Korea and the World Economy, Vol. 20, No. 2 (August 2019) 157-191

Complementarity between GVC Participation and R&D Investment: Evidence from Korean Firm-level Data*

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This paper investigates complementarity between firms' participation in global value chains (GVCs) and R&D investment by employing a bivariate probit model and firm-level data of South Korea — 2014 Survey of Business Activities (SBA). We document complementary relationships between the two activities because each activity requires substantial fixed costs, but reinforces one another through cost reductions. Moreover, contrary to the findings of previous literature, we do not find that one-way trade and R&D investment are complementary. Lastly, complementarity between GVC participation and R&D investment holds at the intensive margins as well as at the extensive margin.

JEL Classification: F14, O32

Keywords: global value chain, R&D investment, innovation, complementarity

* Received July 11, 2019. Revised August 30, 2019. Accepted August 31, 2019. This paper is based on the thesis submitted by Eutteum Lee in fulfillment of the requirement for the Master of Art in Economics at Sogang University. The thesis was written under the supervision and with the help of Jung Hur.

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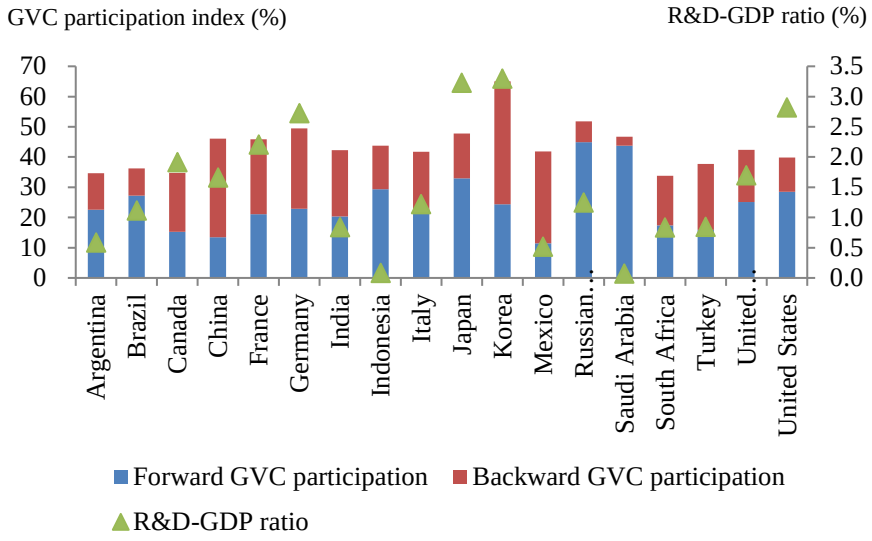
1. INTRODUCTION

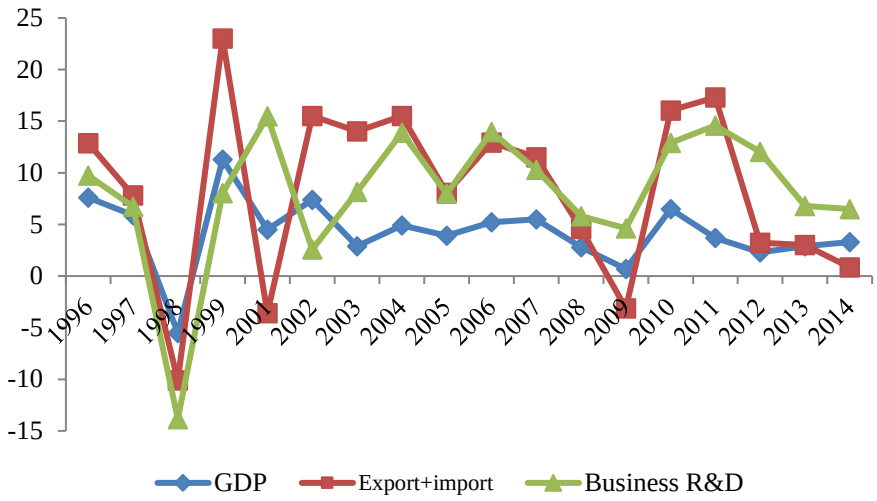
Due to the acceleration in the decrease of trade costs and the advancement of state-of-the-art technologies, global value chains (GVCs) are expanding precipitously. A GVC is defined as a phenomenon where stages of the production process are located across different countries. A GVC participation index of a country is computed as a percentage of gross exports and has two components: domestic value added contained in inputs sent to third countries for further processing and export (forward GVC participation) and foreign value added content of exports (backward GVC participation). According to figure 1, the total GVC participation index of South Korea was about 65% in 2009. In particular, its backward GVC participation index was about 41% in the same year. As implied by these statistics, South Korea is highly embedded in global value chains.

