

The Interaction Between Boundary Spanning and Intra-Unit Knowledge Networks: Differentiation of R&D organizations and Knowledge Transfer

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Abstract

Innovation requires not only exploitation of existing knowledge but also exploration of new knowledge across boundaries. However, when firms differentiate their R&D organizations and different norms and languages are established within each unit, it could become more difficult for inventors to effectively acquire knowledge from other units. Prior research has focused on boundary spanners (BSs) to solve difficulties in inter-unit knowledge transfer. Furthermore, due to the differentiation of R&D organizations, knowledge networks form between knowledge elements within each unit, and knowledge transfer from BSs to unit members may depend on the positions of the knowledge elements held by BSs within intra-unit knowledge networks. Therefore, this study examined how the interaction between inventors' boundary spanning and the positions of their knowledge elements within intra-unit knowledge networks influences knowledge transfer. The analysis revealed the following points. First, the interaction between inventors' boundary-spanning and their intra-unit knowledge centrality promotes knowledge transfer to unit members. Second, the interaction between inventors' boundary-spanning and

the extent to which they bridge intra-unit knowledge structural holes hinders knowledge transfer to unit members. These results suggest that while BSs play a crucial role in facilitating knowledge sharing across units, the positions of their knowledge elements within intra-unit knowledge networks influence knowledge transfer mediated by BSs.

Keywords

boundary spanner, knowledge networks, differentiation of R&D organizations, knowledge transfer

1. Introduction

Innovation requires not only the exploitation of existing knowledge but also the exploration of new knowledge across boundaries (Tushman, 1977; March, 1991). Firms with multiple products and businesses tend to differentiate their research and development (R&D) organizations into units such that inventors who possess related knowledge are grouped into the same units. Each unit then develops a dominant organizational norm that allows unit members to share and utilize knowledge more efficiently (Dougherty, 1992; Tushman, 1977). However, different organizational norms hinder inventors from effectively acquiring knowledge from other units (Dougherty, 1992; Carlile, 2004). Prior research has focused on boundary spanners (BSs) to solve difficulties in inter-unit knowledge transfer (Tushman, 1977; Tortoriello et al., 2012; Mell et al., 2022). In R&D activities, BSs acquire knowledge from other units, translate it, and transmit it to their unit members (Tushman 1977).

When knowledge and knowledge are combined, new knowledge is created (Kogut and Zander, 1992; Nonaka and Takeuchi, 1995). Due to the differentiation of R&D

organizations, not only does different knowledge accumulate in each unit, but the way knowledge is combined may also vary by unit. Many knowledge elements exist within a company, and as connections form between them, knowledge networks within a unit are formed. For example, suppose there are two units, A and B, and both possess knowledge elements a and b. It is possible that in Unit A, knowledge elements a and b are combined, whereas in Unit B, they are not. Previous research has shown that the specific knowledge elements possessed by inventors influence creation and transfer of knowledge (Wang et al. 2014; Brennecke and Rank, 2017; Markus et al., 2025). However, prior research has not taken into account the differentiation within R&D organizations. Given this, knowledge transfer from BSs to unit members also depends on the positions of the knowledge elements held by BSs within intra-unit knowledge networks.

Therefore, this study examines Company A, a major Japanese audio electronics manufacturer with R&D organizational and innovation process characteristics typical of large corporations, to investigate how the interaction between inventors' boundary-spanning and the positions of their knowledge within intra-unit knowledge networks influences knowledge transfer. The analysis revealed the following points. First, the interaction between inventors' boundary spanning and the centrality of their knowledge within intra-unit knowledge networks promotes knowledge transfer to unit members. Second, the interaction between inventors' boundary spanning and the extent to which their knowledge bridge structural holes within intra-unit knowledge networks hinders knowledge transfer to unit members. These results suggest that while boundary spinners play a crucial role in knowledge sharing across units, the position of their knowledge within intra-unit knowledge networks influences knowledge transfer through boundary spinners.

2. Theoretical Background and Hypotheses

2-1 Differentiation of R&D Organizations and Inter-unit Knowledge Transfer

Firms with multiple products or businesses tend to differentiate their R&D organizations by unit, with inventors who possess related knowledge within the same unit (Tushman, 1977). Consequently, while different knowledge accumulates in each unit, distinct norms and languages also form within each unit (Tushman, 1977; Dougherty, 1992). Inventors seek to acquire knowledge from other inventors and create new knowledge in accordance with these norms and languages. The norms formed within each unit tend to be more specific and shared than those formed across the entire firm (Harris, 1994). Consequently, inventors are more strongly influenced by unit norms than by firm-wide norms. While these unit-specific norms facilitate knowledge transfer within a unit, they could hinder inter-unit knowledge transfer because they make it difficult for inventors to understand knowledge from other units (Tushman, 1977; Dougherty, 1992). For example, ideas that align with a unit's behavioral norms are more likely to be accepted, while those that deviate from them are less likely to be accepted. Furthermore, since knowledge from other units does not necessarily align with a unit's norms, knowledge sharing across units becomes difficult (Dougherty, 1992; Schilling, 2005). There are significant advantages to acquiring knowledge from other units. As different norms are formed within each unit, similar knowledge continues to accumulate. While this knowledge is familiar to unit members, it is new to members of other units. Consequently, inventors can more easily acquire novel knowledge from other units that is not available within their own units (Tushman, 1977; Miller et al., 2007). Furthermore, innovations based on such distant knowledge enable the recombination of new knowledge, thereby exerting a greater influence on subsequent technological development (Rosenkopf and Nerkar, 2001; Miller et al., 2007). Consequently,

because knowledge from other units is highly novel, inventors can create new knowledge by acquiring such knowledge. To summarize the above discussion, while knowledge from other units offers a high degree of novelty, it is difficult to absorb. Prior research has focused on boundary spanners (BSs) to solve difficulties in inter-unit knowledge transfer (Tushman, 1977; Tortoriello et al., 2012; Mell et al., 2022).

2-2 Characteristics of Boundary Spanners

BSs are responsible for acquiring knowledge from other units and transmitting it to their members (Tushman, 1977). Therefore, BSs have two roles: knowledge acquirers and providers. We reviewed previous studies on each role.

