant should be created. It is unclear if the lead factory concept positively influences the company's aim of achieving a competitive advantage. Moreover, it remains to be analyzed if and under what contingencies the lead factory concept produces concrete advantages over a more traditional model.

As this field of research continues to characterize the roles of different kinds of plants, the need for a better understanding of the factors that render the lead factory concept more or less efficient than the traditional network structure becomes apparent. Within an international distributed R&D and manufacturing network, the efficiency of knowledge transfer is crucial. Different contingencies may render knowledge transfer more efficient in traditional network structures or lead factory-based network structures; however, this question has yet to be analyzed. Therefore, we compare knowledge transfer within a network that includes a lead factory (lead factory concept) to a network without a lead factory (traditional network structure) to identify the primary differences between these networks and how these differences result in competitive advantages.

The lead factory concept economizes knowledge generation and may foster knowledge transfer from exploration to exploitation. In particular, the true potential of the lead factory concept may be influenced by certain contingencies; hence, this study is directed by the following research question:

> What factors determine the relative advantages and disadvantages of the lead factory concept and the traditional network structure?

By answering this research question, we contribute to network studies by clarifying the lead factory concept and by deriving the factors that render the lead factory concept more efficient than the traditional network structure.

The remainder of the paper is structured as follows. The following section describes the theoretical background of knowledge transfer in R&D and manufacturing networks, which is followed by a description of the two distinct network structures. Section 3 presents the analytical model of the two distinct network structures. Section 4 describes the primary results of this study, and Section 5 concludes the paper.

2. Theory

2.1 Knowledge transfer in R&D and manufacturing networks

Applying a knowledge-based view to a firm means that a firm's key role is to create, store, and apply knowledge [7]. In the field of operations management, the focus is on creating, transferring, and applying manufacturing know-how. Many managers report that their systems for creating, transferring, and applying manufacturing know-how are often informal, i.e., the systems are ad-hoc, implicit, and not well organized [8]. This "adhocracy" contrasts with the fact that internal knowledge transfer is an important source of competitive advantage for many organizations [9-12].

Knowledge transfer is influenced by many factors: e.g., the properties of the knowledge itself (i.e., tacitness) [13], the strength of the ties through which knowledge is transferred [14], and the absorptive capacity of the recipients (i.e., diversity of backgrounds) [15]. A main conceptual distinction should be made between explicit and tacit knowledge [e.g. 16-20]. In contrast to explicit knowledge, tacit knowledge is often unarticulated; e.g., it is tied to senses, movement, skills, physical experiences, intuitions, or implicit "rules-of-thumb" [21].

Knowledge transfer is affected by the type of knowledge that is being transferred. Tacit knowledge is largely shared through complex interactions. The stronger the personal ties, the easier the process of absorbing and interpreting tacit knowledge. Strong ties promote mutual trust and understanding [21]. Moreover, the recipient's relevant knowledge, experience, and breadth of background also improve the effectiveness of transferring and sharing relevant tacit knowledge [15, 22].

Although knowledge transfer within a single plant is challenging, intra-organizational knowledge transfer is even more complicated. The vertical transfer of technology, e.g., the transfer of a product from R&D to manufacturing, brings up additional problems because the shared codes of functional groups differ across functional units. Shared codes provide a common base of understanding through which organizational members with disparate experience, knowledge and backgrounds can transfer knowledge [23]. The greater the background diversity between the sending and the receiving units, the more complicated the knowledge transfer becomes [15].

We focus our analysis on knowledge transfer within an internationally distributed R&D and manufacturing network. Knowledge is transferred from the R&D department to the manufacturing units to produce the developed product. The production of the first product, the so-called prototype, is based on explicit and tacit knowledge. The R&D department produces detailed and explicit production manuals, whereas manufacturing employees have to implement the processes and improve them in a pragmatic, real-time setting. This implementation is highly influenced by the employees' experience and background, relying primarily on tacit knowledge. To start serial production, manufacturing know-how has to be codified and recorded in operations manuals and embedded in the equipment, which is, again, a process that conveys explicit knowledge [11].

Internationally distributed manufacturing networks reveal that the costs of transferring R&D knowledge into production know-how occur within different plants. These costs differ within the network depending on how weak or strong the personal ties between the R&D department and the plants are. Furthermore, the absorptive capacity of the receiving plants differs due to the often highly heterogeneous backgrounds, experiences, and knowledge of their workers. Absorptive capacity is the ability to recognize the value of new information, to assimilate it, and to apply it based on prior related knowledge of the department [15]. The knowledge transfer from the R&D department to plants within the same regional area is usually more efficient than the knowledge transfer to plants of distant countries because departments of the same regional area normally have strong relationships, which positively promotes knowledge sharing [24]. Furthermore, departments in the same regional area normally possess higher absorptive capacities because their respective backgrounds are similar [15].

Moreover, the knowledge transfer between R&D and manufacturing departments consists of explicit knowledge (e.g., manuals) as well as tacit knowledge (e.g., experience). After receiving R&D information about a new product, the manufacturing department needs to further experiment with and improve the process to begin production. These activities are highly influenced by the background experiences of the employees and heavily depend on tacit knowledge. The greater the differences between the shared functional codes of the sending and receiving entities, the less efficient the knowledge transfer [23].