Figure 1 GVC Participation Index and R&D-GDP Ratio in 2009



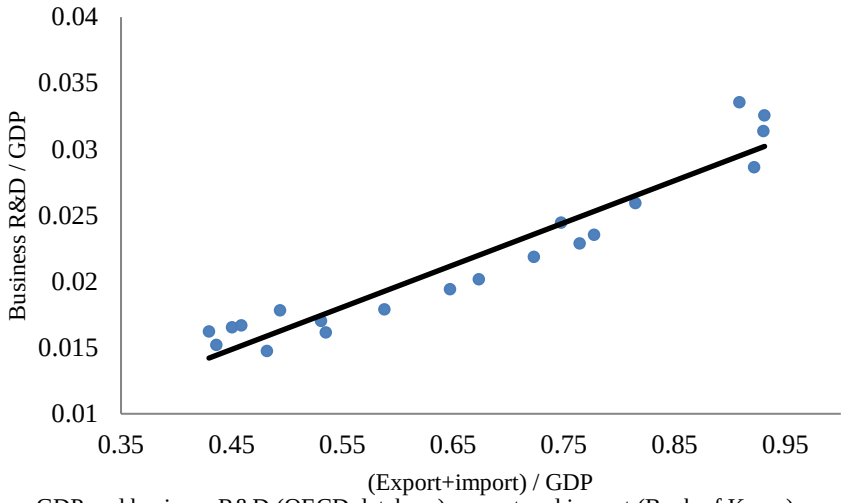
Note: One caveat regarding the GVC participation index is that most countries were likely to be affected by 2008 Global Financial Crisis.
Sources: GVC participation index (OECD, 2013); R&D-GDP ratio (World Bank).

Figure 2 Growth Rates (%)



Sources: GDP and business R&D (OECD database); export and import (Bank of Korea).

Figure 3 Trade Values and Business R&D Expenditures as Share of GDP



Source: GDP and business R&D (OECD database); export and import (Bank of Korea).

Another important observation to be made is that South Korea shows a remarkably high R&D investment relative to its GDP. Figure 1 shows that

about 3.3% of Korean GDP was spent on R&D investment in 2009.[1] As such, South Korea is highly involved in both GVCs and R&D investment and thus it can be conjectured that there could be a relationship between GVC participation and R&D spending. Figures 2 and 3 imply that engagement in GVCs and R&D investment are possibly correlated. Figure 2 plots growth rates of GDP, the sum of export values and import values, and business R&D expenditures of South Korea from 1996 to 2014. Both trade values and business R&D expenditures seem to be highly pro-cyclical at the macro-level. On the other hand, figure 3 shows the scatter plot of business R&D spending divided by GDP against trade values as share of GDP from 1995 to 2014. Clearly, there seems to be a strong association between trade values and business R&D expenditures at the macro-level even after GDP is controlled for. Noting that GVC participation involves both exporting and importing, GVC participation and R&D investment are likely to be interrelated.

Motivated by a possible interdependence between trade values and business R&D expenditures at the macro-level, this paper investigates a relationship between firms' GVC participation and R&D investment by employing firm-level data of South Korea — 2014 Survey of Business Activities (SBA). It should be noted that defining whether a firm participates GVCs is an arduous task since firm-level data rarely contains information on exported inputs and imported inputs.[2] Due to the aforementioned limitations of data, this paper uses SBA and follows recent firm-level studies which use firms' two-way trade as a proxy for GVC participation of firms (Baldwin and Yan, 2014). Although there could be concerns about using this proxy, consumption goods merely account for about 10% of total import values according to Korea Customs Service, which suggests that the methodology that we use is not severely problematic.[3]

Complementarity is defined as a relationship where two activities reinforce

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[1] https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS.

[2] Although using plant-level data of South Korea (Mining and Manufacturing Survey) would enable us to define GVC participation at the micro level more precisely, this dataset does not contain information regarding export values and import values of plants.