First, studies on BSs as knowledge acquirers have analyzed BSs' characteristics that enable them to effectively acquire knowledge from other units (Tortoriello et al., 2012; Nakauchi et al., 2017). Tortoriello et al. (2012) found that when BSs have strong ties or cohesive networks with members of other units, trust is more likely to be built, and knowledge transfer between units is facilitated. Furthermore, they discovered that when BSs have a wide range of networks, they could absorb different types of knowledge, thus facilitating the acquisition of knowledge from other units. Nakauchi et al. (2017) focused on the knowledge transfer between functional units and showed that the effects of strong ties and cohesive networks between BSs and members of other units depend on knowledge characteristics. This discussion indicates that BSs must be familiar with the organizational norms of other units to acquire knowledge from them, and such familiarity requires close networks with members of other units and high absorptive capacity. In other words, even if BSs are connected to members of other units, they will not necessarily be able to absorb knowledge if they do not have close networks or absorptive capacity.

Second, existing studies have explored BSs as knowledge providers. BSs can translate the knowledge of other units because they are familiar with these units' organizational norms (Tushman, 1977). BSs are not only connected with other units but also have many connections with members within their units. Therefore, they are called internal communication stars (Tushman, 1977; Tushman and Scanlan, 1981). Unit members frequently consult with BSs because of their advanced technological skills (Allen, 1977)¹. When BSs have such networks in their units, the knowledge they acquire from other units is efficiently diffused within their own units. Moreover, recent studies have shown that BSs' meta-knowledge, or knowledge of who knows what, encourages knowledge integration because they can transmit the knowledge of other units to members who are most related to it (Mell et al., 2022). As BSs are internal communication stars, they are thus rich in meta-knowledge. However, even if BSs are internal communication stars connected with many unit members, their knowledge may not always be transferred effectively.

Thus, research on BSs has primarily focused on their social networks, and their effects have been clarified. However, the relationship between boundary spanning and knowledge networks remains unclear.

2-3 Knowledge Networks

Individuals' social networks influence their performance and behavior (Phelps et al., 2012). As discussed in the previous section, social networks of BSs have been paid attention to, and it has been demonstrated that they influence their performance. Meanwhile, recent research has pointed out that inventors are embedded not only in social networks but also in knowledge networks (Wang et al., 2014; Brennecke and Rank, 2017). While nodes of social networks are

¹ Allen (1977) focused on gatekeepers who are individuals with ties to the outside of the firm and indicated that they are communication stars within the firm, similar to BSs.

individuals, nodes of knowledge networks are knowledge elements (Wang et al., 2014). Knowledge elements are socially defined categories that include a set of tentative conclusions held by the research community in a scientific or technical field regarding the facts, theories, methods, and procedures surrounding a specific subject (Wang et al., 2014). While connections within social networks indicate relationships between individuals, connections within knowledge networks indicate relationships among knowledge elements regarding a subject (Wang et al., 2014). Each firm possesses its knowledge networks, which can be described as the history of combinations within the firm regarding which knowledge elements are related and, conversely, which are not (Carnabuci and Bruggeman, 2009). Within such knowledge networks, each knowledge element holds a unique position. For example, just as there are central individuals in social networks who are connected to many others, there are also central knowledge elements in knowledge networks that are connected to many other knowledge elements. Conversely, just as there are non-central individuals, there are also non-central elements.

Inventors are also connected to multiple knowledge elements through their educational and work experiences (Brennecke and Rank, 2017). Previous research has shown that the knowledge elements possessed by inventors occupy unique positions within a firm's knowledge networks and influence their performance. (Wang et al., 2014; Brennecke and Rank, 2017). As R&D organizations become more specialized, not only does each unit accumulate different knowledge, but the way that knowledge is combined may also vary by unit. Figure 1 illustrates knowledge networks of units 1 and 2 within Company A, the subject of this analysis. When a knowledge element is connected to another knowledge element, the two are linked by a straight line. First, knowledge networks differ between units 1 and 2. For example, while knowledge element X (H04L) is utilized in both units, how it connects to other knowledge elements is different. In unit 1, knowledge element X is connected to 14 other knowledge elements, whereas

in unit 2, it is connected to only 3 other knowledge elements. Suppose two inventors, A and B, in unit 1 possess three knowledge elements. Inventor A possesses knowledge elements 1–3. Knowledge element 1 is connected to three other knowledge elements, and its knowledge centrality (degree centrality) within the unit is 3. This indicates that this element has been combined with three other knowledge elements within the unit in the past. Knowledge element 2 has a knowledge centrality of 5, which is greater than that of knowledge element 1. Therefore, knowledge element 2 is more likely to be combined with other knowledge elements than knowledge element 1. Knowledge element 3 has a knowledge centrality of 2. Inventor A’s average intra-unit knowledge centrality is 3.3, indicating that Inventor A possesses knowledge elements that have, on average, been combined with 3.3 other knowledge elements within the company in the past. Similarly, Inventor B possesses knowledge elements 4–6, and Inventor B’s average intra-unit knowledge centrality is 2.3, which is lower than that of Inventor A. Therefore, the knowledge elements possessed by Inventor A are, on average, more likely to be combined with other knowledge elements than those possessed by Inventor B.

It has been demonstrated that the position of inventors’ knowledge elements within such knowledge networks influences knowledge creation (Wang et al., 2014; Guan and Liu, 2016; Markus et al., 2025) and knowledge transfer (Brennecke and Rank, 2017)². Therefore, the performance of BSs may also depend on the position of their knowledge elements within the knowledge networks of their units.

Insert Figure 1 about here

² Brennecke and Rank (2017) conduct their analysis by focusing on work-related advice. Furthermore, Guan and Liu (2016) demonstrate that individuals’ positions within a firm’s knowledge networks influence innovation.

2-4 Boundary Spanning, Knowledge Networks and Knowledge Transfer

Knowledge from other units is a crucial source for creating new knowledge due to its high novelty, yet it is difficult to absorb. However, BSs can acquire knowledge from other units, translate it for unit members, and transmit it. Consequently, unit members can acquire knowledge from other units through BSs in the same unit without having direct connections to other units (Tushman, 1977; Mell et al., 2022).

