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**Reciprocal Benefits of International Collaboration in the Semiconductor Industry: A Patent Citation Analysis of US-Asian Tiger Partnerships**

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## **Abstract**

This study examines the reciprocal benefits of international collaboration in the semiconductor industry, by focusing on partnerships between the United States and the Asian Tigers (Japan, South Korea, and Taiwan). Utilizing patent data from the United States Patent and Trademark Office (USPTO) and employing a negative binomial model, the research analyzes patent citation counts as a measure of collaboration impact. Four key hypotheses are investigated: the benefits of international collaboration for U.S.-based firms, the advantages for firms in the Asian Tiger countries, the comparative value of team-based versus individual inventorship, and the influence of past international collaboration experience on patent performance. The findings reveal that cross-border collaborations yield mutual benefits, with higher citation counts reflecting the successful integration of knowledge leadership and production expertise. Moreover, inventors with prior collaboration experience tend to produce more impactful patents. These results highlight the crucial role of international partnerships in driving innovation within the global semiconductor industry, contributing to our understanding of knowledge spillovers and collaborative dynamics in high-tech sectors.

**Keywords:** International collaboration, patent citations, semiconductor industry, innovation, knowledge spillovers

## Table of Content

1. Introduction	4
2. Literature review:	6
2.1 Knowledge Spillover Theory	6
2.2 Innovation and Patents in the Semiconductor Industry	7
2.4 International Collaboration in Innovation	9
2.5 Country-Specific Insights in the Semiconductor Industry	9
3. Data and methodology	12
Data	12
Methodology	15
4. Results	17
Interaction of Firm Age and Collaboration Variables	27
Robustness check	29
5. Conclusion and Discussion	30
Limitations	32
References	33
Appendix	37

## 1. Introduction

In an era of rapid technological advancement and global interconnectedness, the semiconductor industry stands as a paragon of innovation and international collaboration. This critical sector, which underpins much of modern technology, offers a unique lens through which to examine the dynamics of knowledge spillovers, innovation, and cross-border collaboration in high-tech industries. As the global landscape of semiconductor production and innovation continues to evolve, understanding the interplay between established leaders like the United States and emerging powerhouses such as Japan, South Korea, and Taiwan becomes increasingly crucial. The semiconductor industry is selected for this study due to several key factors. Firstly, it has become highly globalized, particularly in recent decades, making it an ideal context for examining the variation in R&D characteristics (Phene & Almeida, 2008). Additionally, U.S. semiconductor firms exhibit high rates of technological innovation (Stuart, 2000) and a strong propensity to patent their technologies (Hall & Ziedonis, 2001). Consequently, patent data provides a more comprehensive representation of the innovative activities in the semiconductor industry compared to other industries where patenting is less central, serving as a superior proxy for innovation in this context.

The United States has long been at the forefront of semiconductor innovation, home to industry giants like Intel, Qualcomm, and Texas Instruments. However, the rise of the Asian Tigers – Japan, South Korea, and Taiwan – has reshaped the global semiconductor landscape. These countries have leveraged strategic industrial policies, significant R&D investments, and unique business models to establish themselves as formidable players in the industry (Mathews & Cho, 2000). This shift has led to a complex ecosystem of competition and collaboration, raising important questions about the nature and direction of knowledge flows in the industry. Thus, the study aims to provide answer to the following question:

*Does international collaboration between inventors from the United States and the Asian Tiger countries enhance patent citation counts, reflecting the beneficial integration of knowledge leadership and production expertise for both regions?*

Patent data and citation analysis provide valuable tools for tracing these knowledge flows and measuring innovation in the semiconductor industry. As Hall, Jaffe, and Trajtenberg (2005) demonstrated, patent citations not only reflect the transfer of knowledge between inventors and companies but also correlate with firms' market valuations, underscoring the economic significance of knowledge spillovers. In this context, examining patterns of international collaboration and their impact on patent quality, as measured by citation counts, can offer insights into the dynamics of innovation in the global semiconductor industry. This study aims to investigate the reciprocal nature of benefits derived from international collaboration in the semiconductor industry, focusing on partnerships between the United States and the Asian Tigers. Building on previous research by Alnuaimi, Singh, and George (2012), which examined the impact of cross-country collaboration on innovation in multinational corporations, we seek to understand whether and how firms from different countries benefit from such collaborations. More importantly, is this collaboration mutually beneficial?

This research is guided by four key hypotheses. First, whether U.S.-based firms benefit from international collaborations with Japan, Taiwan, and Korea, compared to domestic collaborations. Second, I investigate the reverse scenario, examining whether firms in these Asian countries gain advantages from collaborating with U.S. inventors. Third, I aim to confirm previous findings on the value of team-based and international collaborations compared to individual inventorship (Singh & Fleming, 2010; Singh, 2008). Finally, I examine the impact of past international collaboration experience on patent performance for U.S.-based assignees. This study contributes to our understanding of knowledge spillovers, international collaboration, and innovation in the semiconductor industry. The findings suggest that collaboration between nations yields mutual benefits for both established leaders and emerging powerhouses. Furthermore, inventors with previous collaboration experience tend to produce patents that are significantly stronger and more valuable than those without such experience.

The organization of this paper is as follows: the literature review discusses knowledge spillover theory and its implications for innovation and collaboration. Following this, I detail the data and methodology employed in our analysis, which is succeeded by a presentation of the results. Finally, I conclude with a discussion of the findings and their broader implications.

## 2. Literature review

### 2.1 Knowledge Spillover Theory

Knowledge spillover theory, a fundamental concept in innovation economics and management, describes the unintentional transfer of knowledge between entities. This theory is particularly relevant in knowledge-intensive industries such as semiconductors, where rapid technological advancements and global interconnectedness facilitate the flow of ideas and innovations. The concept of knowledge spillovers originated in the endogenous growth models developed by economists in the late 20th century. Pioneering works by Romer (1986), Lucas (1988), and Grossman and Helpman (1995) emphasized the crucial role of knowledge externalities in driving economic growth and technological progress.

Knowledge spillovers can be categorized into two main types: internal and external. Internal knowledge spillovers occur within an organization as knowledge is shared among individuals or departments, while external knowledge spillovers involve the transfer of knowledge between different organizations or across industry boundaries. Simonen and McCann (2008) found “knowledge flows are an important resource for developing inter-organizational collaboration to spread and gain access to knowledge. Knowledge spillovers therefore also have a positive effect on cooperation agreements”. In the semiconductor industry, both types of spillovers are significant due to the industry's collaborative nature and the frequent movement of skilled workers between firms. Knowledge spillovers significantly boost innovation and productivity in the semiconductor industry. They enable firms to leverage others' R&D efforts without direct collaboration or compensation, resulting in increased innovation rates as firms build on existing knowledge to develop new technologies and products. This process enhances productivity through improved production processes and efficiency, thereby accelerating technological progress due to the cumulative effect of these spillovers. Measuring knowledge spillovers presents challenges due to their intangible nature. However, several approaches have been developed to address these challenges. Patent citation analysis examines the citations between patents to trace knowledge flows (Jaffe and Trajtenberg 2002).

## 2.2 Innovation and Patents in the Semiconductor Industry

Patents play a pivotal role in the semiconductor industry, serving as both a measure of innovation and a mechanism for protecting intellectual property. In this rapidly evolving sector, patents are crucial for safeguarding technological advancements and providing a quantifiable metric for assessing progress. They represent novel ideas, processes, or technologies that have been deemed sufficiently unique, and the number and quality of patents held by a company can indicate its innovative capacity and technological leadership (Narin, Noma, & Perry, 1987)

Patent citations are particularly valuable for understanding the dynamics of innovation in the semiconductor sector. These citations provide a paper trail of knowledge flow, indicating how ideas and technologies are built upon and disseminated across the industry. By analyzing citation patterns, researchers can trace the trajectory of technological development and identify key innovations that have had widespread impact. Patent citations are references made by a patent applicant to prior patents, integral to understanding knowledge spillovers. Each citation establishes a link between the new invention and existing knowledge, illustrating how current innovations build on previous discoveries. Numerous scholarly works have focused on quantifying the economic and technological significance of patents. Notably, researchers have found that the number of citations a patent receives correlates with various direct indicators of its value. These indicators include the consumer surplus generated by the patented innovation (Trajtenberg, 1990), expert assessments of patent worth (Albert et al., 1991), rates of patent renewal (Harhoff et al., 1999), and the patent's contribution to a company's market valuation (Hall et al., 2005). As a result, measures of invention value based on citation counts have been employed in numerous studies to assess the impact and importance of patented innovations. Analyzing patent citations offers several key insights. First, citations trace the flow of knowledge between inventors, companies, and regions, highlighting pathways of knowledge transfer and collaboration. Second, the frequency and pattern of citations can indicate the impact and influence of a particular patent on subsequent technological developments. Third, highly cited patents often belong to seminal inventions, allowing the identification of key innovators and influential companies within the industry.

The value of knowledge spillovers in the semiconductor industry can be estimated through the analysis of patent citations. Hall, Jaffe, & Trajtenberg (2001) found patent citations can be used as an indicator of the importance of a firm's patents and the firm's market valuation.

This research showed that citations not only reflect the transfer of knowledge between inventors and companies but also correlate with the market value of firms, suggesting that the ability to generate and absorb knowledge spillovers is a significant factor in a company's success. Studies focusing on the U.S. semiconductor industry like the one by Alnuaimi, Singh, and George (2012) have demonstrated that citation analysis is a powerful tool for understanding the dynamics of innovation and the diffusion of technological knowledge. Key findings from such studies include, firstly, citations reveal how knowledge generated by one firm can influence and be utilized by others, even without direct collaboration or compensation. Second, analyzing citations across geographical boundaries helps understand the global nature of knowledge spillovers and the role of international networks in fostering innovation. Third, the time lag between patent filings and subsequent citations can provide insights into the speed at which new knowledge diffuses and its adoption within the industry.