[3] https://unipass.customs.go.kr:38030/ets/index_eng.do.

each other by making each activity less costly. We seek to examine whether firms' GVC participation and R&D investment are complementary activities. Findings of this paper can be summarized as follows. First, by employing a bivariate probit model and 2014 SBA, we find that firms' GVC participation and R&D investment are complementary. We document complementarity between the two activities because each activity requires substantial fixed costs, but reinforces one another through cost reductions. Second, we do not find that one-way trade and R&D investment are complementary, contrary to the previous literature which finds that one-way trade and innovation are complementary. Lastly, complementarity between GVC participation and R&D investment holds at the intensive margins as well as at the extensive margin.

This paper is organized as follows. Section 2 reviews the existing literature and section 3 discusses theoretical backgrounds. Section 4 describes data and variables. Section 5 presents empirical regularities, and section 6 discusses an empirical strategy and estimation results. Section 7 concludes the paper.

2. LITERATURE REVIEW

Despite the growing importance of GVC, previous studies primarily focused on relationships between firms' one-way trade and innovation. Table 1 summarizes the existing literature.

Export & innovation: Many papers examined relationships between export and innovation at the firm level. Channels through which firms' exporting affects innovation include "learning by exporting". For example, Salomon and Shaver (2005) argued that exporting has a positive effect on the likelihood of a firm innovating by using firm-level data of Spain from 1990 to 1997 and a nonlinear GMM estimation model. In the opposite direction, literature on "self-selection" suggests that innovation may have positive effects on the probability that a firm exports. Since exporting is subject to fixed costs,

Table 1 Summary of Existing Literature on Relationships between Firms' One-way Trade and Innovation

Causal	One-way trade → Innovation	Export → Innovation Import → Innovation	Learning, competition	Salomon and Shaver (2005) Bloom, Draca and Van Reenen (2016)
	Innovation → One-way trade	Innovation → Export Innovation → Import	Self-selection	Bernard and Jensen (1999); Roper and Love (2002); Cassiman and Golovko (2011) Vogel and Wagner (2010)
Complementary	One-way trade & innovation	Export & Innovation Import & Innovation	Cost reduction	Girma, Gorg, and Hanley (2008); Golovko and Valentini (2011) Bøler, Moxnes and Ulltveit-Moe (2015)

Note: Estimation methods, analysis period and data, and theoretical channels for the results are elaborated in section 2.

innovation may enhance productivity of a firm and thus enables it to enter export markets. Bernard and Jensen (1999) showed that exporters are more productive than domestic firms by utilizing a sample of US manufacturing plants from 1984 to 1992 and a linear probability model in first differences. Roper and Love (2002) analyzed the impact of innovation on the probability of a firm exporting by using a sample of UK and German plants from 1991 to 1994 and a Tobit model where the dependent variable is export propensity. Cassiman and Golovko (2011) investigated the same question by using a sample of Spanish manufacturing firms from 1991 to 1998 and utilizing a dynamic random effects probit model.

On the other hand, a few papers investigated complementarity between exporting and innovation by using micro-level data. Rationale for complementarity is that both exporting and innovation are costly, but one activity reduces costs of the other and vice versa, which makes a virtuous cycle. Girma *et al*. (2008) documented complementarity between the two activities using firm-level database for the Ireland from 2000 to 2003 and a bivariate probit model, whereas they did not in case of the sample of UK from

1996 to 2003 with the same estimation model. Golovko and Valentini (2011) found complementary relationships between exporting and innovation using a sample of Spanish manufacturing firms over the period 1990 to 1999 and a bivariate probit framework. In particular, they argued that advertising explains the complementarity between exporting and innovation.

Import & innovation: Some studies focused on firm-level relationships between import and innovation. Importers may learn from technologies disembodied in imported inputs and/or they could face import competition. Using micro-level data of twelve European countries from 1996 to 2007 and OLS in five-year differences, Bloom *et al*. (2016) showed that Chinese imports increased innovation of European firms by competition effects. In the opposite direction, self-selection mechanisms imply that innovation has positive effects on the probability that a firm imports. That is, as importing is subject to fixed costs, a firm which enhances its productivity through innovation can import. For example, Vogel and Wagner (2010) showed this self-selection mechanism by using a micro-level data of Germany from 2001 to 2005 and OLS.

Similar to complementarity between export and innovation, import and R&D investment could also be complementary activities. Bøler *et al*. (2015) noted that both importing inputs and obtaining new knowledge are subject to fixed costs, but as they lead to cost savings, this makes R&D investment and international sourcing complementary. They showed this by using the introduction of a tax credit for R&D investment in Norway in 2002 as a natural experiment and employing firm-level data of Norway from 1997 to 2005 with a difference-in-differences model, and built a model of complementarity between R&D investment and international sourcing.