2.2 R&D and Manufacturing networks

To a large extent, the efficiency of the knowledge transfer between R&D and manufacturing is determined by the structure of the entire R&D and manufacturing network. In this section, we identify the "traditional" network structure and the lead factory concept as two general models of network structures, and therein, we characterize them according to their knowledge transfer features.

2.2.1 Traditional network structure

One of the key descriptive factors of a traditional network structure is spatial separation. Traditionally, R&D departments and manufacturing units have been organizationally separated. This separation has permitted the R&D department to focus on exploration activities, whereas the manufacturing units have concentrated their resources on exploitation [2]. Within the traditional network structure, the R&D department focuses on generating basic innovations, developing product platforms, and standardizing modules. Besides generating new ideas, the R&D department also focuses on the adjustment of existing products to regional markets and customers [3].

At the same time, overall efficiency goals require the R&D department to consider the effect of its decisions on the manufacturability of the products, e.g., the resultant manufacturing costs; however, the spatial and organizational separation of R&D and manufacturing tasks limits knowledge transfer that might facilitate this sort of consideration, which is necessary to improve manufacturability and reduce manufacturing costs [25].

Within traditional networks, the R&D department explores new products and processes and transfers the results to the manufacturing sites. The manufacturing sites are responsible for producing the new products and exploiting the existing product portfolio. Each of the internationally distributed manufacturing sites interacts with the R&D department and translates R&D knowledge into manufacturing processes and specifications. Knowledge sharing within a traditional network depends on the location of the receiving plant. Usually, only a plant in the same regional area as the R&D department profits from strong personal ties with the R&D department. More distant plants have much weaker personal ties and therefore lower levels of absorptive capacity, which limits the effectiveness of knowledge transfer between the R&D

department and these plants.

From a process perspective, each of the plants has the responsibility to turn R&D knowledge into a prototype and to start serial production based on subsequent improvements of the prototype. Because several plants usually produce the same products that have been developed by the R&D department, the costs associated with transferring R&D knowledge into a prototype and the subsequent improvements continuing up to the serial production of the new product have to be incurred at each plant.

2.2.2 The lead factory concept

The idea of the lead factory concept is to transform one of the manufacturing units into an “intermediary” between the R&D department and the other geographically distributed manufacturing units [26]. This “intermediary” is called the lead factory. It works closely together with the R&D department to facilitate knowledge transfer from exploration (R&D) to exploitation (production). New products, processes, and technologies are developed by the R&D department in collaboration with the lead factory. The lead factory holds an overall mandate for innovations: The production of the prototype and the respective processes are ultimately the responsibility of the lead factory [5]. The knowledge acquired by the lead factory during its engagement in the development process and production of the prototype enables the lead factory to “incorporate” substantial amounts of knowledge into the design of the process for serial production, which is then transferred to other manufacturing units. The "intermediation" of the lead factory enables other manufacturing units to benefit from knowledge that is generated by the lead factory and then either explicitly communicated to the manufacturing units or implicitly incorporated into the design of the manufacturing process. As a result, the manufacturing units are able to develop more stable and reliable manufacturing processes. The lead factory also assesses and optimizes manufacturing methods, trains staff at new sites, gathers and validates optimization ideas, and generally drives continuous improvement [3]. Within the lead factory concept, the manufacturing unit focuses on the production of the products developed by the R&D and lead factory, on continuous improvement of the manufacturing processes, and if needed, on the adaptation of the product to local requirements. If changes are required, the manufacturing unit reports them back to the lead factory, which, in turn, makes the changes either together with the R&D department or alone and then transfers the solution back to all production subsidiaries for which the changes are relevant. In summary, the lead factory is the capability or knowledge creator for the network, whereas the other manufacturing units are capability or knowledge recipients [9, 5].

Comparing the two networks introduced above, the lead factory concept has major structural advantages over traditional networks. The R&D department interacts more frequently with the lead factory in comparison to the overall interactions between R&D and manufacturing within the traditional network structure. This higher frequency of interactions leads to the development of a shared code of knowledge between exploration and exploitation units and, therefore, facilitates knowledge transfer between R&D and the lead factory. Its manufacturing expertise and the experience accumulated in the development and production of the prototype enable the lead factory to transfer more knowledge to the manufacturing units than is usually transferred within a non-intermediated network structure. Moreover, the lead factory transfers that knowledge more efficiently because it shares the same functional codes as the manufacturing units [17].

The investment of the receiving plant to start serial production is much more efficient under the lead factory model than without the lead factory's intermediation; however, the equipment, production layout, and capabilities of the lead factory and the branch factories are often quite heterogeneous. The greater the difference between the lead factory and the branch factories, the less the branch factories profit from the lead factory's knowledge. Specifically, the need to produce a second prototype would appear if the branch factory had to develop manufacturing processes that differed from those developed by the lead factory.