The relationship between patents and a firm's market value is particularly pronounced in the semiconductor industry. Companies with strong patent portfolios often command higher market valuations, reflecting the perceived value of their intellectual property and innovative capacity. This relationship underscores the importance of patents not just as legal instruments, but as strategic assets that can drive a company's competitive advantage and financial performance (Hall, Jaffe, & Trajtenberg, 2005).

The semiconductor industry's patent landscape is highly globalized, reflecting the international nature of the sector. The United States, Taiwan, and Japan are among the leading countries in semiconductor patent filings, with companies like Macronix, Micron Technology, and Advanced Micro Devices being major contributors. This global distribution of patents highlights the importance of international collaboration and knowledge exchange in driving innovation in the industry.

## 2.4 International Collaboration in Innovation

International collaboration is increasingly important in driving innovation, particularly in knowledge-intensive industries like semiconductors. One major benefit is the enhanced knowledge pool; firms can access a broader and more diverse knowledge base, leading to novel and valuable innovations (Grant, 1996). Additionally, diversity in collaborative teams fosters creativity and innovation, as diverse backgrounds and perspectives are more likely to generate innovative ideas (Reagans & Zuckerman, 2001). International collaboration also allows firms to tap into specialized expertise from different countries, exemplified by the collaboration between U.S. firms and Taiwanese manufacturers in the semiconductor industry. Furthermore, international collaboration helps distribute the significant risks and costs associated with high-tech innovation, making it particularly relevant for industries with high development costs, such as semiconductors. It also provides insights into local markets, aiding firms in adapting innovations to different geographical contexts, which is crucial for global expansion. For firms from smaller countries or those with limited domestic resources, international collaboration is a means to overcome resource constraints and compete on a global scale. While international collaboration offers substantial benefits in terms of enhanced knowledge, creativity, and resource sharing, it also presents challenges that require careful management. In the semiconductor industry, where technological complexity and diverse expertise are essential, effective international collaboration is a key driver of innovation and competitive advantage.

## 2.5 Country-Specific Insights in the Semiconductor Industry

In this Study the focus is on two groups, USA and the Asian Tigers – Japan, Korea and Taiwan. The United States holds a prominent position in the global semiconductor industry, serving as a hub for innovation and technological advancement. Historically, the U.S. has been home to some of the world's leading semiconductor companies, such as Intel, Texas Instruments, and Qualcomm, which have significantly contributed to the development of cutting-edge technologies (Macher & Mowery, 2009). On the other hand, the Asian Tiger countries - South Korea, Japan, and Taiwan - have established themselves as major players in the global semiconductor industry primarily as manufacturers. They have emerged as formidable competitors to the United States in the global semiconductor industry. While the U.S. maintains its leadership in semiconductor design and advanced chip manufacturing, these Asian nations have made significant strides in various segments of the industry. Japan, once a dominant force, has seen its market share decline but remains strong in semiconductor

manufacturing equipment and materials (Macher et al., 2007). South Korea, led by Samsung and SK Hynix, has become a world leader in memory chip production, challenging U.S. companies in this sector (Kim & Lee, 2014). Taiwan, through its foundry model pioneered by TSMC (Taiwan Semiconductor Manufacturing Company), has become the world's largest contract chip manufacturer, playing a crucial role in the global semiconductor supply chain and even surpassing the U.S. in some areas of advanced chip manufacturing (Rasiah et al., 2013). The U.S., however, maintains its edge in semiconductor design, research and development, and intellectual property (Brown & Linden, 2011). This dynamic landscape has led to a complex interdependence between these countries, with each specializing in various aspects of the semiconductor value chain. The ongoing competition and collaboration between the U.S. and these Asian Tigers continue to drive innovation and technological advancement in the industry, shaping the global semiconductor landscape (Mathews & Cho, 2000).

With extensive academic research on knowledge spillover and cross-country collaboration, this study aims to determine if the benefits of collaboration are reciprocated on both ends. Specifically, it investigates whether U.S. firms benefit from collaborating with the Asian Tigers, and whether firms in these Asian countries also gain advantages from such partnerships. Alnuaimi, Singh, and George (2012) examine how cross-country collaboration affects the innovative capabilities of subsidiaries in multinational corporations (MNCs). They conclude that subsidiaries in emerging economies benefit less from cross-country collaboration compared to those in advanced economies. This perspective informs the first three hypotheses of this paper. Hypothesis 1 explores whether U.S.-based firms benefit from international collaboration, questioning if the U.S., despite its leadership, can still learn from emerging competitors.

*H1: For U.S.-based assignees, international collaborations with Japan, Taiwan, and Korea result in significantly higher patent citations compared to collaborations within the United States.*

Hypothesis 2 investigates the reverse scenario, examining whether firms in the Asian Tiger countries benefit from their collaboration with U.S. inventors.

*H2: For international assignees, collaborations with the U.S. result in significantly higher patent citations compared to collaborations within their home country.*

- H2.1: *For assignees based in Japan, international collaboration with the U.S. results in significantly higher patent citations compared to collaborations within Japan.*

- H2.2: *For assignees based in Korea, international collaboration with the U.S. results in significantly higher patent citations compared to collaborations within Korea.*

- H2.3: *For assignees based in Taiwan, international collaboration with the U.S. results in significantly higher patent citations compared to collaborations within Taiwan.*

Prior literatures have already established that working with a team of inventors yields higher impact inventions than working individually (Singh and Fleming, 2010) and working in a team composed of multinational inventors yields an even higher impact (Singh, 2008). The third hypothesis serves as a confirmation, comparing the value of patents with no collaboration versus those with either domestic or international collaboration.

*H3: Patents with a single inventor (i.e., no collaboration) result in significantly lower patent citations compared to both international collaborations and within-country collaborations.*

Finally, the fourth hypothesis examines whether inventors with past international collaboration experience produce higher-performing patents.

*H4: For U.S.-based assignees, past collaborations result in significantly higher patent citations for the inventor.*

### 3. Data and methodology

#### Data

This study utilizes patent data from the United States Patent and Trademark Office (USPTO) database, a comprehensive source of information on filed and granted patents. The USPTO database was chosen for several reasons. First, it provides detailed information on inventor locations, allowing for accurate identification of international collaborations. Second, the use of USPTO data enhances comparability with previous research on R&D internationalization, as most patent-based studies in this field have utilized this database (Hall et al., 2001; Patel & Pavitt, 1991). Citation counts were used as a proxy for patent quality and impact, following established practices in innovation research (Trajtenberg, 1990; Hall et al., 2005).

Additional data regarding U.S.-based firms was obtained from the Orbis database. An initial version of the primary dataset was provided by the thesis supervisor. The sample specifically includes patents classified under CPC code H01L, pertaining to semiconductors. This study examines patents granted between 1974 and 2023. The sample encompasses patents assigned to both U.S. and international assignees, specifically from Korea, Taiwan, and Japan. The dataset includes both single-inventor patents and collaborative patents.

*Table 3.1 Number of Unique patents and assignees per country*

	Number of unique patents	Number of unique assignees
United States	143430	5451
Taiwan	48509	1089
Japan	111060	1766
Korea	37926	652

The dependent variable in the analysis is the number of forward citations a patent receives, and the primary independent variable is the presence of collaboration between inventors. To ensure the robustness of our findings, we have included several control variables: firm age, patent age, R&D dummy in the firm, and inventor count per patent. Each of these controls is crucial for isolating the effect of collaboration on patent citations

Table 3.2 *Variable description*

Variable Name	Description
<b>Dependent Variable</b>	
<i>Cite3</i>	The number of citations received by a patent within three years of its issuance.
<i>Cite5</i>	The number of citations received by a patent within five years of its issuance.
<b>Control variable</b>	
<i>Log of Firm Age</i>	The natural logarithm of the firm's age in the dataset, calculated from the year of establishment to the present year.
<i>R&amp;D Dummy</i>	A binary variable indicating whether the firm engages in research and development (1 if yes, 0 if no).
<i>Patent Age</i>	The age of the patent, calculated from the year of issuance to the present year.
<i>Firm Age</i>	The number of years since the firm's establishment.
<i>Inventor Count per Patent</i>	The number of inventors listed per patent for the firm.
<b>Independent variable</b>	
International collaborations	
<i>US_JPCollab</i>	Dummy variable indicates the patent resulted from a collaboration between U.S.-based and Japan-based inventors for US based firms (1 if yes, 0 if no).
<i>US_TWCollab</i>	Dummy variable indicates the patent resulted from a collaboration between U.S.-based and Taiwan-based inventors for US based firms (1 if yes, 0 if no).
<i>US_KRCollab</i>	Dummy variable indicates the patent resulted from a collaboration between U.S.-based and Korea-based inventors for US based firms (1 if yes, 0 if no).
<i>JP_USCollab</i>	Dummy variable indicates the patent resulted from a collaboration between Japan-based and U.S.-based inventors for Japan based firms (1 if yes, 0 if no).
<i>TW_USCollab</i>	Dummy variable indicates the patent resulted from a collaboration between Taiwan-based and U.S.-based inventors for Taiwan based firms (1 if yes, 0 if no).
<i>KR_USCollab</i>	Dummy variable indicates the patent resulted from a collaboration between Korea-based and U.S.-based inventors for Korean firms (1 if yes, 0 if no).
Within country collaboration	
<i>US_USCollab</i>	Dummy variable indicates the patent resulted from collaboration between U.S.-based inventors (1 if yes, 0 if no).
<i>JP_JPCollab</i>	Dummy variable indicates the patent resulted from collaboration between Japan-based inventors (1 if yes, 0 if no).
<i>KR_KRCollab</i>	Dummy variable indicates the patent resulted from collaboration between Korea-based inventors (1 if yes, 0 if no).
<i>TW_TWCollab</i>	Dummy variable indicates the patent resulted from collaboration between Taiwan-based inventors (1 if yes, 0 if no).