Contribution of this paper: First, we depart from the earlier literature which mostly examines relationships between firms' one-way trade and innovation, and investigate complementary relationships between firms' GVC participation and R&D investment by providing theoretical justifications and by employing a bivariate probit model and firm-level data of South Korea in 2014. Second, we highlight how the complementarity between GVC

participation and R&D investment differs from any possible relationship between one-way trade and R&D investment, and this study does not find that one-way trade and R&D investment are complementary, contrary to the earlier papers. Third, while papers studying complementarity are mostly restricted to the extensive margin, we also investigate complementarity at the intensive margin. Lastly, we alleviate some econometric issues that earlier papers did not take into account. The existing literature did not control for export (import) when they examined complementarity between import (export) and R&D investment. This could lead to econometric concerns since Kasahara and Lapham (2013) found that exporting and importing are complementary. Moreover, earlier papers which employed a bivariate probit model used a panel data for analysis, but using a panel data could be problematic because of serial correlation issues. We handle these econometric issues in this paper.

3. THEORETICAL JUSTIFICATION REGARDING COMPLEMENTARY BETWEEN GVC PARTICIPATION AND R&D INVESTMENT

When firms engage in GVCs which involve stages of production disseminated across different countries, they pay fixed costs associated with exporting and importing. Hence, participation in GVCs require substantial fixed costs than one-way trade does. The same fixed cost issue applies to innovative firms. They are also required to pay considerable fixed costs of R&D investment. However, participation in GVCs can provide resources to invest in R&D and vice versa. First, GVC participation could lead firms to reduce their costs (through cheaper imported inputs and economies of scale) and to increase their sales (due to larger market sizes in the world), which empower them to have more resources to invest in innovation, which requires substantial fixed costs. In the other direction, GVC participation becomes less costly to R&D firms since they can save their cost through process innovation. Furthermore, as R&D firms enjoy higher sales due to product

innovation, they could obtain more resources needed for GVC participation, which also requires considerable fixed costs.

Hypothesis 1: GVC participation and R&D investment are complementary whereas one-way trade and R&D investment are not.

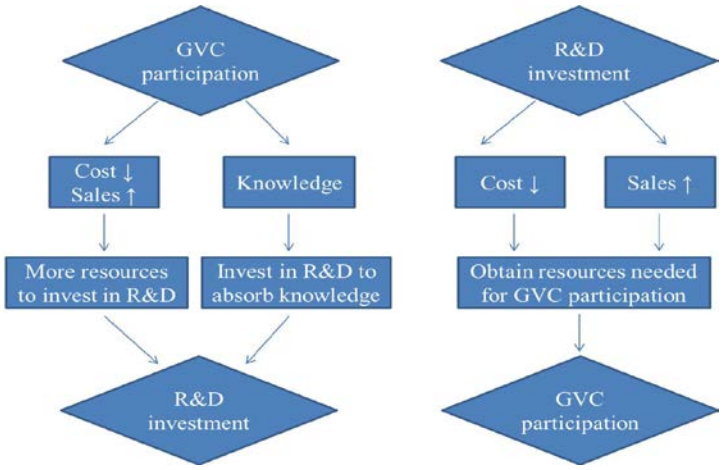
Complementarity is defined as a relationship where two activities reinforce one another by making each activity less costly. For the aforementioned reasons, R&D investment and GVC participation could be complementary. On the other hand, our analysis suggests that one-way trade and R&D investment may not be complementary activities, contrary to the existing papers. One possible explanation is related to a question whether cost savings through one-way trade are great enough to empower firms to engage in R&D investment. R&D investment is subject to substantial fixed costs and requires internal funds (Schumpeter, 1939). Firms could reduce their costs and thus R&D investment becomes less costly by either exporting goods (through economies of scale) or importing goods (through cheaper intermediate goods). However, these cost reductions of one-way trade may not suffice for making R&D investment more likely, whereas cost savings are greater for GVC firms which export and import simultaneously. Moreover, exporting and importing each require fixed costs, but as Kasahara and Lapham noted (2013), firms can reduce fixed costs associated with international trade by engaging in both activities simultaneously. In light of these, cost reductions are smaller for firms which engage in one-way trade.