3. The Model

We consider a firm that produces a certain product and has a choice between two distinct intra-firm network structures: (a) the traditional network structure, wherein the R&D department and the production plants are organizationally separated, and (b) the lead factory concept, wherein the R&D department works closely together with the lead factory and transfers knowledge to the branch factories. In our analysis, we focus on the knowledge transfer within an R&D and manufacturing network. Because companies not only have to invent or improve products within the R&D department but also have to efficiently communicate generated knowledge to the production units, knowledge transfer is a central part of achieving a competitive advantage [3]. We therefore analyze the efficiency of knowledge transfer from exploration to exploitation by comparing the efficiency of the knowledge transfer within the lead factory concept and the traditional network structure. Because knowledge transfer influences overall manufacturing costs, we compare the cost efficiency of both forms of organization.

In order to make our model more tractable, we consider the development and production of a single product. This product is developed by the R&D department either with or without the collaboration of a lead factory and is then produced by one or more manufacturing units according to the following cost function:

$$C(q) = c_1(q) + c_2(q),$$

where $q > 0$ denotes the number of units that are produced. The total manufacturing costs consist of two components: (i) labor and material costs, $c_1(q)$, and (ii) ramp-up and learning costs, $c_2(q)$. Labor and material costs are determined by a convex cost function $c_1(q)$ with $c'_1(q) > 0$ and $c''_1(q) \geq 0$. Ramp-up and learning costs are normalized to zero if the production process is optimally adapted to all production requirements and are positive if the process is not yet optimally adapted. We assume that, before production takes place, the firm is able to form expectations about the ramp-up and learning costs given by $E\left[c_2(q)\right]$.

We further distinguish between the basic dimensions and the specific dimensions of a production process. The basic dimensions refer to sub-processes that are executed within each plant, which usually do not differ between plants. Knowledge with respect to these basic dimensions is much easier to effectively transfer because it does not require scarce expertise, and instead, this knowledge is usually based on common processes and shared codes of manufacturing know-how. Examples of basic dimensions of knowledge include industry-wide welding, brazing, or dyeing standards.

The specific dimensions of the production process refer to sub-processes that depend on specialized equipment or expertise. Knowledge with respect to these specific-dimensions is much harder to transfer from the lead factory to geographically dispersed manufacturing units because it requires either highly skilled employees or a specific technology. Because highly skilled workers and specific technologies are scarce, these specific processes differ across geographically distributed manufacturing units. Basically, the more heterogeneous the manufacturing units with respect to their technologies, equipment, capabilities, and skills, the more difficult the knowledge transfer from exploration to exploitation.

We denote the basic and specific dimensions of the production process P by p_b and p_s, respectively, and weight them according to:

$$P = \mu p_b + (1-\mu) p_s,$$

where $\mu \in [0,1]$ is a weight parameter that represents the relative importance of the basic (compared to the specific) dimensions of the production process. We specify p_b and p_s as follows:

$$p_b = \left(\hat{\theta}_b - x_b\right)^2 \text{ and } \mathrm{p}_s = \left(\hat{\theta}_s - x_s\right)^2,$$

where $\hat{\theta}_b$ and $\hat{\theta}_s$ are independent, continuously distributed random variables with $E[\hat{\theta}_b] = \theta_b > 0$, $E[\hat{\theta}_s] = \theta_s > 0$, and $Var[\hat{\theta}_b] = \sigma_b^2 \in (0,\infty)$, $Var[\hat{\theta}_s] = \sigma_s^2 \in (0,\infty)$. The realizations of the random variable $(\hat{\theta}_b, \hat{\theta}_s)$ are given by (τ_b, τ_s). The variables x_b and x_s are choice variables that are used to optimally adapt the production process, contingent on the knowledge of $\hat{\theta}_b$ and $\hat{\theta}_s$. Thus, expectations concerning the second cost component are given by:

$$E\left[c_2(q)\right] = \mu E\left[\left(\hat{\theta}_b - x_b\right)^2\right] + (1\text{-}\mu) E\left[\left(\hat{\theta}_s - x_s\right)^2\right].$$

We assume that knowledge regarding τ_b and τ_s is acquired through the production of a prototype.

In the lead factory concept, the prototype is constructed in the lead factory, whereas in the traditional manufacturing network, the prototype is directly constructed in each manufacturing plant. The prototype is the last step where R&D is involved before the first production series is run. Production of the prototype may be interpreted as the final "rehearsal." After the prototype has been produced, adaptations are eventually made on the product or process, depending on the experienced gained during the manufacturing of the prototype.

Whether knowledge about τ_b and τ_s (after the production of the prototype) can be effectively transferred from the lead factory to the manufacturing plants depends on the heterogeneity between the production plants, which is given by η. We assume that knowledge about the basic and the specific dimensions of the production process can be effectively transferred to the production plants if $\eta < \alpha_2 < \alpha_1$, whereas only knowledge concerning basic dimensions can be effectively transferred if $\alpha_2 < \eta < \alpha_1$. No knowledge can be effectively transferred to the production plants if $\alpha_2 < \alpha_1 < \eta$, where α_1 and α_2 represent threshold parameters.

Finally, even if all relevant knowledge about the production process is fully communicated to the plants, there are (one-time) adaptation costs in each plant, which are given by $k_b > 0$ for basic processes and $k_s > 0$ for specific processes. One-time adaptation costs reflect the efforts of a plant to adapt to the new circumstances (e.g. investments in new equipment, technologies, and training and efforts in data handling). We proceed by analyzing the traditional network structure in the next section and the lead factory concept in Section 3.2. We compare both network structures in Section 4.