In this study, we hypothesize that whether BSs' knowledge is utilized within the unit depends on the position of their knowledge elements within intra-unit knowledge networks. Below, we derive hypotheses by focusing on two characteristics: knowledge centrality and knowledge structural holes. First, when inventors possess central knowledge elements within intra-unit knowledge networks, their knowledge elements have been combined with many other knowledge elements within the unit in the past (Wang et al., 2014). Such knowledge elements are easy for unit members to combine with their own knowledge elements, so that they are likely to be utilized within the unit (Brennecke and Rank, 2017). Given this, when BSs possess central knowledge elements within the unit, they are expected to be utilized within the unit because they possess knowledge from other units and include knowledge elements that are easy to combine with other knowledge elements. On the other hand, when BSs possess non-central knowledge elements, unit members will likely perceive them as highly novel other knowledge elements, but find it difficult to combine them with their own knowledge elements.

While the discussion above focuses on the role of BSs as knowledge providers, BSs also play the role of knowledge acquirers. When inventors possess central knowledge elements within a unit, they expect that their knowledge elements can be combined with other knowledge elements. Such inventors are likely to actively explore new knowledge elements (Wang et al., 2014). Although BSs are connected to other units, they cannot necessarily acquire knowledge

from them due to differences in norms and language (Dougherty, 1992). When BSs possess central knowledge elements within the unit, they can overcome such barriers and actively explore and acquire knowledge from other units. Knowledge from other units acquired by such BSs is likely to be considered beneficial to unit members. Conversely, if BSs possess non-central knowledge elements in the unit, these elements are difficult to combine with other knowledge elements, so BSs are unlikely to actively explore knowledge from other units. Therefore, centrality within intra-unit knowledge networks is expected to have a positive effect on both the knowledge provision and acquisition roles of BSs.

Hypothesis 1

The interaction between inventors' boundary spanning and their centrality within intra-unit knowledge networks promotes knowledge transfer to unit members.

Next, when inventors possess knowledge elements that bridge structural holes within intra-unit knowledge networks, their knowledge elements connect previously unconnected knowledge elements (Burt, 1992; Wang et al., 2014). Because such knowledge elements provide unit members with opportunities to combine knowledge that has not yet been utilized within the unit (Brennecke and Rank, 2017). Given this, when BSs possess knowledge elements that bridge structural holes in the unit, they hold knowledge from other units, and this knowledge provides opportunities to combine knowledge that has not yet been utilized within the unit. However, we expect that such knowledge will not be readily utilized within the unit. This is because such knowledge elements are highly novel to unit members, making them difficult to understand (Cohen and Levithal, 1990). Conversely, if BSs possess knowledge elements that form redundant networks within the unit, they will be novel to unit members but easier to understand due to their deep connections with other knowledge elements.

The above discussion focuses on the role of BSs as knowledge providers, but BSs also play the role of knowledge acquirers. When inventors possess knowledge elements that bridge structural holes within a unit, the networks form a non-redundant structure, resulting in fewer constraints when searching for new ideas. Such inventors are able to freely explore new knowledge (Guan and Liu, 2016). However, BSs may not necessarily be able to acquire knowledge from other units due to differences in norms and language (Dougherty, 1992). When BSs possess knowledge elements that bridge structural holes within the unit, there are few constraints on the search for new ideas, allowing them to overcome such obstacles and actively explore and acquire knowledge from other units. However, because the knowledge acquired by such BSs may be very novel to unit members, it would be difficult for them to understand it. When BSs possess central knowledge elements within the unit, they try to explore knowledge in other units that can be easily combined with their knowledge elements. On the other hand, when BSs possess knowledge elements that bridge structural holes within the unit, they try to seek entirely new knowledge in other units. Thus, structural holes in intra-unit knowledge networks are expected to have a negative impact on both the knowledge provision and acquisition roles of BSs.

Hypothesis 2

The interaction between innovators' boundary-spanning and the extent to which they bridge structural holes within intra-unit knowledge networks hinders knowledge transfer to unit members.

3. Empirical Analysis

3-1 Data

Many previous studies on knowledge creation and transfer have used patent data. While patent data have advantages in creating variables of knowledge creation and transfer and inventor networks, which are the focus of this study, they alone make it difficult to identify inventors' organizational affiliations within firms. Therefore, prior studies using patent data have paid little attention to the differentiation of R&D organizations. To address this limitation, we collaborated with a major Japanese audio electronics firm and obtained detailed data on the organizational affiliations of its inventors.

Company A was selected for our analysis for three reasons. First, it has more than 1,000 engineers and applies for approximately 400–600 patents annually, giving it strong technological capabilities. Company A is a global company whose products are sold worldwide, and some of its products have the largest market share in the world. Second, the company has eight product-based units within its R&D organizations. We conducted interviews with the chief of the development department and 20 engineers. According to the chief of the development department, the engineers tended to be good at deepening their knowledge but not at expanding it. One engineer said, “I don't know anything about other units because they are like different companies.” Since each unit had a different approach to enhancing product value, unit norms are likely to form within each unit. Third, while the company has a long history as a major audio electronics manufacturer and has accumulated much knowledge, the chief of the development department identified the integration of knowledge across units as a major issue. The company recently established a large research institute to facilitate communication between different units. While the company's R&D organization was becoming increasingly specialized, the need for integration between units emerged. In this way, Company A has an R&D organization and innovation process that is typical of large companies. However, it has the special characteristic

of having few personnel transfers between units, which is desirable as an analysis target for inter-unit knowledge transfers.

Therefore, in this study, Company A provided data on inventors and the units to which they belonged in patents filed with the Japan Patent Office between 2007 and 2016. Based on the application numbers, we connected to the IIP Patent Database (Goto and Motohashi, 2007) and EPO Worldwide Patent Statistical Database (PATSTAT) to obtain bibliographic information for each application.

3-2 Variables

Dependent Variable

We used the number of citations of the focal inventor's patent by other patents as a proxy for knowledge transfer (Paruchuri, 2010; Paruchuri and Eisenman, 2012)³. The number of observations was based on the inventor and year, and the period for measuring the frequency of citations was 2012–2016. The number of inventors was 577. For example, if a patent filed by an inventor was cited from within the unit once in 2012 and twice in 2014, the dependent variable would be 1 for 2012, 2 for 2014, and 0 for the other periods.