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Single inventor	
<i>US_NC</i>	Dummy variable indicates the patent was created by a single U.S.-based inventor with no collaboration (1 if yes, 0 if no).
<i>JP_NC</i>	Dummy variable indicates the patent was created by a single Japan-based inventor with no collaboration (1 if yes, 0 if no).
<i>TW_NC</i>	Dummy variable indicates the patent was created by a single Taiwan-based inventor with no collaboration (1 if yes, 0 if no).
<i>KR_NC</i>	Dummy variable indicates the patent was created by a single Korea-based inventor with no collaboration (1 if yes, 0 if no).
Past collaboration	
<i>US_yes</i>	Dummy variable indicates prior collaboration of U.S.-based inventors (1 if yes, 0 if no).
<i>JP_yes</i>	Dummy variable indicates prior collaboration of Japan-based inventors (1 if yes, 0 if no).
<i>TW_yes</i>	Dummy variable indicates prior collaboration of Taiwan-based inventors (1 if yes, 0 if no).
<i>KR_yes</i>	Dummy variable indicates prior collaboration of Korea-based inventors (1 if yes, 0 if no).

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In this section, I present the rationale for including specific control variables in the negative binomial regression model, which examines the effect of collaboration on patent citations.

**Firm age** is an essential control variable because older firms may have more established reputations, resources, and experience, which can influence the quality and impact of their patents. Older firms might also have more extensive networks and better access to external knowledge, which can enhance the likelihood of their patents being cited (Huerigo & Jaumandreu, 2004; Sørensen & Stuart, 2000).

**Patent age** is a critical control variable because older patents have had more time to accumulate citations. Controlling patent age helps to account for the temporal dimension of citation accumulation, ensuring that the observed effects are not merely due to the passage of time (Hall, Jaffe, & Trajtenberg, 2001; Trajtenberg, 1990).

**R&D** dummy variable for whether a firm engages in R&D activities is important because firms with dedicated R&D departments are likely to produce more innovative and higher-quality patents. These patents may be more frequently cited due to their novelty and impact on subsequent technological developments (Cohen & Levinthal, 1990; Griliches, 1990).

**The number of inventors listed on a patent** is a proxy for the collaborative effort involved in its creation. Patents with more inventors may benefit from a diverse set of skills and knowledge, potentially leading to higher-quality innovations that are more likely to be

cited. Controlling the inventor count allows us to isolate the specific effect of collaboration beyond just the number of contributors (Singh & Fleming, 2010; Fleming, Mingo, & Chen, 2007).

By including these control variables in the regression model, it helps to provide a more accurate and nuanced understanding of how collaboration among inventors affects the citation impact of patents. Each control variable addresses a specific aspect of the innovation process that could confound the relationship between collaboration and patent citations, thereby enhancing the validity of the findings

## Methodology

The primary estimation technique employed in this study is the negative binomial regression model. This choice is motivated by the nature of the dependent variable (patent citations), which is a count variable that exhibits overdispersion (variance greater than the mean). The negative binomial model is well-suited to handle such data, providing more efficient and unbiased estimates compared to the Poisson model when overdispersion is present.

To test the 4 different hypotheses in this study, Negative Binomial regression was conducted on patents assigned to each country specifically US, Korea, Taiwan and Japan. The dependent variable in this analysis is the citation count of the patents within 3 and 5 years of patent grant. The primary independent variables are the collaboration types, specifically collaborations between inventors within the country, and between US inventors and those from Japan, Korea, and Taiwan. The baseline equation is as follows:

$$E(\text{Patent Citation}_{it}) = \exp(\beta_0 + \beta_1 \text{Collab}_{it} + \beta_2 \text{Gender}_{it} + \beta_3 \text{R\&D}_{it} + \beta_4 \text{Firm Age}_{it} + \beta_5 \text{Patent Age}_{it} + \beta_6 \text{Inventor Count}_{it} + A_f + B_y + \epsilon_{it})$$

Where dependent variable  $E(\text{Patent Citation}_{it})$  is the Expected Number of Patent citation - Cite3 and Cite5,  $\beta_0$  is the constant.  $\text{Collab}_{it}$  represents the collaboration variable, which includes inventors collaborating within the US, and between US inventors and those from Japan, Korea, and Taiwan.  $\text{Gender}_{it}$  is a dummy variable, denotes the gender of the inventor.  $\text{R\&D}_{it}$  is a dummy variable indicating whether the firm engages in research and development.  $\text{Firm Age}_{it}$  refers to the age of the firm.  $\text{Patent Age}_{it}$  denotes the age of the patent.  $\text{Inventor Count}_{it}$  is the number of inventors on the patent.  $A_f$  represents firm fixed effects.  $B_y$  represents year fixed effects.  $\epsilon_{it}$  is the error term. Due to the limited availability of data for firm

age and R&D for patents with Asian tiger countries as assignees, these two control variables are omitted from the regression analyses involving patents assigned to Korea, Japan, and Taiwan.

For Hypothesis 3, the dummy independent variables US\_NC, JP\_NC, KR\_NC, and TW\_NC were constructed to include only patents with single inventors from the respective countries and assignees. For Hypothesis 4, I examined at inventor level, the dummy independent variables US\_Yes, JP\_Yes, KR\_Yes, and TW\_Yes were created to indicate whether inventors from specific countries had previously collaborated. If an inventor had collaborated in the past, the variable takes a value of 1 otherwise, it is 0.

## 4. Results

Table 4.1 presents the effects of collaboration between inventors from the United States, Korea, Japan, and Taiwan for firms based in the United States (US assignees). The marginal effects are detailed in Table 4.1a. When US based inventors collaborate, it increases the expected number of patent citations within 3 years of patent grant by 0.049 citations, *ceteris paribus*. Similarly, when US based inventors collaborate with Japan based inventors and Korea based inventors it increases the expected number of patent citation within 3 years of patent grant by 0.461 and 1.103 citations, *ceteris paribus*, respectively. However, when US based inventors collaborate with Taiwan based inventors, it decreases the expected number of patent citation within 3 years of patent grant by 1.188 citations, *ceteris paribus*. All these effects are significant at a 1 percent significance level and consistent when the number of patent citations within 5 years of patent grant is considered. The results indicate that collaborations between inventors from Japan and Korea with US based inventors yield a significantly higher patent citation compared to US based inventors domestically collaborating. Conversely, collaborations between US inventors and Taiwanese inventors result in a significantly lower patent output, as measured by citations. Therefore, hypothesis 1 holds true for Japan and Korea but fails to hold for Taiwan.

Table 4.2 presents the effects of collaboration between inventors from the United States and Japan for firms based in Japan (Japanese assignees). Model 11 examines collaborations among Japan-based inventors, while Model 12 examines collaborations between Japanese and US-based inventors on patents for Japanese firms. The marginal effects are detailed in Table 4.2a. When Japan based inventors collaborate within themselves, it decreases the expected number of patent citations within 3 years of patent grant by 0.046 citations, *ceteris paribus*. Whereas, when US based inventors collaborate with Japan based inventors it decreases the expected number of patent citation within 3 years of patent grant by 0.281 citations, *ceteris paribus*. All these effects are significant at a 1 percent significance level and consistent when the number of patent citations within 5 years of patent grant is considered. The results indicate that collaborations between Japanese and US inventors have a smaller impact compared to within-country collaborations among Japanese inventors for Japanese firms. This leads us to believe that international collaboration is not better than within country collaboration for Japanese firms or inventors. In this case hypothesis 2.1 does not hold.

Table 4.3 presents the effects of collaboration between inventors from the United States and Korea for firms based in Korea (Korean assignees). Model 17 examines collaborations among Korea-based inventors, while Model 18 examines collaborations between Korean and

US-based inventors on patents for Korean firms. The marginal effects are detailed in Table 4.3a. When Korea based inventors collaborate within themselves, it decreases the expected number of patent citations within 3 years of patent grant by 0.06 citations, *ceteris paribus*. Whereas, when US based inventors collaborate with Korea based inventors it increases the expected number of patent citations within 3 years of patent grant by 0.435 citations, *ceteris paribus*. All these effects are significant at a 1 percent significance level and consistent when the number of patent citations within 5 years of patent grant is considered. The results indicate that collaborations between Korean and US inventors have a larger significant impact compared to within-country collaborations among Korean inventors for Korean firms. This means international collaboration is highly beneficial for Korean firms and thus hypothesis 2.2 holds true.

Table 4.4 presents the effects of collaboration between inventors from the United States and Taiwan for firms based in Taiwan (Taiwanese assignees). Model 23 examines collaborations among Taiwan-based inventors, while Model 24 examines collaborations between Taiwan and US-based inventors on patents for Taiwanese firms. The marginal effects are detailed in Table 4.4a. When Taiwan based inventors collaborate within themselves, it decreases the expected number of patent citations within 3 years of patent grant by 0.058 citations, *ceteris paribus*. Whereas, when US based inventors collaborate with Taiwan based inventors it increases the expected number of patent citations within 3 years of patent grant by 0.446 citations, *ceteris paribus*. All these effects are significant at a 1 percent significance level and consistent when the number of patent citations within 5 years of patent grant is considered. The results indicate that collaborations between inventors based in Taiwan and US have a larger positive significant impact compared to within-country collaborations among Taiwanese inventors for Taiwanese firms. This means international collaboration is beneficial for Taiwanese firms and hypothesis 2.3 also holds true.

Table 4.1 *Negative Binomial Regression Results for Patents by US Assignees*

	(1)	(2)	(3)	(4)
Dependent variable:	cite3	cite3	cite3	cite3
US_USCollab	0.025*** (0.006)			
US_JPCollab		0.237*** (0.019)		
US_TWCollab			-0.611*** (0.028)	
US_KRCollab				0.567*** (0.032)
Gender	0.097*** (0.007)	0.098*** (0.007)	0.097*** (0.007)	0.092*** (0.007)
R&D	-0.173*** (0.008)	-0.172*** (0.008)	-0.174*** (0.008)	-0.166*** (0.008)
Firm age	-0.088*** (0.006)	-0.086*** (0.006)	-0.089*** (0.006)	-0.084*** (0.006)
Patent age	0.117*** (0.002)	0.115*** (0.002)	0.118*** (0.002)	0.116*** (0.002)
Inventor count	0.036*** (0.001)	0.032*** (0.001)	0.041*** (0.001)	0.034*** (0.001)
Constant	-24.572 (7,126.379)	-24.493 (7,145.538)	-24.622 (7,099.862)	-24.504 (7,104.742)
Year FE	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included
Observations	402,853	402,853	402,853	402,853

Note: This table presents the effects of collaborations on patent citation counts for patents with US assignees from 1974 to 2023, using Negative Binomial regression. Column 1 shows results for US inventors collaborating domestically, Column 2 for US and Japan-based inventors collaborating, Column 3 for US and Taiwan-based inventors collaborating, and Column 4 for US and Korea-based inventors collaborating. Results for dependent variable cite5 are in appendix Table no. A.1. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .

Table 4.1a *Marginal Effect of Negative Binomial Regression Results for Patents by US Assignees*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable:	cite3	cite3	cite3	cite3	cite5	cite5	cite5	cite5
US_USCollab	0.049				0.092			
US_JPCollab		0.461				0.824		
US_TWCollab			-1.188				-2.935	
US_KRCollab				1.103				3.181

Note: This table presents the marginal effect of collaborations on patent citation counts for patents with US assignees from 1974 to 2023, using Negative Binomial regression. Column 1 shows results for US inventors collaborating domestically, Column 2 for US and Japan-based inventors collaborating, Column 3 for US and Taiwan-based inventors collaborating, and Column 4 for US and Korea-based inventors collaborating. The dependent variable for Columns 1-4 is cite3, and for Columns 5-8 is cite5. All coefficients are significant at 1 percent significance level.

Table 4.2 *Negative Binomial Regression Results for Patents by Japan Assignees*

	(11)	(12)	(13)	(14)	(15)	(16)
Dependent variable:	cite3	cite3	cite3	cite5	cite5	cite5
JP_JPCollab	-0.033*** (0.007)			-0.050*** (0.006)		
JP_USCollab		-0.205*** (0.020)			-0.252*** (0.019)	
JP_NC			-0.083*** (0.010)			-0.132*** (0.009)
Gender	-0.036*** (0.009)	-0.037*** (0.009)	-0.036*** (0.009)	-0.033*** (0.008)	-0.034*** (0.008)	-0.033*** (0.008)
Patent Age	0.021*** (0.002)	0.021*** (0.002)	0.022*** (0.002)	0.033*** (0.002)	0.033*** (0.002)	0.033*** (0.002)
Inventor Count	0.039*** (0.001)	0.044*** (0.001)	0.037*** (0.001)	0.038*** (0.001)	0.044*** (0.001)	0.034*** (0.001)
Constant	-22.717 (53,903.207)	-22.401 (55,906.353)	-22.163 (56,026.182)	-1.654 (1.657)	-1.720 (1.657)	-1.595 (1.657)
Year FE	Included	Included	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included	Included	Included
Observations	294,185	294,185	294,185	294,185	294,185	294,185

Note: This table presents the effects of collaborations on patent citation counts for patents with Japan assignees from 1974 to 2023, using Negative Binomial regression. Column 1 shows results for Japan based inventors collaborating domestically, Column 2 for US and Japan-based inventors collaborating, Column 3 shows results for Japan based inventors not collaborating, single inventor per patent. The dependent variable for Columns 1-3 is cite3, and for Columns 4-6 is cite5. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 4.2a Marginal Effect of Negative Binomial Regression Results for Patents by Japan Assignees

	(11)	(12)	(13)	(14)	(15)	(16)
Dependent variable:	Cite3	Cite3	Cite3	Cite5	Cite5	Cite5
JP_JPCollab	-0.046			-0.154		
JP_USCollab		-0.281			-0.780	
JP_NC			-0.114			-0.409

Note: This table presents the marginal effect of collaborations on patent citation counts for patents with Japan assignees from 1974 to 2023, using Negative Binomial regression. Column 1 shows results for Japan based inventors collaborating domestically, Column 2 for US and Japan-based inventors collaborating, Column 3 shows results for Japan based inventors not collaborating, single inventor per patent. The dependent variable for Columns 1-3 is cite3, and for Columns 4-6 is cite5. All coefficients are significant at 1 percent significance level.

Table 4.3 Negative Binomial Regression Results for Patents by Korea Assignees

	(17)	(18)	(19)	(20)	(21)	(22)
Dependent variable:	cite3	cite3	cite3	cite5	cite5	cite5
KR_KRCollab	-0.072*** (0.013)			-0.089*** (0.012)		
KR_USCollab		0.522*** (0.057)			0.496*** (0.056)	
KR_NC			-0.201*** (0.022)			-0.282*** (0.021)
Gender	0.009 (0.008)	0.010 (0.008)	0.009 (0.008)	0.016** (0.008)	0.016** (0.008)	0.016** (0.008)
Patent Age	0.090*** (0.005)	0.091*** (0.005)	0.091*** (0.005)	0.138*** (0.005)	0.139*** (0.005)	0.139*** (0.005)
Inventor Count	0.045*** (0.003)	0.049*** (0.002)	0.040*** (0.003)	0.037*** (0.002)	0.043*** (0.002)	0.029*** (0.002)
Constant	-22.297 (3,844.789)	-22.397 (3,844.313)	-22.363 (3,846.896)	-25.401 (7,561.135)	-25.248 (6,686.352)	-25.485 (7,585.849)
Year FE	Included	Included	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included	Included	Included
Observations	119,615	119,615	119,615	119,615	119,615	119,615

Note: This table presents the effects of collaborations on patent citation counts for patents with Korea assignees from 1974 to 2023, using Negative Binomial regression. Column 1 shows results for Korea based inventors collaborating domestically, Column 2 for US and Korea-based inventors collaborating, Column 3 shows results for Korea based inventors not collaborating, single inventor per patent. The dependent variable for Columns 1-3 is cite3, and for Columns 4-6 is cite5. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 4.3a *Marginal Effect of Negative Binomial Regression Results for Patents by Korea Assignees*

	(17)	(18)	(19)	(20)	(21)	(22)
Dependent variable:	Cite3	Cite3	Cite3	Cite5	Cite5	Cite5
KR_KRCollab	-0.060			-0.169		
KR_USCollab		0.435			0.940	
KR_NC			-0.167			-0.535

Note: This table presents the marginal effect of collaborations on patent citation counts for patents with Korea assignees from 1974 to 2023, using Negative Binomial regression. Column 1 shows results for Korea based inventors collaborating domestically, Column 2 for US and Korea-based inventors collaborating, Column 3 shows results for Korea based inventors not collaborating, single inventor per patent. The dependent variable for Columns 1-3 is cite3, and for Columns 4-6 is cite5. All coefficients are significant at 1 percent significance level.

Table 4.4 *Negative Binomial Regression Results for Patents by Taiwan Assignees*

	(23)	(24)	(25)	(26)	(27)	(28)
Dependent variable:	cite3	cite3	cite3	cite5	cite5	cite5
TW_TWCollab	-0.058*** (0.012)			-0.066*** (0.012)		
TW_USCollab		0.445*** (0.025)			0.595*** (0.024)	
TW_NC			-0.070*** (0.023)			-0.094*** (0.023)
Gender	-0.013 (0.010)	-0.014 (0.010)	-0.013 (0.010)	-0.025*** (0.009)	-0.027*** (0.009)	-0.026*** (0.009)
Patent Age	0.171*** (0.005)	0.171*** (0.005)	0.171*** (0.005)	0.196*** (0.005)	0.195*** (0.005)	0.196*** (0.005)
Inventor Count	0.039*** (0.003)	0.038*** (0.003)	0.040*** (0.003)	0.048*** (0.003)	0.047*** (0.003)	0.049*** (0.003)
Constant	-3.954** (1.749)	-3.997** (1.744)	-3.946** (1.749)	-4.929*** (1.843)	-4.941*** (1.835)	-4.906*** (1.843)
Year FE	Included	Included	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included	Included	Included
Observations	158,022	158,022	158,022	158,022	158,022	158,022

Note: This table presents the effects of collaborations on patent citation counts for patents with Taiwan assignees from 1974 to 2023, using Negative Binomial regression. Column 1 shows results for Taiwan based inventors collaborating domestically, Column 2 for US and Taiwan-based inventors collaborating, Column 3 shows results for Taiwan based inventors not collaborating, single inventor per patent. The dependent variable for Columns 1-3 is cite3, and for Columns 4-6 is cite5. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 4.4a Marginal Effect of Negative Binomial Regression Results for Patents by Taiwan Assignees

	(23)	(24)	(25)	(26)	(27)	(28)
Dependent variable:	Cite3	Cite3	Cite3	Cite5	Cite5	Cite5
TW_TWCollab	-0.058			-0.160		
TW_USCollab		0.446			1.427	
TW_NC			-0.070			-0.226

Note: This table presents the marginal effect of collaborations on patent citation counts for patents with Taiwan assignees from 1974 to 2023, using Negative Binomial regression. Column 1 shows results for Taiwan based inventors collaborating domestically, Column 2 for US and Taiwan-based inventors collaborating, Column 3 shows results for Taiwan based inventors not collaborating, single inventor per patent. All coefficients are significant at 1 percent significance level.

Next, hypothesis 3 aims to evaluate the impact of non-collaborative patents, i.e., patents with single inventor, on patent citations in comparison to patents where inventors collaborate either within-country or internationally. For US-based firms, a comparison between Model 1 and Model 9 from Table 4.5a, as well as Models 2, 3, and 4 from Table 4.1a, reveals that collaborative efforts among inventors result in significantly higher patent citations compared to patents with singular inventors. When US based inventors do not collaborate, it decreases the expected number of patent citations within 3 years of patent grant by 0.16 citations, *ceteris paribus* as opposed to when there is collaboration within US inventors it increases the expected number of patent citations within 3 years of patent grant by 0.049 citations, *ceteris paribus*. Similarly, when US based inventors collaborate with Japan based inventors and Korea based inventors it increases the expected number of patent citation within 3 years of patent grant by 0.461 citations and 1.103 citations, *ceteris paribus*, respectively. However, when US based inventors collaborate with Taiwan based inventors, it decreases the expected number of patent citation within 3 years of patent grant by 1.188 citations, *ceteris paribus*.