3.1 Traditional network structure

In this section, we model the traditional network structure and assume the following timing of the production process:

> Stage 1: Each production plant manufactures its own prototype, such that knowledge about the basic and specific processes is directly generated in each plant; thus, no (or very low) adaptation costs are incurred.
>
> Stage 2: The serial production of the product takes place in each production plant.

3.1.1 Stage 1

In stage 1, each production plant manufactures its own prototype. Thus, each plant acquires knowledge about the basic and specific process. The manufacturing costs of the prototype in each production plant are derived in the next lemma:

Lemma 1

In Stage 1, the manufacturing costs C_P for the prototype in each production plant are given by: $C_P = c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2$.

<u>Proof:</u> See Appendix A.1

Manufacturing costs C_P for the prototype are composed out of material costs $c_1(1)$ and ramp-up and learning costs $\mu\sigma_b^2 + (1-\mu)\sigma_s^2$. Note that to minimize the expected costs $E[c_2]$ of the second cost component, each production plant has set $(x_b, x_s) = (\theta_b, \theta_s)$ in stage 1, such that $E[c_2] = \mu\sigma_b^2 + (1-\mu)\sigma_s^2$. After the production of the prototype, each plant has generated knowledge about τ_b and τ_s. Thus, in the subsequent production, each plant can optimally adapt its production process with respect to the basic and specific processes.

3.1.2 Stage 2

In stage 2, each production plant sets $(x_b, x_s) = (\tau_b, \tau_s)$, such that the production process runs efficiently, i.e., it is now optimally adapted regarding the basic and specific processes, such that $E[c_2] = 0$. It follows that manufacturing costs for q units are subsequently given by $c_1(q)$.

Thus, the firm's total manufacturing costs for producing q units in each plant are given by:

$$C_{TN} = n \cdot [\underbrace{c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2}_{\text{costs for prototype (stage 1)}} + \underbrace{c_1(q)}_{\text{total costs for q units (stage 2)}}] = n \cdot [C_P + c_1(q)].$$

3.2 Lead factory concept

In this section, we consider the lead factory concept and assume the following timing of the production process:

Stage 1: The prototype is designed in cooperation with the R&D department and is manufactured in the lead factory. During this phase, the lead factory generates general and specific knowledge. The extent to which this knowledge can be transferred to the manufacturing units critically depends on the heterogeneity of the respective production plants.

Stage 2: At this stage, we differentiate three generic scenarios that reflect the heterogeneity of the production plants and the resulting effectiveness of the knowledge transfer from the lead factory to the various plants. With the knowledge acquired in stage 1, each plant optimally adapts the basic and specific dimensions of its production process, after which, serial production begins.

3.2.1 Stage 1

The costs of producing the prototype in the lead factory are given by:[1]

$$C_P = c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2 .$$

In the process of producing the prototype, the lead factory learns the realizations of $\hat{\theta}_b$ and $\hat{\theta}_s$. Whether this knowledge can be effectively communicated to the production plants depends on the heterogeneity of these plants. As indicated, we differentiate three basic scenarios: low, medium, and high production plant heterogeneity.

3.2.2 Stage 2

Scenario 1: Low heterogeneity

In this scenario, we assume that $\eta < \alpha_2 < \alpha_1$, i.e., the heterogeneity between the production plants is sufficiently low, such that knowledge about τ_b and τ_s can be effectively communicated from the lead factory to each production plant after it has been acquired by the lead factory (which acquired this knowledge during the design and implementation of the manufacturing processes of the prototype). In this scenario, only one-time adaptation costs for both the basic and the specific process, which are given by k_b and k_s, have to be incurred in each production plant. Once the manufacturing units have acquired knowledge about τ_b and τ_s from the lead factory, each production plant will optimally adapt its production process regarding both dimensions by setting $(x_b, x_s) = (\tau_b, \tau_s)$, such that $E[c_2] = 0$. After the successful adaptation, efficient serial production takes place in each plant.

In Scenario 1, the firm's total manufacturing costs for producing q units in each plant are thus given by:

$$C_{LF}^1 = \underbrace{c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2}_{\text{costs for prototype in LF (stage 1)}} + \quad n \cdot \underbrace{\left[k_b + k_s + c_1(q)\right]}_{\text{total costs for } q \text{ units in each plant (stage 2)}} \quad = C_P + n\left[k_b + k_s + c_1(q)\right].$$

[1] See Lemma 1. Moreover, note that the lead factory sets $(x_b, x_s) = (\theta_b, \theta_s)$ to minimize expected costs $E[c_2]$ of the second cost component in stage 1.

Scenario 2: Medium heterogeneity

In this scenario, we assume that $\alpha_2 < \eta < \alpha_1$, i.e., the heterogeneity between the production plants is established, such that only knowledge τ_b regarding the basic dimensions of the production process can be effectively transferred from the lead factory to the production units. Knowledge regarding specific process dimensions cannot be effectively transferred to the production units.