Figure 2 illustrates an overview of the analysis, focusing on Inventor A who belongs to unit 1. First, inventor A has co-invented with inventor B in unit 2, and they are thus connected. Therefore, inventor A is a BS linking two different units. Furthermore, inventor A possesses three knowledge elements, each of which occupies a position within the unit's knowledge networks. As previously mentioned, the dependent variable is the number of citations. This has three characteristics. First, since this study focuses on knowledge transfer from BSs to their unit

³ The number of patent citations is considered a measure of knowledge flow, including noise (Jaffe et al., 2000a; Jaffe et al., 2000b), and has been used in many studies focusing on knowledge transfer between and within firms. In addition, self-citations on an inventor basis are excluded in this study.

members, the number of citations is limited to citations within the unit, excluding citations from other units. In Figure 1, inventor A's patent is cited by inventor C's patent, who belongs to the same unit 1, indicating knowledge transfer from inventor A to inventor C. Second, both the citing patent of inventor C and the cited patent of inventor A often have multiple co-inventors. Therefore, if the two patents in a citation relationship share the same inventors, it means self-citation and is excluded from the data. Third, patent citations include inventor citations where inventors cite and examiner citations where examiners cite (Alcácer et al., 2009). This study utilizes only inventor citations because citations made by inventors as prior art are considered a more appropriate proxy for knowledge flow than citations made by examiners for purposes such as rejection decisions⁴.

Insert Figure 2 about here

Explanatory Variables

(1) Boundary Spanning

Some prior studies identified BSs based on the frequency of communication with other units (Tushman, 1977; Tushman and Scanlan, 1981). However, this study does not directly measure communication with other units but focuses on co-inventions with other units, which are less frequent. If inventors have a co-inventor in another unit, they are considered engaged in boundary-spanning activities. Furthermore, the greater the number of units to which a co-

⁴ While previous studies have counted only the citations after patent registration as the dependent variable (Nerkar and Paruchuri, 2005), we also counted citations before patent registration.

inventor belongs, the higher the degree of boundary-spanning activity and the greater the potential for acquiring novel knowledge. Therefore, we constructed a variable of *boundary spanning*: 0 indicates no co-inventors from other units in the past three years, 1 indicates co-inventors from one other unit in the past three years, and 2 indicates co-inventors from two or more other units in the past three years (Fleming and Waguespack, 2007)⁵.

(2) Intra-unit Knowledge Centrality

While previous research on knowledge networks has focused on knowledge networks within a firm, this study focuses on knowledge networks within units. *Intra-unit knowledge centrality* indicates the average extent to which the knowledge elements possessed by an inventor are combined with other knowledge elements in past inventions within the unit (Wang et al., 2014), and was calculated using the following procedure. First, we constructed an intra-unit knowledge network for each IPC subclass based on patents filed over the past three years by the unit to which the inventor belongs. When a firm files a patent for an invention, an IPC is assigned. In this study, these IPC subclasses were treated as knowledge elements, and the relevant information was collected from Patstat. Furthermore, when multiple IPC subclasses are assigned to a single patent application, they are considered to be connected, thereby forming an intra-firm knowledge network. Based on patents filed over the past three years, the degree centrality of each IPC subclass was calculated using UCINET VI (Borgatti et al., 2002). Since inventors may possess multiple knowledge elements, we calculated the average knowledge centrality for each inventor based on patents filed over the past three years. For example, if the dependent variable is 2016, we use the average knowledge centrality of the IPC subclasses

⁵ Company A has inventors outside of the R&D organizations (production, sales, etc.), and their knowledge is considered important for innovation. Therefore, we included units other than the R&D organizations in the list of units to which co-inventors belong. In addition, some inventors did not have co-inventors in their units and were unlikely to play a role in boundary-spanning activities. Therefore, inventors with no co-inventors in the unit were assigned a value of 0.

contained in patents filed between 2013 and 2015.

(3) Intra-unit Knowledge Structural Holes

Intra-unit knowledge structural holes indicates the average extent to which knowledge elements tied to an inventor's knowledge elements are disconnected, without being combined in previous inventions (Wang et al., 2014). Similar to knowledge centrality, its calculation involves several steps. First, using patents filed by Company A over the past five years, the average level of structural holes for each IPC subclass was calculated using UCINET VI (Borgatti et al., 2002). Since inventors may possess multiple knowledge elements, the average level of knowledge structural holes was calculated for each inventor based on patents filed over the past three years. In this study, we used the constraint index proposed by Burt (1992) to calculate knowledge structural holes and subtracted the constraint index from 2 (Lee, 2010; Wang et al., 2014).

Control Variables

In the regression analysis, we include several control variables as follows. The first variable is the number of citations within a unit and other units in the previous year (*prior intra-unit citations*) (Paruchuri, 2010). It is a lagged dependent variable. The second variable is the number of *prior patent applications* (Paruchuri, 2010)⁶. The presence of more patent applications creates more opportunities for inventors to be cited by others within a firm. The third variable is the average *number of claims* (Nerkar and Paruchuri, 2005; Paruchuri, 2010). Other inventors tend to perceive inventors with a higher number of claims as possessing high-quality knowledge. The fourth variable is the average number of *citations made* by the focal

⁶ The number of partial patent applications divided by the number of inventors was used.

inventor (Nerkar and Paruchuri, 2005; Paruchuri, 2010). Other inventors are likely to assume that a higher number of citations signifies a richer knowledge base. The fifth variable is the number of outside co-inventors (*external collaborators*) (Paruchuri, 2010). Inventors perceive inventors with external collaborators as possessing high-quality knowledge. The sixth variable is patenting *tenure*, measured as the number of years between the application year for the inventor's first patent and the preceding year (Paruchuri, 2010; Wang et al., 2014). The seventh variable is the mean of the difference between year t and the application year of the inventor's applications (*age of patents*) (Nerkar and Paruchuri, 2005; Paruchuri, 2010). The eighth variable is the centrality of the inventor's co-application networks. The more an inventor is connected to other inventors, the greater their access to knowledge, which improves the quality of their knowledge and makes it more likely to be cited. Similar to knowledge centrality, we use degree centrality in the unit. The ninth and tenth factors are *unit and year dummies*. The basic statistics and correlation coefficients are summarized in Tables 1 and 2, respectively. *Intra-unit knowledge centrality* and *structural holes* are centralized.