Another distinction is that more knowledge is gained through GVC participation than through one-way trade. Firms access knowledge either by exporting goods (learning by exporting) (Hahn and Park, 2010) or by learning from technologies disembodied in imported inputs. Thus, firms are likely to invest in R&D in order to absorb the knowledge (Cohen and Levinthal, 1989), and as R&D investment makes GVC participation less costly through process innovation and product innovation as mentioned above, innovation reinforces GVC participation. Since GVC firms export and import simultaneously,

Table 2 Benefits and Costs of R&D Investment, GVC Participation, and One-way Trade

	R&D	GVC	Export	Import
Cost	Fixed cost $_{R\&D}$	Fixed cost $_{GVC}$	Fixed cost $_{Export}$	Fixed cost $_{Import}$
Benefit	Process innovation	Fixed cost $_{GVC}$		
		(< Fixed cost $_{Export}$ + Fixed cost $_{Import}$)		
		Larger market sizes	Larger market sizes	Cheaper inputs
	Product innovation	Economies of scale	Economies of scale	
		Cheaper inputs		
		Knowledge $_{Export}$	Knowledge $_{Export}$	Knowledge $_{Import}$
		Knowledge $_{Import}$		

Figure 4 Complementarity between GVC Participation and R&D Investment



Note: This flowchart explains how GVC participation and R&D investment could be complementary activities in a brief and intuitive manner.

these knowledge channels makes the possible complementarity between GVC participation and R&D investment stronger, while the amount of knowledge gained from one-way trade may not big enough to have firms absorb knowledge by investing in R&D. Other plausible explanations for why we do not find complementarity between one-way trade and R&D investment could be related to econometric issues and country-specific characteristics, and will be discussed later in section 6.2.

Once we find that hypothesis 1 holds, we explore possible explanatory variables which explain the complementarity between the two activities. Considering that each of these activities requires considerable fixed costs, it must be noted that not all firms can engage in GVCs and R&D investment at the same time. We conjecture that the firms which can pay substantial costs of both activities are multinational enterprises (MNEs). In fact, MNEs play a key role in GVCs, and R&D investment is generally made in headquarters (i.e., MNEs). We propose the second hypothesis to be tested.

Hypothesis 2: Whether a firm is an MNE or not explains the complementarity between GVC participation and R&D investment.

Furthermore, we hypothesize that advertising intensity may explain the complementarity between GVC participation and R&D investment. Considering that both GVC participation and R&D investment require substantial fixed costs, firms may have incentives to increase advertisement so that they can promote sales and have more resources to invest in GVC participation and R&D investment in the future. In addition, GVC participation, R&D investment, and advertising are highly related to intangible assets. GVC participation enables firms to access knowledge through the learning-by-exporting channel and through technologies disembodied in imported inputs. Also, R&D investment and advertising are considered as expenditure on intangible assets. It is also worthy to note that Golovko and Valentini (2011) documented that advertising explains the complementarity between export and innovation.

Hypothesis 3: Advertising intensity explains the complementarity between GVC participation and R&D investment.

4. DATA AND VARIABLES

4.1. Data

This paper employs Korean firm-level data, 2014 Survey of Business Activities (SBA) provided by Statistics Korea.[4] We use a cross-section data instead of a panel data because of econometric issues, which will be explained later in section 6. This database is advantageous since it contains various financial data of firms including export values, import values, and R&D expenditures. Moreover, this dataset is highly representative because it includes all firms with 50 employees or more.[5] We focus on manufacturing sectors since the objective of this study is related to GVC participation and R&D investment.

The sample constructed in this study consists of manufacturing firms which survived from 2013 to 2014. Specifically, we use one-year lagged independent variables to alleviate possible endogeneity problems. That is, dependent variables and independent variables are constructed by using 2014 SBA and 2013 SBA, respectively. The sample consists of 5,640 firms. As about 95% of firms in the 2014 sample are included in the 2013 sample, attrition bias is not a threat when using this sample.

Moreover, since the variables that we collect from the SBA are nominal, we use the following deflators to construct real variables. First, we compute deflators of value added for each two-digit industry and each year by utilizing data obtained from 2016 Korea Industrial Productivity and then we construct real value added by using the deflators.[6] Second, we compute yearly deflators of tangible fixed assets by using data from Bank of Korea and construct real tangible fixed assets.[7]

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[4] http://kostat.go.kr/portal/eng/index.action.
[5] According to Cho, Chun, and Hur (2014), total value added of the manufacturing firms in 2007 SBA accounts for about 70% of the entire value added of the manufacturing firms in South Korea.
[6] http://www.kpc.or.kr/eng/Productivity/kip.asp.
[7] http://ecos.bok.or.kr/.