Successfully adapting the production process with respect to its basic dimension results in adaptation costs of k_b. Because knowledge transferred from the lead factory only relates to the basic dimensions of the production process, each production plant has to produce its own prototype to generate knowledge τ_s regarding the specific dimensions of its production process. This second production of a plant-specific prototype costs:

$$\hat{C}_P \equiv c_1(1) + E\left[c_2\right] = c_1(1) + (1-\mu)\sigma_s^2$$

because the unit management will set $(x_b, x_s) = (\tau_b, \theta_s)$.[2]

We refer to $\hat{C}_P$ as the "reduced" manufacturing costs for the plant-specific prototype because they are lower than those associated with the first prototype produced at the lead factory, i.e., $\hat{C}_P < C_P$. This reduction results because the basic dimension can be transferred from the lead factory to the plant.

After the production of its plant-specific prototype, each production unit has acquired knowledge τ_s about the specific dimensions of its production process, such that it is able to fully adapt its production process with respect to both dimensions. Consequently, management at each plant will set $x_s = \tau_s$ such that $E[(\hat{\theta}_s - x_s)^2] = 0$. The costs of serially producing q units of the respective product will then be given by $c_1(q)$.

In Scenario 2, the total costs of producing q units in each plant are thus given by:

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[2] Note that $E[c_2] = (1-\mu)E[(\hat{\theta}_s - x_s)^2] = (1-\mu)\sigma_s^2$ because each production plant already has the information τ_b regarding the basic process.

$$C_{LF}^2 = \underbrace{c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2}_{\text{costs for prototype in LF (stage 1)}} + n \cdot [\underbrace{k_b + c_1(1) + (1-\mu)\sigma_s^2 + c_1(q)}_{\text{total costs for } q \text{ units in each plant (stage 2)}}] = C_P + n\left[k_b + \widehat{C}_P + c_1(q)\right].$$

Scenario 3: High heterogeneity

In this scenario, we assume that $\alpha_2 < \alpha_1 < \eta$, i.e., the heterogeneity between the production plants is so high that neither knowledge about the specific dimensions nor knowledge regarding the basic dimensions of the production process can be effectively transferred from the lead factory to the production plants. In this scenario, each production unit has to produce its own prototype to acquire the knowledge necessary to optimally adapt its production process, and thus, no adaptation costs are incurred. After producing its plant-specific prototype, which costs C_P, each unit has acquired knowledge τ_b and τ_s about the basic and specific dimensions of its production process, respectively, and will then be able to optimally adapt its process. The costs of serially producing q units are then given by $c_1(q)$.

In Scenario 3, the total costs for producing q units in each plant are thus given by:

$$C_{LF}^3 = \underbrace{c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2}_{\text{costs for prototype in LF (stage 1)}} + n \cdot \underbrace{\left[c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2 + c_1(q)\right]}_{\text{total costs for } q \text{ units in each plant (stage 2)}} = C_P + n\left[C_P + c_1(q)\right].$$

4. Results

In this section, we compare the total manufacturing costs under the lead factory concept to the total manufacturing costs in traditional networks for each of the three scenarios. The results are summarized in Proposition 1.

Proposition 1:

(i) The lead factory concept is more efficient than the traditional network structure if and only if

(a) $n \cdot (k_b + k_s) < (n-1) \cdot C_P$ (Scenario 1) and (b) $n \cdot (k_b + \widehat{C}_P) < (n-1) \cdot C_P$ (Scenario 2).

(ii) The traditional network structure is always more efficient than the lead factory concept if neither knowledge about the basic dimension nor knowledge about the specific dimension can effectively be transferred from the lead factory to the production units (Scenario 3).

Proof: See Appendix A.2.

Part (i) of the proposition shows that in Scenarios 1 and 2, the lead factory concept may be more efficient than the traditional network structure.

(a) In Scenario 1, the lead factory concept is more efficient than the traditional network structure if n-times the combined adaptation costs, $k_b + k_s$, of the basic and specific processes are lower than *(n-1)*-times the manufacturing costs C_P of the prototype.

Remember that the prototype has to be manufactured in the traditional network structure in each production plant, whereas in the lead factory concept, it is only manufactured in the lead factory. Moreover, in Scenario 1, knowledge about the basic and specific dimensions of the production process can be effectively transferred from the lead factory to the production units, which can then optimally adapt their production process (after adaptation costs of $k_b + k_s$).

Thus, ceteris paribus, the relative cost advantage of the lead factory concept depends on the following critical factors:

- A higher number n of production plants: This is intuitively clear because the manufacturing costs of the prototype occur in each of the n production plants under the traditional network structure, whereas in the lead factory concept, these costs are incurred only once. As multiple plants profit from the prototyping efforts within the lead factory, the concept effectively reduces the production costs of the prototype by a factor of *(n-1)*. If there are $n = n'$ production plants with $n' \equiv \frac{C_P}{C_P - (k_b + k_s)}$, then both network structures are equally efficient. If $n > n'$, then the lead factory concept is more efficient. Lower adaptation costs for either dimension of the production process (or, equivalently, higher manufacturing costs of the prototype) lead to a lower threshold number *n'*.
- Lower adaptation costs k_b and k_s for the basic and specific dimensions of the production process, respectively: Remember that in the lead factory concept, each manufacturing unit incurs adaptation costs to optimally adapt the production process with respect to each dimension in every production unit. As the cost of each kind of adaption decreases, the more cost efficient the lead factory concept becomes.
- Higher manufacturing costs C_P of the prototype: Because the prototype has to be manufactured in every production unit using the traditional network structure and only once

using the lead factory concept, the cost advantage of the lead factory concept increases with higher C_P.