Insert Table 1 about here

Insert Table 2 about here

Analysis

The dependent variable is count data, but since the simple Poisson model makes the strong assumption that the mean and variance are equal, we utilize the negative binomial model (Cameron and Trivedi, 1998). Next, since this study focuses on the differentiation of R&D organizations, we use unit fixed effects to control for the effects of unit characteristics. Furthermore, while the negative binomial model assumes individuals are independent, inventors belonging to the same unit may be more similar to each other than to inventors from different units. In analyzing knowledge transfer, since we utilize longitudinal data, inventors have multiple observations. To address two types of within-group correlation, we use the standard errors clustered by units (Cameron and Miller, 2015).

Furthermore, robustness checks are performed using two methods. First, since boundary spanning of the independent variable may be endogenous, we adopt the control function approach (Wooldridge, 2010). In the first stage, *boundary spanning* is regressed on the breadth of collaborators' expertise, the number of external co-inventors, the size of the unit, the mean boundary spanning of the unit, and year dummies using the ordered probit model, and the approximate residual is calculated (see results in the Appendix)⁷. In the second stage, we estimate the negative binomial model that included it in the second stage. Second, since the number of clusters (units) in this study is small (8 units), cluster-robust standard errors may be problematic (Cameron and Miller, 2015). Therefore, we perform the robustness check using the multilevel negative binomial model with random intercepts for units and inventors (Snijders and Bosker, 2012; McNeish and Stapleton, 2016).

4. Analysis Results

Table 3 summarizes the estimation results. Model 1 includes only control variables and *prior*

⁷ To exclude the influence of the focal inventor, we calculated the mean boundary spanning of other members within the unit.

intra-unit citations, *prior patent applications*, and *external collaborators* are all significantly positive at the 1% level. In addition, *tenure* and *collaboration network centrality* are significantly positive at the 5% level. In Model 2, three explanatory variables are added, but are not statistically significant. In Model 3, an interaction term between *boundary spanning* and *intra-unit knowledge centrality* is added, but it is not statistically significant. In Model 4, the interaction term between *boundary spanning* and *intra-unit knowledge centrality* is replaced with an interaction term between *boundary spanning* and *intra-unit knowledge structural holes*, which is not statistically significant. Model 5 includes two interaction terms, and the interaction term between *boundary spanning* and *intra-unit knowledge centrality* is significantly positive at the 1% level, while the interaction term between *boundary spanning* and *intra-unit knowledge structural holes* is significantly negative at the 5% level, supporting both Hypothesis 1 and Hypothesis 2. Model 6 utilizes the negative binomial model that accounts for endogeneity, and the results of the interaction terms remain the same. Furthermore, Model 7 utilizes the multilevel negative binomial model for a robustness check, and the results are similar. Therefore, the above results can be considered robust.

In Models 5 and 7, the main effect of *boundary spanning* is significantly positive. This indicates that, for inventors with average *intra-unit knowledge centrality* and *knowledge structural holes*, *boundary spanning* has a positive effect on knowledge transfer to unit members. Furthermore, in Models 5 and 7, the main effect of *intra-unit knowledge structural holes* is significantly positive. This indicates that, for inventors who do not bridge unit boundaries and have average *intra-unit knowledge centrality*, *intra-unit knowledge structural holes* have a positive effect on knowledge transfer to unit members.

Figure 3 illustrates the relationship between *boundary spanning* and knowledge transfer across different levels of *intra-unit knowledge centrality*, based on Model 5 in Table 3. When *intra-unit knowledge centrality* is high (mean minus one standard deviation), the effect

of *boundary spanning* on knowledge transfer is positive. Figure 4 illustrates the relationship between *boundary spanning* and knowledge transfer across different levels of intra-unit knowledge *structural holes*, based on Model 5 in Table 3. When *intra-unit knowledge structural holes* are low (mean minus one standard deviation), the effect of *boundary spanning* on knowledge transfer is positive. In both cases, the effect is stronger when inventors span multiple units. This would be because, while inventors can acquire more novel knowledge in such situations, it is not easy for unit members to absorb that knowledge.

Insert Table 3 about here

Insert Figure 3 about here

5. Summary

Innovation requires not only exploitation of existing knowledge but also exploration of new knowledge across boundaries (Tushman, 1977; March, 1991). However, when firms differentiate their R&D organizations and different norms and languages are established within each unit, it could become more difficult for inventors to effectively acquire knowledge from other units. Prior research has focused on boundary spanners (BSs) to solve difficulties in inter-unit knowledge transfer (Tushman, 1977; Tortoriello et al., 2012; Mell et al., 2022). Furthermore, due to the differentiation of R&D organizations, knowledge networks form between knowledge elements within each unit, and knowledge transfer from BSs to unit

members may depend on the positions of the knowledge elements held by BSs within intra-unit knowledge networks. Therefore, this study examined how the interaction between inventors' boundary spanning and the positions of their knowledge elements within intra-unit knowledge networks influences knowledge transfer.

The analysis revealed the following points. First, the interaction between inventors' boundary-spanning and their intra-unit knowledge centrality promotes knowledge transfer to unit members. Second, the interaction between inventors' boundary-spanning and the extent to which they bridge intra-unit knowledge structural holes hinders knowledge transfer to unit members. These results suggest that while BSs play a crucial role in facilitating knowledge sharing across units, the positions of their knowledge elements within intra-unit knowledge networks influence knowledge transfer mediated by BSs.

The following implications may be drawn from this study. First research on knowledge networks has shown that the specific knowledge elements possessed by inventors influence creation and transfer of knowledge (Wang et al., 2014; Brennecke and Rank, 2017; Markus et al., 2025). However, such studies do not take into account the differentiation of R&D organizations. The analysis results suggest that differentiation of R&D organizations not only leads to the accumulation of different knowledge in each unit but also results in the formation of distinct knowledge networks across units, which may influence knowledge transfer within the firm.

Second, previous research pointed out that central knowledge elements are more likely to be utilized by other inventors (Brennecke and Rank, 2017). The analysis revealed that the interaction between inventors' boundary spanning and their knowledge centrality within intra-unit knowledge networks has a positive effect. Even if BSs acquire knowledge from other units, if they possess knowledge elements that are not frequently utilized within their unit, that knowledge becomes difficult for unit members to utilize. Therefore, it is desirable for BSs to

possess knowledge elements that can be easily combined with other knowledge elements within the unit.