4.2. Dependent Variables

The first dependent variable is GVC participation of a firm. As mentioned earlier, GVC participation index can be computed by using information on domestic value added contained in inputs sent to third economies and foreign value added content of exports. However, as micro-level data barely contains information on exported inputs and imported inputs, it is an extremely difficult task to define GVC participation at the firm level. Thus, many studies use two-way trade as a proxy for GVC participation of a firm (Baldwin and Yan, 2014). Thus, following this methodology, we use *GVC*, a dummy which takes 1 if a firm exports and imports simultaneously, to identify whether a firm is involved in GVCs. In addition, we construct an alternative measure of GVC participation, *GVC intensity*, which is defined as the sum of export value and import value divided by sales to investigate complementarity at the intensive margin.

The second dependent variable is R&D investment of a firm. *R&D* takes 1 if a firm invests in R&D. Alternatively, *R&D intensity*, defined as R&D expenditure divided by sales, is used to examine complementarity at the intensive margin.

4.3. Independent Variables

We use 6 independent variables listed in table 3. Note that all independent variables are one-year lagged as mentioned earlier to alleviate plausible endogeneity. The first four variables are basic characteristics of firms and we additionally include the last two variables to test hypothesis 2 and 3.

First, ln(*Size*) is the logarithm of *L*, the number of employees of a firm excluding temporary and dispatched workers, and it is a proxy for a firms' size. Considering that both exporting and importing are subject to fixed costs, it may be expected that larger firms are more likely to engage in GVCs. Similarly, if the size of a firm increases, then the firm is more likely to have internal funds to invest in R&D (Schumpeter, 1939).

Table 3 Description of variables

Variables		Description
Dependent	*GVC*	Dummy indicating whether a firm exports and imports at the same time
	R&D	Dummy indicating whether a firm invests in R&D
	GVC intensity	(Export values+import values)/sales
	R&D intensity	R&D expenditures/sales
Independent	ln(*Size*)	logarithm of the number of employees; a proxy for a firm's size
	ln(*K/L*)	logarithm of real tangible fixed assets per employee
	ln(*Labor productivity*)	logarithm of real value added per employee
	Foreign parent	Dummy indicating whether more than 50% of shares of a firm are owned by a foreign firm
	Foreign affiliate	Dummy indicating whether a firm owns more than 20% of shares of a foreign firm; a proxy for an MNE
	ln(*Advertising intensity*)	ln(0.001+advertising expenditures/sales)

Notes: All independent variables are one-year lagged to avoid a possible endogeneity problem. As for advertising, we use a logarithm since advertising intensity is highly skewed to the right. Moreover, considering that about 21% of the sample report 0 advertisement expenditure, a non-zero number is added to avoid a sample loss. We choose 0.001 because taking the logarithm of the sum of 1 and advertising intensity does not adjust for the aforementioned skewness.

Second, ln(*K/L*) is defined as the logarithm of capital intensity of a firm where *K* reflects real tangible fixed assets owned by a firm. It is expected that ln(*K/L*) is positively correlated with *R&D* since Bound *et al*. (1984) found that capital intensity and R&D intensity are complementary.

Third, ln(*Labor productivity*) is the logarithm of per-worker real value added. It is plausible that labor productivity is positively correlated with firms' GVC participation since exporting and importing involve fixed costs. Jung and Hur (2019) has shown this relationship.

Fourth, *Foreign parent* is a dummy which takes 1 if more than 50% of shares of a firm are owned by a foreign firm (i.e., if a firm has a foreign parent). Note that GVC participation of a country is positively associated with FDI inward stock of a country (OECD *et al*., 2014). Hence, it may be conjectured that *Foreign parent* is positively associated with GVC participation of a firm. On the contrary, it must be pointed out that R&D investment generally takes

place in headquarters of a firm, which leads to the expectation that *Foreign parent* is negatively correlated with R&D investment of a firm.