In the case of Japanese firms, a comparison between Model 11 and Model 13 from Table 4.2a shows that within-country collaboration among Japanese inventors yields better results than patents by singular inventors. When Japan based inventors do not collaborate, it decreases the expected number of patent citations within 3 years of patent grant by 0.114 citations, *ceteris paribus*. When Japan based inventors collaborate within themselves, it decreases the expected number of patent citations within 3 years of patent grant by 0.046 citations, *ceteris paribus*, which in absolute term is higher than the former. However, this positive effect does not extend to international collaborations involving US-based inventors, as evidenced when comparing Model 11 and 12. We see when US based inventors collaborate with Japan based inventors it decreases the expected number of patent citation within 3 years of patent grant by 0.281 citations, *ceteris paribus*, respectively. All these effects are significant

at a 1 percent significance level and consistent when the number of patent citations within 5 years of patent grant is considered.

For Korean firms, the analysis of Models 17, 18, and 19 from Table 4.3a demonstrates that both international and within-country collaborations are more beneficial in terms of patent citations than non-collaborative patents. When Korea based inventors do not collaborate, it decreases the expected number of patent citations within 3 years of patent grant by 0.167 citations, *ceteris paribus*. Whereas, when Korea based inventors collaborate within themselves, it decreases the expected number of patent citations within 3 years of patent grant by 0.06 citations, *ceteris paribus*. And, when US based inventors collaborate with Korea based inventors it increases the expected number of patent citation within 3 years of patent grant by 0.435 citations, *ceteris paribus*. All these effects are significant at a 1 percent significance level and consistent when the number of patent citations within 5 years of patent grant is considered.

Similarly, for Taiwanese firms, Models 23, 24, and 25 from Table 4.4a indicate that collaborative efforts, whether international or within-country, lead to higher patent citations compared to patents with singular inventors. These findings are consistent with both *cite3* and *cite5*. When Taiwan based inventors do not collaborate, it decreases the expected number of patent citations within 3 years of patent grant by 0.07 citations, *ceteris paribus*. When Taiwan based inventors collaborate within themselves, it decreases the expected number of patent citations within 3 years of patent grant by 0.058 citations, *ceteris paribus*. Whereas, when US based inventors collaborate with Taiwan based inventors it increases the expected number of patent citations within 3 years of patent grant by 0.446 citations, *ceteris paribus*. All these effects are significant at a 1 percent significance level and consistent when the number of patent citations within 5 years of patent grant is considered.

For hypothesis 4 we look at inventor level, examining whether if the inventor has collaborated in the past, it affects the patent citation of their patents. We do this only for US based firms (US Assignees). Thus, we consider inventors who have collaborated in the past on a patent by US based firms. The regression results in Table 4.6 and marginal effect from Table 4.6a. When US based inventors collaborated in the past for US firms, it increased the expected number of patent citations within 3 years of patent grant by 0.298 citations, *ceteris paribus*. Similarly, when Japan based inventors and Korea based inventors collaborated in the past for US firms, it increased the expected number of patent citation within 3 years of patent grant by 0.814 citations and 0.75 citations, *ceteris paribus*, respectively. However, when Taiwan based inventors collaborated in the past for US firms, it decreases the expected number of patent citations within 3 years of patent grant by 0.104 citations, *ceteris paribus*. All these effects are significant at a 1 percent significance level and consistent when the number of patent citations

within 5 years of patent grant is considered. This reveals that except for Taiwan, the inventors who have collaborated in the past have positive and higher patent citation now compared to the ones who have not collaborated in the past.

Table 4.5 *Negative Binomial regression result for patent of US assignees*

Dependent variable:	(1) cite3	(9) cite3	(5) cite5	(10) cite5
US_USCollab	0.025*** (0.006)		0.021*** (0.006)	
US_NC		-0.082*** (0.011)		-0.099*** (0.010)
Gender	0.097*** (0.007)	0.097*** (0.007)	0.077*** (0.006)	0.078*** (0.006)
R&D	-0.173*** (0.008)	-0.174*** (0.008)	-0.212*** (0.007)	-0.212*** (0.007)
Firm age	-0.088*** (0.006)	-0.089*** (0.006)	-0.096*** (0.005)	-0.097*** (0.005)
Patent age	0.117*** (0.002)	0.117*** (0.002)	0.143*** (0.002)	0.143*** (0.002)
Inventor count	0.036*** (0.001)	0.033*** (0.001)	0.036*** (0.001)	0.032*** (0.001)
Constant	-24.572 (7,126.379)	-24.551 (7,126.717)	-27.178 (15,767.979)	-27.206 (16,309.411)
Year FE	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included
Observations	402,853	402,853	402,853	402,853

Note: This table presents the effects of collaborations on patent citation counts for patents with US assignees from 1974 to 2023, using Negative Binomial regression. Column 1 shows results for US based inventors collaborating domestically, Column 2 shows results for US based inventors not collaborating, single inventor per patent. The dependent variable for Columns 1-2 is cite3, and for Columns 3-4 is cite5. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 4.5a *Marginal Effect*

	(1) Marginal Effect	(9) Marginal Effect	(5) Marginal Effect	(10) Marginal Effect
US_US_Collab	0.049		0.092	
US_NC		-0.160		-0.437

Note: This table presents the marginal effect of collaborations on patent citation counts for patents with US assignees from 1974 to 2023, using Negative Binomial regression. Column 1 shows results for US based inventors collaborating domestically, Column 2 shows results for US based inventors not collaborating, single inventor per patent. The dependent variable for Columns 1-2 is cite3, and for Columns 3-4 is cite5. All coefficients are significant at 1 percent significance level.

Table 4.6 *Negative Binomial Regression Results for Patents by US Assignees with Inventors' Past Collaboration Experience*

	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
Dependent variable:	cite3	cite5	cite3	cite5	cite3	cite5	cite3	cite5
KR_yes	0.386*** (0.014)	0.423*** (0.013)						
JP_yes			0.418*** (0.009)	0.404*** (0.008)				
TW_yes					-0.108*** (0.012)	-0.091*** (0.011)		
US_yes							0.202*** (0.006)	0.192*** (0.006)
Gender	0.082*** (0.007)	0.061*** (0.006)	0.081*** (0.007)	0.061*** (0.006)	0.098*** (0.007)	0.078*** (0.006)	0.096*** (0.007)	0.075*** (0.006)
R&D	-0.164*** (0.008)	-0.199*** (0.007)	-0.173*** (0.008)	-0.210*** (0.007)	-0.170*** (0.008)	-0.209*** (0.007)	-0.187*** (0.008)	-0.225*** (0.007)
Firm Age	-0.083*** (0.006)	-0.089*** (0.005)	-0.089*** (0.006)	-0.097*** (0.005)	-0.087*** (0.006)	-0.095*** (0.005)	-0.091*** (0.006)	-0.099*** (0.005)
Patent Age	0.115*** (0.002)	0.142*** (0.002)	0.110*** (0.002)	0.138*** (0.002)	0.117*** (0.002)	0.143*** (0.002)	0.115*** (0.002)	0.141*** (0.002)
Inventor Count	0.034*** (0.001)	0.033*** (0.001)	0.032*** (0.001)	0.032*** (0.001)	0.037*** (0.001)	0.036*** (0.001)	0.042*** (0.001)	0.042*** (0.001)
Constant	-24.448 (7,124)	-27.057 (15,839)	-24.238 (7,111)	-26.946 (16,399)	-24.573 (7,108)	-27.204 (16,174)	-24.677 (7,124)	-27.300 (15,827)
Year FE	Included							
Firm FE	Included							
Observations	402,853	402,853	402,853	402,853	402,853	402,853	402,853	402,853

Note: This table presents the effects of inventors collaborating in the past on patent citation counts for patents with US assignees from 1974 to 2023, using Negative Binomial regression. Column 1&2 shows results for Korea based inventors who have collaborated in the past, Column 3&4 for Japan based inventors who have collaborated in the past, Column 5&6 shows results for Taiwan based inventors who have collaborated in the past, Column 7&8 shows results for US based inventors who have collaborated in the past. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table 4.6a *Marginal Effect of Negative Binomial Regression Results for Patents by US Assignees with Inventors' Past Collaboration Experience*

	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
Dependent variable:	Cite3	Cite5	Cite3	Cite5	Cite3	Cite5	Cite3	Cite5
KR_yes	0.750	1.862						
JP_yes			0.814	1.784				
TW_yes					-0.104	-0.213		
US_yes							0.298	0.648

Note: This table presents the marginal effect of inventors collaborating in the past on patent citation counts for patents with US assignees from 1974 to 2023, using Negative Binomial regression. Column 1&2 shows results for Korea based inventors who have collaborated in the past, Column 3&4 for Japan based inventors who have collaborated in the past, Column 5&6 shows results for Taiwan based inventors who have collaborated in the past, Column 7&8 shows results for US based inventors who have collaborated in the past. All coefficients are significant at 1 percent significance level.

### Interaction of Firm Age and Collaboration Variables

Interacting firm age and collaboration variables is essential for understanding the nuanced effects of collaboration on patent citations. By incorporating these interaction terms, we can discern how the age of a firm modifies the impact of both within-country and international collaborations on patent citation counts. This approach allows us to capture the heterogeneity in outcomes that might be obscured if we only consider the main effects. For instance, the benefits of collaboration might differ significantly for younger versus older firms due to differences in resources, experience, and strategic priorities. Thus, examining these interactions provides a more comprehensive understanding of the dynamics at play, enabling us to draw more precise conclusions about the efficacy of different types of collaborations across the lifespan of firms. For the sake of readability only marginal effects are presented here, regression results are presented in Table number A.2 and A.3 in Appendix.