Third, the analysis revealed that the interaction between inventors' boundary spanning and the extent to which they bridge structural holes within intra-unit knowledge networks has a negative effect. If BSs possess knowledge elements that connect previously unconnected knowledge elements, they can provide new combination opportunities for unit members. However, such knowledge elements are difficult to understand. On the other hand, the main effect of intra-unit knowledge structural holes was positive. In other words, for inventors who do not bridge unit boundaries and possess average intra-unit knowledge centrality, the effect of intra-unit knowledge structural holes on knowledge transfer to unit members is positive. Given the differentiation of R&D organizations, it is difficult for unit members to find new combination opportunities within their unit. However, inventors who possess knowledge elements that bridge knowledge structural holes within the unit provide new combination opportunities. Given these points, the desirable knowledge elements differ between BSs and non-BSs in terms of knowledge transfer to unit members. BSs should possess knowledge elements with redundant networks, while non-BSs should possess knowledge elements that bridge knowledge structural holes. This suggests that managers need to employ different management approaches for BSs and non-BSs.

Finally, we will discuss the limitations of this study. First, because this study focuses on a single firm, it does not account for the characteristics of the firm's knowledge networks (Guan and Liu, 2016). A firm's knowledge networks can be described as the history of internal combinations of knowledge elements—specifically, which elements are related and, conversely, which are not (Carnabuci and Bruggeman, 2009). Therefore, knowledge networks formed within firms are likely to differ across firms. For example, firms with many highly central knowledge elements likely have many knowledge elements that have been combined with

numerous other knowledge elements in the past. Consequently, the role of BSs may not be particularly significant. On the other hand, firms with many knowledge elements characterized by low knowledge centrality contain a larger number of elements that have not previously been combined with other knowledge elements within the firm. Therefore, the role of BSs is expected to become more important in such firms. The Second concerns another role of BSs. BSs acquire knowledge from other units and transmit it to unit members (Tushman, 1977). Thus, they have two roles: knowledge acquirers and providers. However, BSs do not merely convey knowledge acquired from other units to their own unit and can also recombine it with their own knowledge to create new knowledge (Tang et al, 2025). Thus, they also serve as knowledge creators. Consequently, the type of knowledge elements that BSs possess may influence not only knowledge transfer but also knowledge creation.

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Figure 1: An Example of Knowledge Networks in Two Units