(b) In Scenario 2, the lead factory concept is more efficient than the traditional network if $n \cdot (k_b + \widehat{C}_P) < (n-1)C_P$. The left-hand side of this inequality represents the adaptation costs k_b for the basic dimension of the production process in each plant and the (reduced) manufacturing costs $\widehat{C}_P$ for a further prototype in each plant (if the production process is only optimally adapted regarding the basic dimensions) times the number n of production plants. If these costs are lower than *(n-1)*-times the (full) manufacturing costs C_P for a prototype, then the lead factory concept is more efficient.

Thus, ceteris paribus, the following factors favor the lead factory over the traditional network structure:

- A higher number n of production plants, lower adaptation costs k_b for the basic dimensions of the production process, and higher (full) manufacturing costs C_P for the prototype: These factors have effects that are similar to those observed in Scenario 1. As in Scenario 1, we compute the threshold number n'' of production plants for which both networks are equivalently efficient as $n'' \equiv \frac{C_P}{C_P - \left(k_b + \widehat{C}_P\right)}$. If $n > n''$, then the lead factory is more efficient than the traditional network structure. Higher (full) manufacturing costs for the prototype (or, equivalently, lower adaptation costs with respect to the basic dimensions of the production process and lower manufacturing costs for the second prototype) result in a lower threshold n'' for which both networks are equivalently efficient.
- Lower manufacturing costs $\widehat{C}_P$ for the second prototype (produced at a production plant) if knowledge about the basic dimensions of the production process can be effectively transferred to the production units: Even though a further prototype has to be built in stage 2 in each production plant using the lead factory concept, manufacturing costs can be reduced due to the available knowledge regarding the basic dimensions of the production process; however, this is not possible using the traditional network structure, as each plant has to incur the full costs C_P of producing the prototype.

- A lower specificity of the production process, i.e., a higher μ. Note that the manufacturing costs $\widehat{C}_P = c_1(1) + (1-\mu)\sigma_s^2$ decrease with the relative importance of the basic dimensions of the production process, which is given by the weight μ. If the production process is primarily characterized by a basic process, then it is clear that the information τ_b about the basic process communicated from the lead factory to the plants is more valuable because it contains important information about how to optimally adapt the production process. It follows that a high μ also renders the lead factory concept more cost-efficient than the traditional network structure.

The lead factory concept is more efficient in Scenario 1 than in Scenario 2 because the adaptation costs k_s with respect to the specific dimensions of the production process are lower than the manufacturing costs $\widehat{C}_P$ of the prototype. In other words, the lead factory concept is most efficient if the heterogeneity between the production plants is low.

Part (ii) of Proposition 1 shows that the lead factory concept can never dominate the traditional network structure in terms of cost efficiency if the heterogeneity between production plants is so high that no relevant knowledge can be effectively transferred to the production plants (Scenario 3). In this case, the lead factory's production of the prototype creates additional costs without providing additional benefits.

5. Discussion and Conclusion

To be successful, a company's network must be able to efficiently generate and implement innovations while simultaneously exploiting the existing product portfolio [27]. We have therefore analyzed two distinct network structures to understand which concept is the most cost-efficient.

The results derived above demonstrate that the implementation of a lead factory concept can be more efficient than a traditional network if the following factors are present:

1. A high number of production plants.
2. Low adaptation costs for the basic and specific dimensions of the production process.
3. High manufacturing costs for the prototype if information about the basic and specific

dimensions of the production process is not available.

4. Low manufacturing costs for the second prototype (produced at a production plant) if information about the basic dimension of the production process is available.
5. The production process is characterized through a low specificity; i.e., the relative importance of the basic dimension of the production process is high.

It is obviously desirable to have a greater the number of production plants that profit from knowledge transfer from an intermediary. The more alike the plants, the easier it is to transfer knowledge and experience from one plant to another; however, this situation is not always present. Companies that produce at high volumes with less variety often produce the same goods in multiple plants with similar production layouts; however, companies that produce at low volumes with more variety often try to bundle their competences, resulting in comparatively fewer plants that share similar competences and technologies. Therefore, for companies who foster a specialization strategy, wherein every plant has the sole responsibility to produce a determined product, the lead factory concept is not as advantageous.

The second factor listed above reflects a common disadvantage of traditional network structures. Within a traditional network structure, R&D employees have to work with multiple plants, which are sometimes distributed across the globe. Therefore, it is possible that knowledge about each of the individual specifications of the production processes and equipment is not as good as that obtained using the lead factory concept; however, many companies that currently use a traditional network structure try to ameliorate this problem with the concept of “design for manufacture and assembly” [28]. Using this concept, the goal is to design the product according to manufacturing requirements. In order to achieve this goal, the manufacturing employees are included into the development process as early as possible. One consequence of this strategy is that plants have to be assigned to a particular product line at an early stage. Following the requirements of this concept allows companies with a traditional network structure to minimize the disadvantage of higher adaptation costs during the production processes.

Manufacturing costs for a prototype greatly differ. For example, in the case of building an alternator, the prototype is often included in the first product to be sold because the labor and material costs can be extremely high; however, industries with lower labor and material costs (e.g., the production of printer boards, drilling machines, or other consumer goods) have different production processes. The cost of a prototype is therefore another important factor to be considered if manufacturing networks are restructured.