Table 4.7 *Marginal Effects of Negative Binomial Regression for Interaction Between Firm Age and Collaboration*

	(37)	(38)	(40)	(41)	(42)	(43)	(44)	(45)
Dependent variable:	Cite3	Cite5	Cite3	Cite5	Cite3	Cite5	Cite3	Cite5
Independent variable	US_US	US_US	US_JP	US_JP	US_TW	US_TW	US_KR	US_KR
Collab = 0	-0.048	-0.089	-0.048	-0.089	-0.050	-0.090	-0.048	-0.087
Collab = 1	-0.050	-0.091	-0.017	-0.026	-0.080	-0.128	-0.097	-0.236

Note: This table presents the average marginal effects of firm age on patent citations for inventors who have collaborated and those who have not, in patents with US assignees from 1974 to 2023. Columns 1 and 2 show results for domestic collaboration among US-based inventors, Columns 3 and 4 for collaboration between US and Japan-based inventors, Columns 5 and 6 for collaboration between US and Taiwan-based inventors, and Columns 7 and 8 for collaboration between US and Korea-based inventors. All coefficients are significant at the 1 percent significance level.

Table 4.7 provides the average marginal effects of firm age on patent citations for different types of collaborations (US-US, JP-US, TW-US, and KR-US) when the collaboration is present (Collab = 1) or absent (Collab = 0). The table shows results for two different dependent variables: Cite3 (citations within 3 years) and Cite5 (citations within 5 years).

In Model 37 and 38, for both 3-year and 5-year citation windows, US-US collaboration has a minimal impact on the effect of firm age on citations. The negative effect of firm age is slightly stronger with collaboration, but the difference is negligible. The impact of firm age approximately doubles when considering a 5-year window compared to a 3-year window, regardless of collaboration status. These effects are significant at 1 percent significance level.

Japan-US collaboration in Model 39 and 40 significantly mitigates the negative effect of firm age on citations for both 3-year and 5-year windows. The reduction in the negative effect is more pronounced for the 5-year window (from -0.089 to -0.026) compared to the 3-year window (from -0.048 to -0.017). This suggests that Japan-US collaboration is particularly beneficial for older firms in terms of patent impact, especially over a longer time frame. These effects are significant at 1 percent significance level.

In Model 42 and 43, Taiwan-US collaboration amplifies the negative effect of firm age on citations for both time windows, The amplification is more pronounced for the 5-year window (from -0.090 to -0.128) compared to the 3-year window (from -0.050 to -0.080). This indicates that Taiwan-US collaboration may be more advantageous for younger firms, with the effect becoming more pronounced over a longer citation period. These effects are significant at 1 percent significance level.

Korea-US collaboration in Model 44 and 45 strongly amplifies the negative effect of firm age on citations, with the effect being dramatically more pronounced for the 5-year period. For the 3-year period, the negative effect roughly doubles with collaboration (from -0.048 to -

0.097). For the 5-year period, the effect nearly triples (from -0.087 to -0.236). This suggests that Korea-US collaboration is significantly more beneficial for younger firms, especially when considering longer-term citation impacts. These effects are significant at 1 percent significance level.

#### Robustness check

Poisson Pseudo-Maximum Likelihood with High-Dimensional Fixed Effects (PPMLhdfc) is used as a robustness check for a main analysis conducted with a Negative Binomial model. By using PPML as a robustness check, we compare the direction and significance of coefficients with those obtained from the Negative Binomial model. For the sake of readability, the regression tables for PPML are not presented here. (see Table A.4- A.11 in Appendix). From Table A.4 - A.11, we see the direction, magnitude and significance of all the models are consistent with the negative binomial regression models. This consistency in results across different estimation methods strengthens the reliability of the findings. The results are consistent across both methods, providing stronger evidence for the reliability of the conclusions.

## 5. Conclusion and Discussion

This study investigates the occurrence of knowledge spillover and its mutual benefits for the countries involved, focusing on the USA and three Asian leaders in the semiconductor industry: Japan, Korea, and Taiwan. The primary aim is to determine whether US firms benefit from collaborating with inventors from these Asian countries and to assess if the benefits are reciprocal for the Asian firms. Hypothesis 1 aimed to determine whether international collaboration is beneficial for US-based firms. The results indicate that when US-based inventors collaborate with inventors from Korea and Japan, they produce patents with a higher number of citations compared to domestic collaborations, demonstrating the advantages of international collaboration for US firms. However, collaborations with inventors based in Taiwan result in fewer citations, which may be due to Taiwan's transition from a manufacturing-based economy to an innovation-based one (Chen, Chang, Huang, & Fu, 2005). This shift could create conflicts when collaborating with U.S. firms, as both are now focused on innovation. In contrast, Japan and Korea, which remain manufacturing-centric, complement the innovation-centric approach of U.S. firms, leading to more effective collaborations.

Hypothesis 2 aims to determine if the benefits of collaboration are reciprocated by Asian countries. Specifically, this hypothesis examines whether patents from firms in Japan, Korea, and Taiwan receive more citations when collaborating with US inventors compared to domestic collaborations. The findings reveal that for Japanese firms, domestic collaboration yields better outcomes. Japan has strong domestic networks and communication, also has a strong national innovation system, particularly in high-tech industries like semiconductors. This system may foster more effective domestic collaborations due to shared understanding of the domestic innovation ecosystem, easier access to local resources, funding, and support structures. Irwin & Klenow (1994) found “in Japan, various formal and informal barriers, such as investment restrictions and the closed nature of the industry to outsiders, supposedly prevent U.S. firms from acquiring information on Japanese production technology”. Thus Borrus, Tyson, and Zysman (1986, p. 111) claims that "critically important spillovers are indeed generated in this industry, and in Japan's case policy and industry structures combine to keep them isolated from diffusing internationally." These factors may result in domestic collaborations yielding better outcomes than international collaborations with U.S. inventors. In contrast, for Korean and Taiwanese firms, collaborations with U.S. inventors lead to higher patent citations, suggesting that international collaboration with U.S. inventors is more advantageous for these countries. This aligns with most studies on this topic.

When comparing these results with patents where inventors did not collaborate, we see in general collaboration either domestically or internationally is better than not collaborating at all for all the 4 countries in this study. Additionally, this study examines whether past collaborations at the inventor level impact the current patent citation counts. The findings of hypothesis 4 indicate that inventors who have collaborated in the past produce patents with higher citation counts compared to those who have not. These results suggest that past collaboration experience is useful in producing impactful patents. This could be attributed to a few reasons such as – Singh & Fleming (2010) found out past collaborations allow inventors to accumulate diverse knowledge and skills, which can be applied to future inventions. This broader knowledge base may lead to more innovative and impactful patents. Wuchty, Jones, and Uzzi (2007) discuss collaboration exposes inventors to different perspectives and problem-solving approaches, potentially improving their ability to develop more valuable and widely applicable inventions. Powell, Koput, and Smith-Doerr (1996) show that collaborative networks can provide access to a wider range of resources, including equipment, funding, and expertise, which can contribute to the development of higher-quality patents.

Furthermore, an interesting interaction with the firm age was also performed to see if the firm age plays any role in impacting the patent's citation count. Overall, the findings of this interaction indicate that the age of a firm does not substantially influence the citation frequency of collaborative patents. It can be concluded that variations in patent citations are primarily attributable to the different types of collaboration variables employed in the analysis. Additionally, it is noteworthy that the control variable "inventor count" is positive and significant at the 1 percent level across all models in this study. This suggests that a higher number of unique inventors per patent is associated with increased collaboration, leading to a higher expected number of patent citations. This reconfirms the main idea of this study that collaboration is beneficial.

Lastly, a robustness check was performed using the Poisson Pseudo-Maximum Likelihood with High-Dimensional Fixed Effects (Correia, Guimarães, & Zylkin, 2020) PPMLhdfc serves as an excellent robustness check for analyses conducted using the negative binomial model due to its flexibility and minimal assumptions. Unlike the negative binomial model, PPMLhdfc does not require specific distributional assumptions for the dependent variable, making it more versatile. It remains consistent even in the presence of heteroskedasticity and can handle zero values naturally. Furthermore, PPMLhdfc's ability to

incorporate high-dimensional fixed effects allows for controlling various sources of heterogeneity in panel data. And results, the direction and significance of the coefficients in all the models are consistent with the PPML estimator.

### Limitations

While this study provides significant insights into the effects of international collaboration on patent citations, several limitations should be noted while interpreting the results. First, the dataset utilized for this study is limited to patent citations, which, while a common measure of innovation impact, may not fully capture the multifaceted nature of patent value. Citations can be influenced by various factors such as differences in citation practices across countries and industries, which might introduce bias. Second, the data availability for certain control variables was restricted. For example, firm age and R&D intensity data were only available for patents with US assignees, resulting in their exclusion from models involving patents from Korea, Japan, and Taiwan. This limitation potentially omits important variables that could affect patent citations, thus influencing the results. Third, while this study includes year and firm fixed effects to control for unobserved heterogeneity, the potential for omitted variable bias still exists. There may be other influential factors not captured by the fixed effects that could impact patent citations, thereby affecting the study's conclusions. Fourth, while this study focuses on collaborations between US inventors and those from Japan, Korea, and Taiwan in the semiconductor industry, the findings may not be generalizable to other industries or countries. The dynamics of collaboration and its impact on innovation could vary significantly across different sectors and geographical regions. Lastly, the study's temporal scope might not fully account for long-term effects of collaboration on patent citations. Patents can continue to receive citations long after their grant date, and the 3-year and 5-year windows used in this study may not capture the full impact of international collaborations. Future research should consider longer time frames to provide a more comprehensive understanding of the effects of collaboration on patent citations. Despite these limitations, this study contributes valuable knowledge to the field of innovation and international collaboration, offering a foundation for future research to build upon and address these constraints.