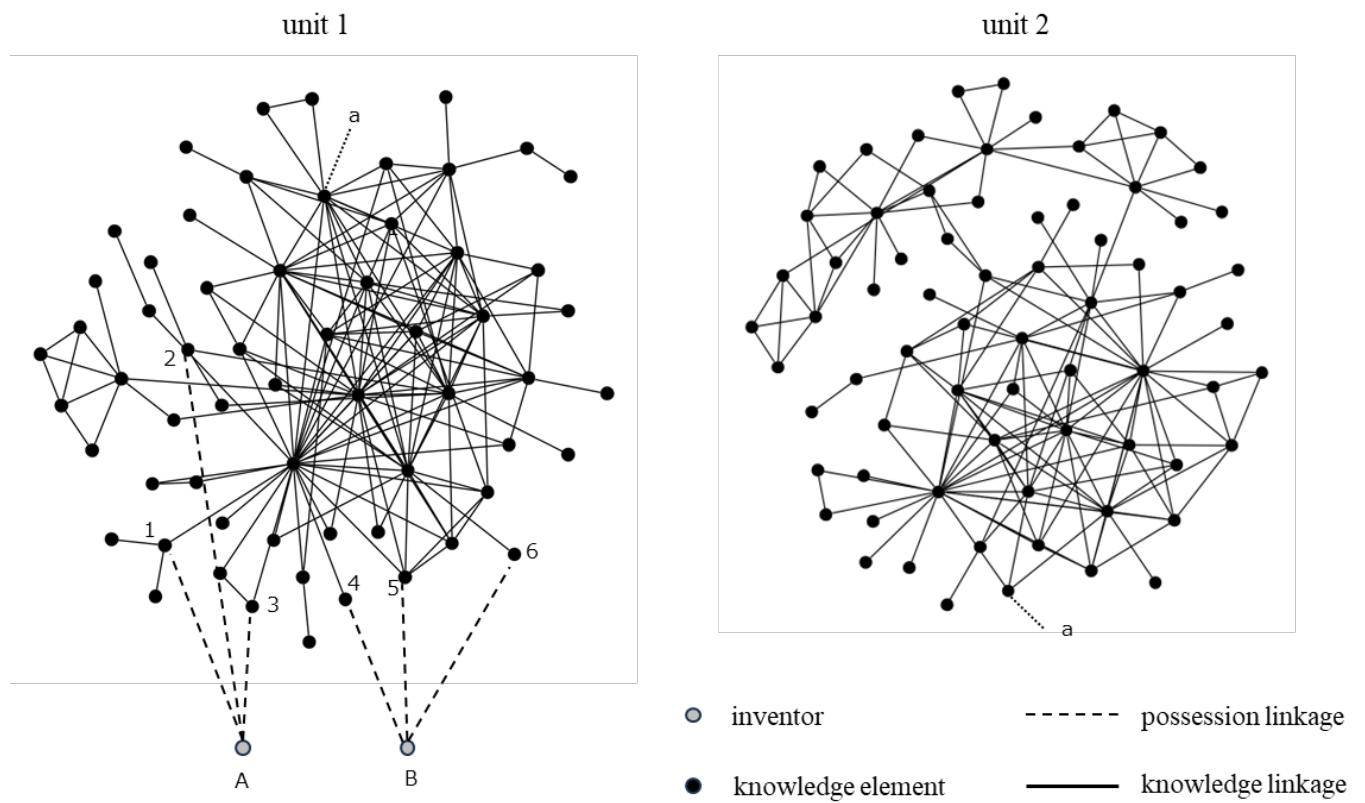


Figure 2: Knowledge Transfer through a Boundary Spanner

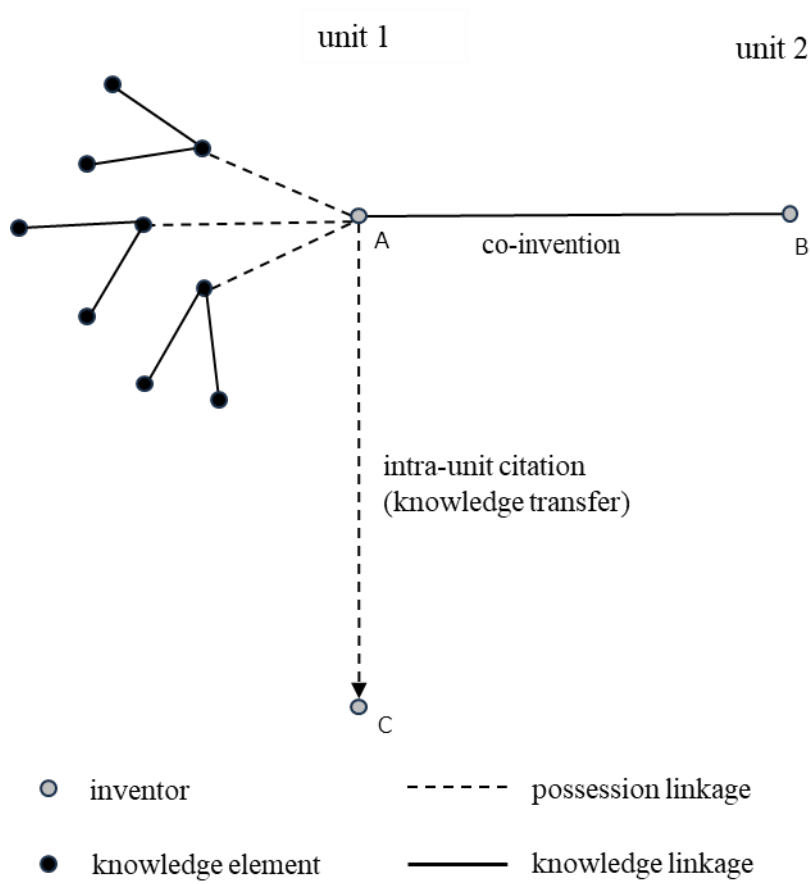


Table 1: Descriptive Statistics (N=1,951)

	Variable	Mean	SD	Min	Max
(1)	Intra-unit citations	0.16	0.63	0.00	7.00
(2)	Prior intra-unit citations	0.14	0.62	0.00	7.00
(3)	Prior patent applications	1.85	1.20	0.11	6.22
(4)	Number of claims	5.14	1.36	1.00	13.00
(5)	Citations made	1.23	0.60	0.00	5.50
(6)	External collaborators	0.10	0.54	0.00	9.00
(7)	Tenure	13.10	9.50	1.00	40.00
(8)	Age of patents	3.65	1.56	0.29	9.00
(9)	Intra-unit centrality	4.06	5.68	0.00	49.42
(10)	Boundary spanner	0.66	1.01	0.00	6.00
(11)	Mean knowledge centrality (intra-unit)	14.63	5.57	0.00	35.00
(12)	Mean knowledge structural holes (intra-unit)	1.75	0.20	0.00	1.92

Table 2: Correlation Matrix (N=1,951)

	Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1)	Intra-unit citations	1.00											
(2)	Prior intra-unit citations	0.33	1.00										
(3)	Prior patent applications	0.19	0.18	1.00									
(4)	Number of claims	-0.01	0.01	0.00	1.00								
(5)	Citations made	0.00	-0.01	0.11	0.14	1.00							
(6)	External collaborators	0.07	0.03	0.02	0.00	0.00	1.00						
(7)	Tenure	0.07	0.08	0.22	0.05	0.07	0.03	1.00					
(8)	Age of patents	0.06	0.11	0.38	0.13	0.01	-0.07	0.34	1.00				
(9)	Intra-unit centrality	0.08	0.12	-0.04	0.03	-0.04	0.13	-0.06	-0.09	1.00			
(10)	Boundary spanner	0.00	-0.01	0.01	0.10	0.00	0.05	0.01	-0.03	0.23	1.00		
(11)	Mean knowledge centrality (intra-unit)	0.08	0.06	0.00	-0.03	-0.06	-0.02	0.03	0.05	-0.02	-0.03	1.00	
(12)	Mean knowledge structural holes (intra-unit)	0.06	0.05	0.04	0.00	-0.10	0.00	0.00	0.05	0.01	-0.02	0.63	1.00

Table 3: Results of Regressions on Knowledge Transfer

Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Intra-unit citations						
Analytical method	NB	NB	NB	NB	NB	NB	MNB
Prior intra-unit citations	0.697*** (0.089)	0.666*** (0.087)	0.666*** (0.088)	0.655*** (0.087)	0.644*** (0.082)	0.636*** (0.084)	0.263* (0.149)
Prior patent applications	0.621*** (0.076)	0.629*** (0.076)	0.626*** (0.077)	0.640*** (0.081)	0.637*** (0.077)	0.627*** (0.077)	0.738*** (0.108)
Number of claims	0.047 (0.117)	0.049 (0.107)	0.050 (0.109)	0.048 (0.101)	0.050 (0.103)	0.046 (0.103)	0.065 (0.093)
Citations made	-0.077 (0.154)	-0.039 (0.124)	-0.048 (0.120)	-0.019 (0.126)	-0.044 (0.121)	-0.032 (0.118)	-0.093 (0.214)
External collaborators	0.268*** (0.054)	0.286*** (0.055)	0.299*** (0.063)	0.262*** (0.062)	0.305*** (0.048)	0.294*** (0.053)	0.334*** (0.128)
Tenure	0.021** (0.010)	0.021** (0.010)	0.020** (0.010)	0.021** (0.009)	0.018** (0.008)	0.018** (0.008)	0.024* (0.013)
Age of patents	-0.063 (0.105)	-0.077 (0.107)	-0.076 (0.105)	-0.068 (0.103)	-0.051 (0.094)	-0.039 (0.084)	-0.032 (0.107)
Collaboration network centrality	0.026** (0.012)	0.025 (0.015)	0.025 (0.015)	0.024 (0.016)	0.025 (0.016)	0.019 (0.019)	0.010 (0.020)
Boundary spanning		0.072 (0.149)	0.006 (0.145)	0.893 (0.576)	1.538** (0.603)	1.831** (0.782)	1.814*** (0.658)
Mean knowledge centrality (intra-unit)		0.027 (0.034)	0.019 (0.037)	0.020 (0.032)	-0.030 (0.043)	-0.031 (0.044)	-0.031 (0.039)
Mean knowledge structural holes (intra-unit)		1.511 (1.382)	1.514 (1.382)	3.007** (1.353)	5.048*** (1.841)	5.169*** (1.917)	4.701** (2.078)
Boundary spanning* Mean knowledge centrality (intra-unit)			0.017 (0.018)		0.088*** (0.030)	0.092*** (0.033)	0.107*** (0.040)
Boundary spanning * Mean knowledge structural holes (intra-unit)				-2.158 (1.540)	-4.757** (1.911)	-4.914** (2.012)	-4.802*** (1.785)
Inverse mills ratio						-0.290 (0.294)	-0.316 (0.263)
Constant	-4.099*** (0.327)	-4.898*** (0.629)	-4.884*** (0.631)	-5.463*** (0.593)	-6.144*** (0.766)	-6.295*** (0.859)	-7.023*** (1.025)
Unit dummies	Yes	Yes	Yes	Yes	Yes	Yes	No
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,951	1,951	1,951	1,951	1,951	1,951	1,951
Log likelihood	-682.3	-677.5	-677.3	-675.9	-672.9	-672.3	-666.8
Pseudo R-squared (NB), AIC (MNB)	0.115	0.121	0.122	0.124	0.127	0.128	1389.6