Fifth, *Foreign affiliate* is a dummy which takes 1 if a firm owns more than 20% of shares of a foreign firm (i.e., if a firm has a foreign affiliate) and it is a proxy for an MNE. Noting that GVC participation and R&D investment both require substantial fixed costs, it is conjectured that MNEs, which are able to pay two sizeable costs, are the firms which participate in GVCs and R&D investment at the same time. Moreover, since MNEs play a central role in GVCs and R&D investment is usually made in headquarters, *Foreign affiliate* is expected to be positively correlated with a firm' GVC participation and R&D investment. We use this independent variable to test hypothesis 2.

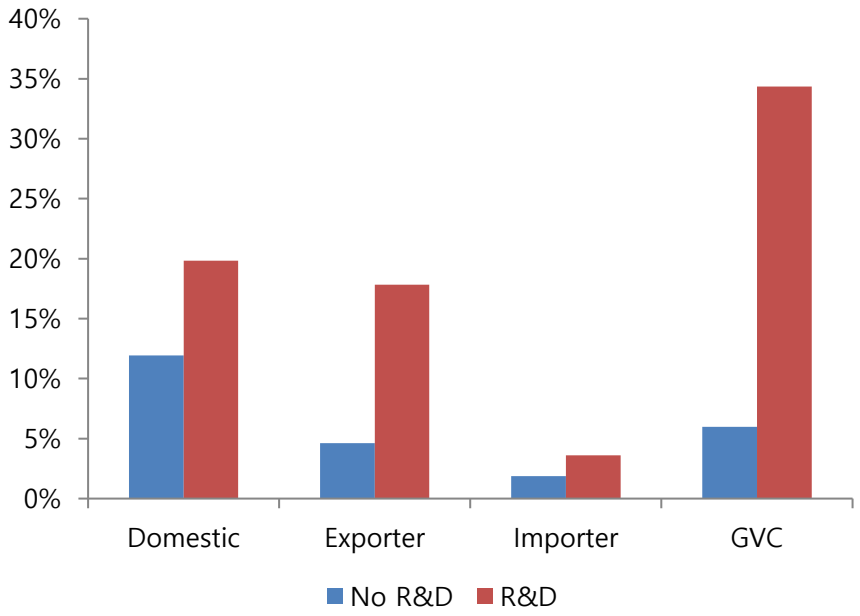
Lastly, ln(*Advertising intensity*) is defined as the logarithm of the sum of 0.001 and advertising intensity (i.e., advertisement expenditures divided by sales, measured in %).[8] To get ready for sizeable fixed costs of GVC participation and R&D investment, firms may have an incentive to increase their sales by increasing advertisement. Furthermore, GVC participation, R&D investment, and advertising are all highly related to intangible assets. GVC participation enables firms to access knowledge, and R&D investment and advertising are considered as spending on intangible assets. By using this variable, we can test hypothesis 3.

5. EMPIRICAL REGULARITIES

Figure 5 presents share of firms which belong to different categories, using the sample constructed above. *Domestic* is a group of firms which neither export nor import. *Exporter* denotes those which export but do not import,

[8] First, we use a logarithm since advertising intensity is highly skewed to the right. In addition, noting that a number of firms (about 21% of the sample) report 0 advertisement expenditure, we add a non-zero number to avoid a sample loss. In particular, 0.001 is added since taking the logarithm of the sum of 1 and advertising intensity does not adjust for the aforementioned skewness.

Figure 5 GVC Participation and R&D Investment



	Domestic	*Exporter*	*Importer*	*GVC*	Total
No R&D	12%	5%	2%	6%	24%
R&D	20%	18%	4%	34%	76%
Total	32%	22%	5%	40%	100%

Notes: Domestic is a group of firms which neither export nor import. Exporter denotes firms which export but do not import, whereas Importer reflect those which import but do not export. GVC indicates those which export and import at the same time (i.e., four categories are mutually exclusive).