The concept of the lead factory is intriguing because the experiences gained during the production of the prototype in the lead factory can be directly shared and discussed with the R&D and manufacturing departments on-site. Depending on the heterogeneity between the production plants, the experiences gained from producing the prototype can be shared, leading to improvements in the plants' manufacturing processes from earlier on. If a second prototype has to be produced at production sites due to greater site heterogeneity, resulting in fewer possibilities to transfer knowledge and experience among the sites, then this second prototype can be produced at lower costs than those typical of traditional networks, wherein the foundational knowledge for prototype production is less established.

Finally, the lead factory concept becomes more efficient as the specificity of a production process decreases; however, many successful companies from developed countries more often follow a strategy of differentiation. Accordingly, their manufacturing processes are likely to be highly specific. This specificity is primarily due to the fact that basic processes are much easier to duplicate than specific processes. The analysis developed herein demonstrates that the lead factory concept becomes relatively more efficient as specificity decreases. This result implies that the relative efficiency of the lead factory concept can be improved as the percentage of the basic processes needed to produce a product increases; however, an ambition toward this simplicity could negatively influence unique selling positions. Manufacturing companies from developed countries are often known for their unique capabilities, such as the ability to fulfill customer needs that are bound to specific processes, which often put them at a competitive advantage. The ultimate result of reducing the degree of specific processes has to be carefully analyzed.

In this study, we highlight the conditions under which the lead factory concept is advantageous for transferring knowledge within an intra-firm network. A key advantage of this concept is the additional knowledge generated within the lead factory through close interaction with R&D. Moreover, only stable processes are transferred to the production plants. Furthermore, the lead factory supports the subsidiaries in the case of any question concerning the production process and the product itself. In sum, these results demonstrate that the lead factory concept has a large potential for achieving a competitive advantage. That said, the factors that influence the potential of the lead factory concept have to be carefully considered. From a theoretical perspective, our analysis clarifies the potential of the lead factory concept; however, we caution readers to consider the factors that render the lead factory concept more or less efficient than the traditional network structure. From a managerial perspective, these results highlight the need to analyze the network structure and to align the structure with the contingency factors. With an aim to improve knowledge transfer, each company has to determine if the specific contingencies that render a lead factory concept more advantageous than the traditional network structure are present.

An interesting avenue for further research in this area would be to empirically test our results. Moreover, it would be interesting to generalize our findings by modeling competition and by allowing for the possibility of producing more than one product. Finally, our model could be extended to more than one period. Introducing temporal dynamics may yield valuable insights into the inter-temporal benefits of the lead factory concept.

Appendix A.

A.1. Proof of Lemma 1

Manufacturing costs C_P for the prototype are composed out of material costs $c_1(1)$ and expected ramp-up and learning costs $c_2(q)$. In order to minimize the expected costs of the second cost component $c_2(q)$, each production plant formally solves the following minimization problem:

$$\min_{(x_b,x_s)} E\left[c_2(q)\right] = \min_{(x_b,x_s)} \left\{\mu E\left[\left(\hat{\theta}_b - x_b\right)^2\right] + (1\text{-}\mu) E\left[\left(\hat{\theta}_s - x_s\right)^2\right]\right\}$$

with $E[\hat{\theta}_b] = \theta_b > 0$, $E[\hat{\theta}_s] = \theta_s > 0$ and $Var[\hat{\theta}_b] = \sigma_b^2 \in (0,\infty)$, $Var[\hat{\theta}_s] = \sigma_s^2 \in (0,\infty)$.

Note that information about the realizations of $\hat{\theta}_b$, given by τ_b, and about $\hat{\theta}_s$, given by τ_s, is not available. Thus, to minimize the expected costs of the basic process, i.e., $\min_{x_b} E\left[\left(\hat{\theta}_b - x_b\right)^2\right]$, each production plant will set $x_b = \theta_b$, such that $E\left[\left(\hat{\theta}_b - \theta_b\right)^2\right] = \sigma_b^2$. Similarly, to minimize the expected costs of the specific process, i.e., $\min_{x_s} E\left[\left(\hat{\theta}_s - x_s\right)^2\right]$, each production plant will set

$x_s = \theta_s$, such that $E\left[\left(\hat{\theta}_s - \theta_s\right)^2\right] = \sigma_s^2$. It follows that the expected costs $E[c_2]$ of the second cost component are given by $E[c_2] = \mu\sigma_b^2 + (1-\mu)\sigma_s^2$. This completes the proof of Lemma 1.

A.2. Proof of Proposition 1

In the traditional network structure, the firm's total manufacturing costs for producing q units in each plant are given by:

$$C_{TN} = n \cdot [c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2 + c_1(q)].$$

In Scenario 1, the firm's total manufacturing costs for producing q units in each plant are given in the lead factory concept by:

$$C_{LF}^1 = c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2 + n \cdot \left[k_b + k_s + c_1(q)\right].$$

We derive $C_{TN} - C_{LF}^1 = (n-1)C_P - n(k_b + k_s)$ with $C_P = c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2$. Thus, the lead factory concept is more cost efficient than the traditional network structure if and only if $n \cdot (k_b + k_s) < (n-1) \cdot C_P$. This completes part (ia) of Proposition 1.