Robust standard errors clustered by units and inventors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Figure 3: Effect of Knowledge Centrality on Intra-unit Citations

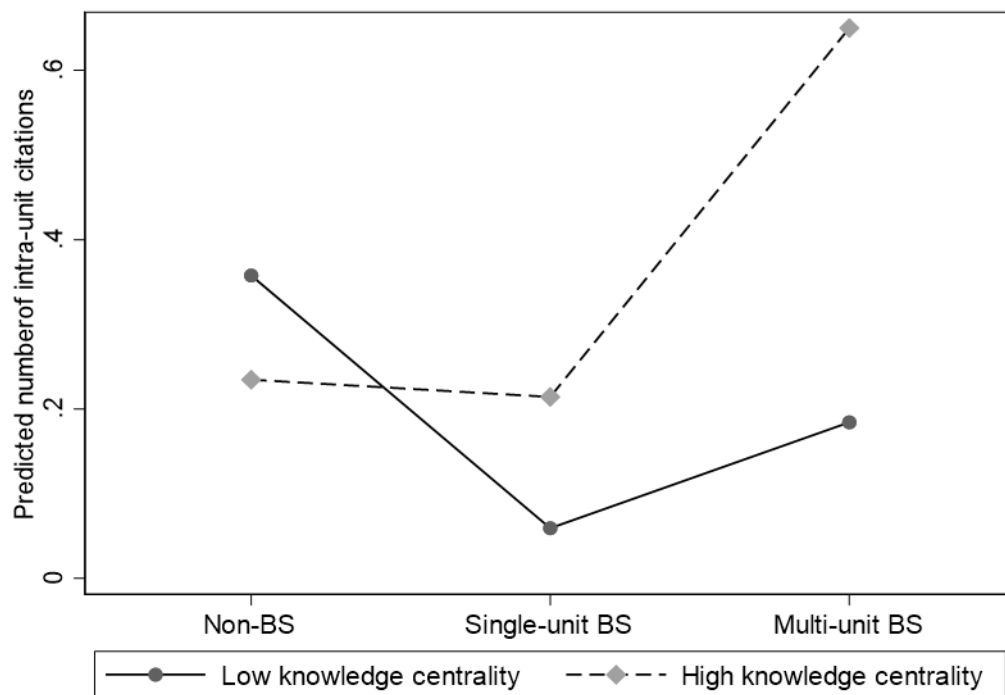
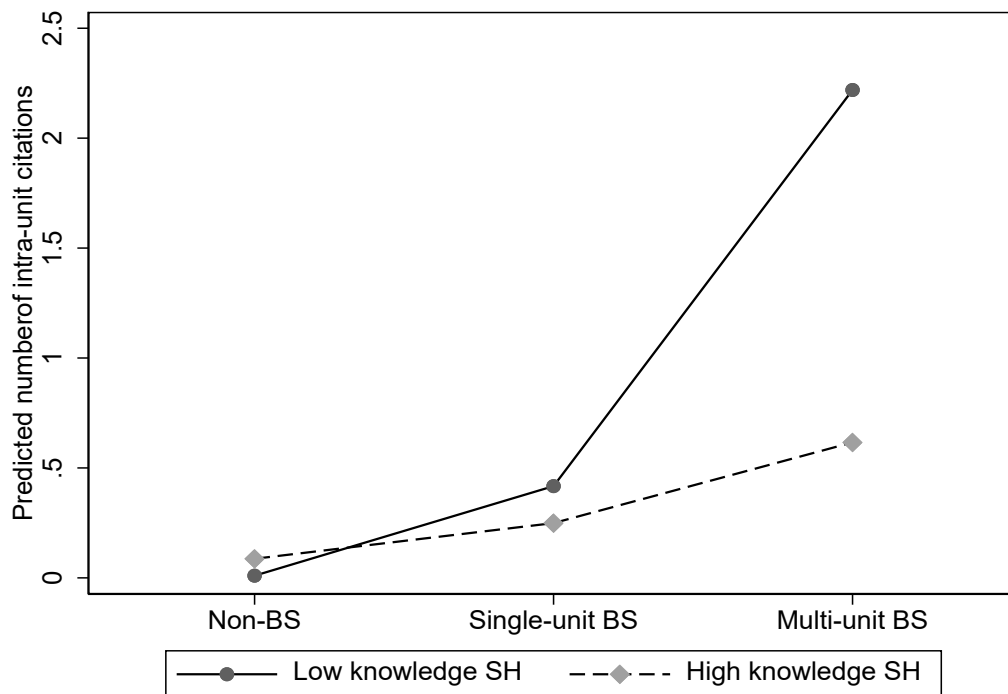


Figure 4: Effect of Knowledge Structural Holes on Intra-unit Citations



Appendix

Results of Regressions for Boundary Spanning

Dependent variable	Boundary spanning
Analytical method	Ordered probit
Collaborators' breadth	0.718*** (0.055)
External collaborators	0.005 (0.056)
Size of unit	-0.038 (0.044)
Mean boundary spanning of unit	1.025*** (0.106)
Year dummies	Yes
Observations	1,951
Log likelihood	-1516
Pseudo R-squared	0.0992

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1