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## Appendix

Table A.1 *Negative Binomial Regression Results for Patents by US Assignees (cite5)*

Dependent variable:	(5) cite5	(6) cite5	(7) cite5	(8) cite5
US_USCollab	0.021*** (0.006)			
US_JPCollab		0.187*** (0.018)		
US_TWCollab			-0.665*** (0.025)	
US_KRCollab				0.721*** (0.030)
Gender	0.077*** (0.006)	0.077*** (0.006)	0.077*** (0.006)	0.071*** (0.006)
R&D	-0.212*** (0.007)	-0.211*** (0.007)	-0.213*** (0.007)	-0.199*** (0.007)
Firm age	-0.096*** (0.005)	-0.095*** (0.005)	-0.097*** (0.005)	-0.090*** (0.005)
Patent age	0.143*** (0.002)	0.142*** (0.002)	0.144*** (0.002)	0.142*** (0.002)
Inventor count	0.036*** (0.001)	0.033*** (0.001)	0.041*** (0.001)	0.032*** (0.001)
Constant	-27.178 (15,767.979)	-27.123 (15,701.761)	-27.254 (15,852.242)	-26.107 (9,668.177)
Year FE	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included
Observations	402,853	402,853	402,853	402,853

Note: This table presents the effects of collaborations on patent citation counts for patents with US assignees from 1974 to 2023, using Negative Binomial regression. Column 1 shows results for US inventors collaborating domestically, Column 2 for US and Japan-based inventors collaborating, Column 3 for US and Taiwan-based inventors collaborating, and Column 4 for US and Korea-based inventors collaborating. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .

Table A.2 *Negative Binomial Regression for Interaction Between Firm Age and Collaboration*

Dependent variable:	(1)	(2)	(3)	(4)
	cite3	cite3	cite3	cite3
Gender	0.095*** (0.007)	0.096*** (0.007)	0.095*** (0.007)	0.090*** (0.007)
R&D	-0.058*** (0.008)	-0.062*** (0.008)	-0.058*** (0.008)	-0.052*** (0.008)
Firm age	0.338*** (0.012)	0.337*** (0.012)	0.342*** (0.012)	0.340*** (0.012)
Patent age	0.119*** (0.002)	0.118*** (0.002)	0.121*** (0.002)	0.118*** (0.002)
Inventor count	0.038*** (0.001)	0.034*** (0.001)	0.045*** (0.001)	0.036*** (0.001)
Firm Age	-0.025*** (0.001)	-0.025*** (0.001)	-0.025*** (0.001)	-0.025*** (0.001)
1.US_US_Collab	0.032* (0.018)			
1.US_US_Collab#c.firm_age	-0.000 (0.001)			
1.JP_US_Collab		-0.350*** (0.071)		
1.JP_US_Collab#c.firm_age		0.017*** (0.002)		
1.TW_US_Collab			0.550*** (0.125)	
1.TW_US_Collab#c.firm_age			-0.037*** (0.004)	
1.KR_US_Collab				0.661*** (0.097)
1.KR_US_Collab#c.firm_age				-0.004 (0.003)
Constant	-25.201 (7,105.006)	-25.871 (10,378.395)	-25.281 (7,105.004)	-24.639 (5,551.242)
Year FE	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included
Observations	402,853	402,853	402,853	402,853

Note: This table presents the interaction effects of collaborations and firm age on patent citation counts for patents with US assignees from 1974 to 2023, using Negative Binomial regression. Column 1 shows results for interaction of firm age with US inventors collaborating domestically, Column 2 for US and Japan-based inventors collaborating, Column 3 for US and Taiwan-based inventors collaborating, and Column 4 for US and Korea-based inventors collaborating. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table A.3 *Negative Binomial Regression for Interaction Between Firm Age and Collaboration*

Dependent variable:	(1)	(2)	(3)	(4)
	cite5	cite5	cite5	cite5
Gender	0.075*** (0.006)	0.076*** (0.006)	0.074*** (0.006)	0.069*** (0.006)
R&D	-0.118*** (0.008)	-0.122*** (0.008)	-0.118*** (0.008)	-0.107*** (0.008)
Firm age	0.248*** (0.011)	0.247*** (0.011)	0.252*** (0.011)	0.251*** (0.011)
Patent age	0.145*** (0.002)	0.144*** (0.002)	0.147*** (0.002)	0.144*** (0.002)
Inventor count	0.038*** (0.001)	0.035*** (0.001)	0.043*** (0.001)	0.034*** (0.001)
Firm Age	-0.020*** (0.001)	-0.020*** (0.001)	-0.020*** (0.001)	-0.020*** (0.001)
1.US_US_Collab	0.022 (0.017)			
1.US_US_Collab#c.firm_age	-0.000 (0.001)			
1.JP_US_Collab		-0.315*** (0.067)		
1.JP_US_Collab#c.firm_age		0.015*** (0.002)		
1.TW_US_Collab			0.223** (0.113)	
1.TW_US_Collab#c.firm_age			-0.028*** (0.003)	
1.KR_US_Collab				0.897*** (0.097)
1.KR_US_Collab#c.firm_age				-0.006** (0.003)
Constant	-27.752 (16,219.378)	-27.682 (15,949.793)	-27.794 (15,709.653)	-26.410 (8,548.414)
Year FE	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included
Observations	402,853	402,853	402,853	402,853

Note: This table presents the interaction effects of collaborations and firm age on patent citation counts for patents with US assignees from 1974 to 2023, using Negative Binomial regression. Column 1 shows results for interaction of firm age with US inventors collaborating domestically, Column 2 for US and Japan-based inventors collaborating, Column 3 for US and Taiwan-based inventors collaborating, and Column 4 for US and Korea-based inventors collaborating. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table A.4 PPML Regression Results for Patents by US Assignees (*cite3*)

Dependent Variable:	(1)	(2)	(3)	(4)	(5)
	<i>cite3</i>	<i>cite3</i>	<i>cite3</i>	<i>cite3</i>	<i>cite3</i>
US_USCollab	0.018** (0.009)				
US_JPCollab		0.241*** (0.039)			
US_TWCollab			-0.642*** (0.043)		
US_KRCollab				0.668*** (0.048)	
US_NC					-0.081*** (0.012)
Gender	0.099*** (0.013)	0.097*** (0.013)	0.098*** (0.013)	0.091*** (0.013)	0.099*** (0.013)
R&D	-0.121*** (0.011)	-0.116*** (0.011)	-0.124*** (0.011)	-0.119*** (0.011)	-0.122*** (0.011)
Firm age	-0.062*** (0.005)	-0.060*** (0.005)	-0.065*** (0.005)	-0.058*** (0.005)	-0.063*** (0.005)
Patent age	0.088*** (0.003)	0.086*** (0.003)	0.092*** (0.003)	0.088*** (0.003)	0.088*** (0.003)
Inventor count	0.035*** (0.001)	0.031*** (0.001)	0.042*** (0.001)	0.034*** (0.001)	0.033*** (0.001)
Constant	-0.818*** (0.063)	-0.776*** (0.063)	-0.889*** (0.064)	-0.814*** (0.063)	-0.799*** (0.063)
Year FE	Included	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included	Included
Observations	402,853	402,853	402,853	402,853	402,853

Note: This table presents the effects of collaborations on patent citation counts for patents with US assignees from 1974 to 2023, using PPML regression. Column 1 shows results for US inventors collaborating domestically, Column 2 for US and Japan-based inventors collaborating, Column 3 for US and Taiwan-based inventors collaborating, Column 4 for US and Korea-based inventors collaborating, and Column 5 for US based inventors not collaborating. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .

Table A.5 PPML Regression Results for Patents by US Assignees(*cite5*)

Dependent Variable:	(1) <i>cite5</i>	(2) <i>cite5</i>	(3) <i>cite5</i>	(4) <i>cite5</i>	(5) <i>cite5</i>
US_USCollab	0.017** (0.008)				
US_JPCollab		0.172*** (0.036)			
US_TWCollab			-0.669*** (0.045)		
US_KRCollab				0.867*** (0.050)	
US_NC					-0.096*** (0.012)
Gender	0.072*** (0.012)	0.072*** (0.012)	0.072*** (0.012)	0.062*** (0.012)	0.073*** (0.012)
R&D	-0.162*** (0.010)	-0.159*** (0.010)	-0.165*** (0.010)	-0.159*** (0.010)	-0.163*** (0.010)
Firm age	-0.075*** (0.005)	-0.074*** (0.005)	-0.077*** (0.005)	-0.069*** (0.005)	-0.076*** (0.005)
Patent age	0.094*** (0.003)	0.092*** (0.003)	0.097*** (0.003)	0.094*** (0.003)	0.094*** (0.003)
Inventor count	0.036*** (0.001)	0.033*** (0.001)	0.042*** (0.001)	0.034*** (0.001)	0.034*** (0.001)
Constant	0.006 (0.057)	0.033 (0.057)	-0.058 (0.058)	0.010 (0.057)	0.028 (0.057)
Year FE	Included	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included	Included
Observations	402,853	402,853	402,853	402,853	402,853

Note: This table presents the effects of collaborations on patent citation counts for patents with US assignees from 1974 to 2023, using PPML regression. Column 1 shows results for US inventors collaborating domestically, Column 2 for US and Japan-based inventors collaborating, Column 3 for US and Taiwan-based inventors collaborating, Column 4 for US and Korea-based inventors collaborating, and Column 5 for US based inventors not collaborating. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .

Table A.6 PPML Regression Results for Patents by Taiwan Assignees

VARIABLES	(1) cite3	(2) cite3	(3) cite3	(5) cite5	(6) cite5	(7) cite5
TW_TWCollab	-0.056** (0.022)			-0.072** (0.029)		
TW_USCollab		0.525*** (0.049)			0.779*** (0.065)	
TW_NC			-0.030 (0.025)			-0.047 (0.032)
Gender	-0.024 (0.018)	-0.025 (0.018)	-0.024 (0.018)	-0.041 (0.027)	-0.042 (0.027)	-0.041 (0.027)
Patent Age	0.166*** (0.009)	0.168*** (0.009)	0.166*** (0.009)	0.149*** (0.012)	0.153*** (0.011)	0.149*** (0.012)
Inventor Count	0.048*** (0.006)	0.045*** (0.005)	0.050*** (0.006)	0.059*** (0.007)	0.053*** (0.007)	0.061*** (0.008)
Constant	-2.056*** (0.128)	-2.113*** (0.125)	-2.080*** (0.127)	-0.888*** (0.167)	-0.979*** (0.164)	-0.916*** (0.167)
Year FE	Included	Included	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included	Included	Included
Observations	158,022	158,022	158,022	158,022	158,022	158,022

Note: This table presents the effects of collaborations on patent citation counts for patents with Taiwan assignees from 1974 to 2023, using PPML regression. Column 1 shows results for Taiwan based inventors collaborating domestically, Column 2 for US and Taiwan-based inventors collaborating, Column 3 shows results for Taiwan based inventors not collaborating, single inventor per patent. The dependent variable for Columns 1-3 is cite3, and for Columns 4-6 is cite5. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table A.7 *PPML Regression Results for Patents by Japan Assignees*

Dependent variable:	(1) cite3	(2) cite3	(3) cite3	(4) cite5	(5) cite5	(6) cite5
JP_JPCollab	-0.050*** (0.009)			-0.066*** (0.012)		
JP_USCollab		-0.216*** (0.020)			-0.261*** (0.020)	
JP_NC			-0.115*** (0.013)			-0.165*** (0.015)
Gender	-0.022* (0.012)	-0.023* (0.012)	-0.022* (0.012)	-0.010 (0.013)	-0.011 (0.013)	-0.010 (0.013)
Patent Age	0.001 (0.003)	0.002 (0.003)	0.002 (0.003)	-0.004 (0.004)	-0.003 (0.004)	-0.003 (0.004)
Inventor Count	0.033*** (0.001)	0.040*** (0.001)	0.031*** (0.001)	0.031*** (0.001)	0.040*** (0.001)	0.028*** (0.001)
Constant	0.412*** (0.065)	0.360*** (0.065)	0.402*** (0.065)	1.324*** (0.084)	1.260*** (0.084)	1.313*** (0.084)
Year FE	Included	Included	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included	Included	Included
Observations	294,185	294,185	294,185	294,185	294,185	294,185

Note: This table presents the effects of collaborations on patent citation counts for patents with Japan assignees from 1974 to 2023, using PPML regression. Column 1 shows results for Japan based inventors collaborating domestically, Column 2 for US and Japan-based inventors collaborating, Column 3 shows results for Japan based inventors not collaborating, single inventor per patent. The dependent variable for Columns 1-3 is cite3, and for Columns 4-6 is cite5. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table A.8 *PPML Regression Results for Patents by Korea Assignees*

Dependent variable:	(1) cite3	(2) cite3	(6) cite3	(3) cite5	(4) cite5	(5) cite5
KR_KRCollab	-0.068*** (0.019)			-0.092*** (0.022)		
KR_USCollab		0.525*** (0.076)			0.484*** (0.080)	
KR_NC			-0.169*** (0.030)			-0.249*** (0.034)
Gender	0.011 (0.013)	0.012 (0.013)	0.011 (0.013)	0.027* (0.015)	0.028* (0.015)	0.027* (0.015)
Patent Age	0.070*** (0.009)	0.070*** (0.009)	0.070*** (0.009)	0.106*** (0.012)	0.106*** (0.012)	0.106*** (0.012)
Inventor Count	0.049*** (0.004)	0.053*** (0.004)	0.046*** (0.004)	0.042*** (0.004)	0.047*** (0.004)	0.036*** (0.005)
Constant	-1.133*** (0.127)	-1.180*** (0.126)	-1.126*** (0.127)	-0.785*** (0.177)	-0.844*** (0.177)	-0.772*** (0.178)
Year FE	Included	Included	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included	Included	Included
Observations	119,615	119,615	119,615	119,615	119,615	119,615

Note: This table presents the effects of collaborations on patent citation counts for patents with Korea assignees from 1974 to 2023, using PPML regression. Column 1 shows results for Korea based inventors collaborating domestically, Column 2 for US and Korea-based inventors collaborating, Column 3 shows results for Korea based inventors not collaborating, single inventor per patent. The dependent variable for Columns 1-3 is cite3, and for Columns 4-6 is cite5. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 4.9 PPML Regression Results for Patents by US Assignees with Inventors' Past Collaboration Experience

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	cite3	cite5	cite3	cite5	cite3	cite5	cite3	cite5
KR_yes	0.448*** (0.024)	0.508*** (0.024)						
JP_yes			0.395*** (0.015)	0.364*** (0.015)				
TW_yes					-0.095*** (0.020)	-0.076*** (0.018)		
US_yes							0.193*** (0.009)	0.185*** (0.008)
Gender	0.087*** (0.013)	0.060*** (0.012)	0.081*** (0.013)	0.057*** (0.012)	0.099*** (0.013)	0.073*** (0.012)	0.097*** (0.013)	0.070*** (0.012)
R&D	-0.122*** (0.011)	-0.163*** (0.010)	-0.118*** (0.011)	-0.160*** (0.010)	-0.119*** (0.011)	-0.161*** (0.010)	-0.138*** (0.011)	-0.178*** (0.010)
Firm Age	-0.059*** (0.005)	-0.072*** (0.005)	-0.063*** (0.005)	-0.075*** (0.005)	-0.062*** (0.005)	-0.075*** (0.005)	-0.065*** (0.005)	-0.078*** (0.005)
Patent Age	0.088*** (0.003)	0.093*** (0.003)	0.084*** (0.003)	0.090*** (0.003)	0.089*** (0.003)	0.094*** (0.003)	0.087*** (0.003)	0.093*** (0.003)
Inventor Count	0.034*** (0.001)	0.035*** (0.001)	0.030*** (0.001)	0.032*** (0.001)	0.036*** (0.001)	0.037*** (0.001)	0.039*** (0.001)	0.040*** (0.001)
Constant	-0.805*** (0.063)	0.019 (0.057)	-0.717*** (0.062)	0.087 (0.057)	-0.827*** (0.063)	0.001 (0.058)	-0.930*** (0.063)	-0.101* (0.058)
Year FE	Included							
Firm FE	Included							
Observations	402,853	402,853	402,853	402,853	402,853	402,853	402,853	402,853

Note: This table presents the effects of inventors collaborating in the past on patent citation counts for patents with US assignees from 1974 to 2023, using PPML regression. Column 1&2 shows results for Korea based inventors who have collaborated in the past, Column 3&4 for Japan based inventors who have collaborated in the past, Column 5&6 shows results for Taiwan based inventors who have collaborated in the past, Column 7&8 shows results for US based inventors who have collaborated in the past. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table A.10 PPML Regression Results for Interaction between Firm Age and Collaboration

Dependent variable:	(1)	(2)	(3)	(4)
	cite3	cite3	cite3	cite3
Gender	0.095*** (0.013)	0.095*** (0.013)	0.094*** (0.013)	0.088*** (0.013)
R&D	-0.015 (0.011)	-0.014 (0.011)	-0.017 (0.011)	-0.014 (0.012)
Firm age	0.332*** (0.015)	0.330*** (0.015)	0.338*** (0.015)	0.334*** (0.014)
Patent age	0.091*** (0.003)	0.088*** (0.003)	0.096*** (0.003)	0.090*** (0.003)
Inventor count	0.037*** (0.001)	0.032*** (0.001)	0.045*** (0.001)	0.036*** (0.001)
Firm Age	-0.023*** (0.001)	-0.023*** (0.001)	-0.024*** (0.001)	-0.023*** (0.001)
1.US_US_Collab	0.019 (0.018)			
1.US_US_Collab#c.firm_age	-0.000 (0.001)			
1.JP_US_Collab		-0.439*** (0.112)		
1.JP_US_Collab#c.firm_age		0.021*** (0.004)		
1.TW_US_Collab			0.776*** (0.107)	
1.TW_US_Collab#c.firm_age			-0.046*** (0.003)	
1.KR_US_Collab				0.599*** (0.098)
1.KR_US_Collab#c.firm_age				0.002 (0.004)
Constant	-1.518*** (0.068)	-1.450*** (0.068)	-1.635*** (0.069)	-1.508*** (0.068)
Year FE	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included
Observations	402,847	402,847	402,847	402,847

Note: This table presents the interaction effects of collaborations and firm age on patent citation counts for patents with US assignees from 1974 to 2023, using PPML regression. Column 1 shows results for interaction of firm age with US inventors collaborating domestically, Column 2 for US and Japan-based inventors collaborating, Column 3 for US and Taiwan-based inventors collaborating, and Column 4 for US and Korea-based inventors collaborating. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table A.11 PPML Regression Results for Interaction between Firm Age and Collaboration

Dependent variable:	(1)	(2)	(3)	(4)
	cite5	cite5	cite5	cite5
Gender	0.070*** (0.012)	0.069*** (0.012)	0.069*** (0.012)	0.059*** (0.012)
R&D	-0.073*** (0.011)	-0.073*** (0.011)	-0.075*** (0.011)	-0.071*** (0.011)
Firm age	0.247*** (0.014)	0.246*** (0.014)	0.253*** (0.014)	0.249*** (0.014)
Patent age	0.095*** (0.003)	0.094*** (0.003)	0.100*** (0.003)	0.095*** (0.003)
Inventor count	0.038*** (0.001)	0.034*** (0.001)	0.045*** (0.001)	0.036*** (0.001)
Firm Age	-0.019*** (0.001)	-0.019*** (0.001)	-0.020*** (0.001)	-0.019*** (0.001)
1.US_US_Collab	0.018 (0.018)			
1.US_US_Collab#c.firm_age	-0.000 (0.001)			
1.JP_US_Collab		-0.340*** (0.103)		
1.JP_US_Collab#c.firm_age		0.016*** (0.004)		
1.TW_US_Collab			0.524*** (0.100)	
1.TW_US_Collab#c.firm_age			-0.039*** (0.003)	
1.KR_US_Collab				0.760*** (0.092)
1.KR_US_Collab#c.firm_age				0.003 (0.003)
Constant	-0.569*** (0.063)	-0.521*** (0.063)	-0.671*** (0.064)	-0.555*** (0.062)
Year FE	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included
Observations	402,847	402,847	402,847	402,847

Note: This table presents the interaction effects of collaborations and firm age on patent citation counts for patents with US assignees from 1974 to 2023, using PPML regression. Column 1 shows results for interaction of firm age with US inventors collaborating domestically, Column 2 for US and Japan-based inventors collaborating, Column 3 for US and Taiwan-based inventors collaborating, and Column 4 for US and Korea-based inventors collaborating. Year and firm fixed effects are included. Standard errors are in parentheses, with significance levels indicated by \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.