In Scenario 2, the firm's total manufacturing costs for producing q units in each plant are given in the lead factory concept by:

$$C_{LF}^2 = c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2 + n \cdot \left[k_b + c_1(1) + (1-\mu)\sigma_s^2 + c_1(q)\right].$$

We derive $C_{TN} - C_{LF}^2 = (n-1) \cdot C_P - n \cdot (k_b + \widehat{C}_P)$ with $C_P = c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2$ and $\widehat{C}_P = c_1(1) + (1-\mu)\sigma_s^2$. Thus, the lead factory concept is more cost efficient than the traditional network structure if and only if $n \cdot (k_b + \widehat{C}_P) < (n-1) \cdot C_P$. This completes part (ib) of Proposition 1.

In Scenario 3, the firm's total manufacturing costs for producing q units in each plant are given in the lead factory concept by:

$$C_{LF}^3 = c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2 + n \cdot \left[c_1(1) + \mu\sigma_b^2 + (1-\mu)\sigma_s^2 + c_1(q)\right].$$

We derive $C_{TN} - C_{LF}^3 < 0$. Thus, the traditional network structure is always more cost efficient than the lead factory concept. This completes part (ii) of Proposition 1.

References

[1] Benner MJ, Tushman ML. Exploitation, exploration, and process management: the productivity dilemma revisited. Academy of Management Review 2003;28(2):238-256.

[2] Raisch S, Birkinshaw J. Organizational ambidexterity: antecedents, outcomes, and moderators. Journal of Management 2008;34:375-409.

[3] Simon S, Näher U, Lauritzen MD. R&D: Aligning the interface with production, in: Abele E et al. (Eds.). Global production: a handbook for strategy and implementation. Berlin, Heidelberg: Springer-Verlag, 2008.

[4] Bartlett CA, Ghoshal S. Managing across borders: The transnational solution. Boston, MA: Harvard Business School Press, 1989.

[5] Enright MJ, Subramanian V. An organizing framework for MNC subsidiary typologies. Management International Review (MIR) 2007;47(6):895-924.

[6] Ferdows K. Making the most of foreign factories. Harvard Business Review 1997;March-April: 73-88.

[7] Grant RM. Toward a knowledge based theory of the firm. Strategic Management Journal 1996;17:109-122.

[8] Ferdows K. Transfer of changing production know-how. Production and Operations Management 2006;15(1):1-9.

[9] Kogut B, Zander U. Knowledge of the firm, combinative capabilities, and the replication of technology. Organization Science 1992; 3: 383-397.

[10] Spender J, Grant R. Knowledge and the firm: overview. Strategic Management Journal 1996;17:5-9.

[11] Argote L, Ingram P. Knowledge transfer: A basis for competitive advantage. Organizational Behavior and Human Decision Processes 2000;82:150-169.

[12] Brown J. Bridging epistemologies: The generative dance between organizational knowledge and organizational knowing. Organization Science 1996;10:381-400.

[13] Fleming L, Marx M. Managing creativity in small worlds. California Management Review 2006;48(4):6-27.

[14] Granovetter M. Economic action and social structure: the problem of Embeddedness. American Journal of Sociology 1985;91(3):481–510.

[15] Cohen W, Levinthal D. Absorptive capacity: a new perspective on learning and

innovation. Administrative Science Quarterly 1990;35(1):128-152.

[16] Polanyi M. The tacit dimension. Routledge&Kegan Paul 1967.

[17] Polanyi M. Personal knowledge: Towards a post-critical philosophy. Routledge 1998.

[18] Nonaka I. The knowledge-creating company. Harvard Business Review 1991;6:96-104.

[19] Nonaka I. A dynamic theory of organizational knowledge creation. Organization science 1994;5(1):14-37.

[20] Nonaka I., von Krogh G. Perspective, tacit knowledge and knowledge conversion: controversy and advancement in organizational knowledge creation theory. Organization Science 2009;20(3):635-652.

[21] Hopp WJ, Iravani SMR, Liu F. Managing white-collar work: an operations-oriented survey. Production and Operations Management 2009;18(1):1-32.

[22] Szulanski G. Exploring internal stickiness: Impediments to the transfer of best practice within the firm. Strategic Management Journal 1996;17:27-43.

[23] Huang X, Kristal MM, Schroeder RG. Linking learning and effective process implementation to mass customization capability. Journal of Operations Management 2008;26(6):714-729.

[24] Tsai W. Knowledge transfer in intraorganizational networks: Effects of network position and absorptive capacity on business unit innovation and performance. Academy of Management Journal 2001;44(5):996-1004.

[25] Birkinshaw J, Gibson CB. Building ambidexterity into an organization. MIT Sloan Management Review 2004:Summer;47-55.

[26] Deflorin P, Dietl H, Scherrer-Rathje M. Die Leitfabrik: Innovativ und Effizient zugleich?. ZFO 2010; in press.

[27] March JG. Exploration and exploitation in organizational learning. Organization Science 1991;2(1):71-85.

[28] Boothroyd G, Dewhurst P, Knight WA. Product design for manufacture and assembly. New York, NY: Marcel Dekker, 2001.