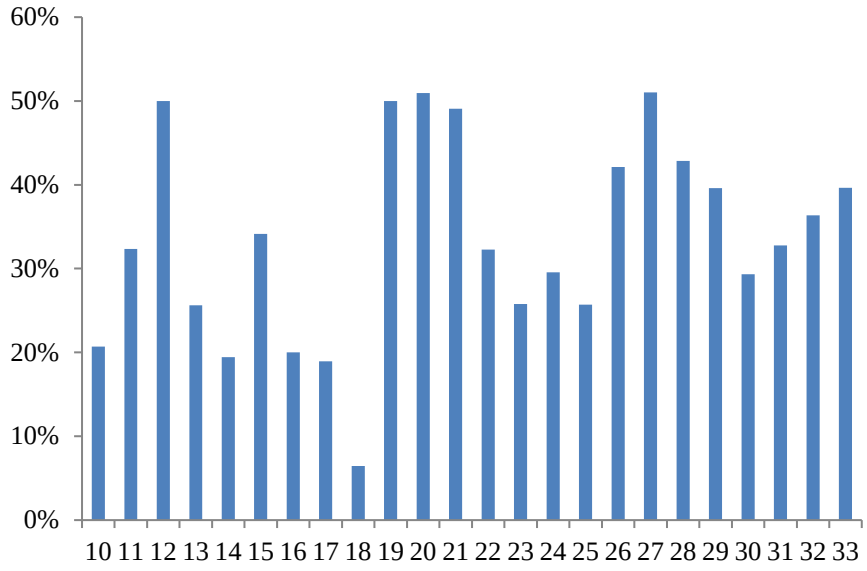
whereas *Importer* reflect those which import but do not export. *GVC* indicates those which export and import at the same time (i.e., four categories are mutually exclusive).

There are several findings to be pointed out. First, the share of *Domestic* is about 32%, which indicates that more than a majority of the firms (about 68%) participate either in exporting or importing. Second, share of *Exporter*, *Importer*, and *GVC* is about 22%, 5%, and 40%, respectively. So, the share

of exporting firms adds up to around 62% (share of *Exporter* + share of *GVC*) and that of importing firms totals around 45% (share of *Importer* + share of *GVC*). Hence, more than a majority (about 65%) of exporting firms import at the same time and about 89% of importing firms export simultaneously. It is suggested that shares of *Exporter* and *Importer* (22% and 5%, respectively) pale in comparison with the percentage of *GVC* (40%). Third, about 76% of firms invest in R&D, which points to the fact that Korean firms actively invest in R&D. Fourth, there is strong evidence which supports complementarity between GVC participation and R&D investment, which is related to hypothesis 1: about 85% of GVC firms invest in R&D at the same time.

Figure 6 displays share of firms engaging in GVCs and R&D investment simultaneously within each two-digit manufacturing industry, based on our

Figure 6 Share of Firms Simultaneously Engaging in GVCs and R&D Investment within each Industry



Note: Numbers in the x-axis denote two-digit manufacturing industries classified by the Korean Standard Industrial Classification.

sample.[9] Even within each industry, share of firms which participate in GVCs and R&D investment at the same time is far from being negligible, ranging from about 6% up to 51%. Moreover, industry heterogeneity in the joint decision to participate in GVCs and R&D investment is documented since each industry shows distinct percentages of firms participating in GVCs and R&D investment at the same time. For example, share of firms engaging both in GVCs and R&D investment is very large in high-technology industries such as industry 20 (manufacture of chemicals and chemical products except pharmaceuticals, medicinal chemicals) and industry 21 (manufacture of pharmaceuticals, medicinal chemicals and botanical products), while it is very small in low-technology industries including industry 18 (printing and reproduction of recorded media).

Next, we investigate a variable which might explain this possible complementarity between the two variables. In table 4, *Both* indicates whether a firm engages in GVCs and R&D investment simultaneously, and *MNE* reflects whether a firm owns more than 20% of shares of a foreign firm (i.e., a proxy for an MNE). In our sample, about 49% of *Both* firms are MNEs, whereas merely about 23% of the other group are MNEs. This strongly suggests that the main determinant of the complementarity between GVC participation and R&D investment is likely to be whether a firm

Table 4 Share of MNEs

MNE	*Both*	
	Yes	No
Yes	956	870
No	981	2,833
Share of MNEs	49%	23%

Note: Both indicates a group of firms which engage in GVCs and R&D investment simultaneously.

[9] This paper follows Korean Standard Industrial Classification (KSIC). Manufacturing consists of 24 industries.

Table 5 Summary Statistics and Correlation Matrix of Continuous Independent Variables

A. Summary Statistics

Variable		Mean	Std. dev	Min	Max	Obs.
Dependent	*GVC*	0.403	0.491	0	1	5,640
	R&D	0.756	0.430	0	1	5,640
	GVC intensity	0.187	0.324	0	1.800	5,640
	R&D intensity	0.018	0.044	0	1.819	5,640
Independent	*ln(Size)*	4.971	0.837	3.912	11.470	5,640
	ln(K/L)	4.604	1.062	−3.955	9.002	5,640
	ln(Labor productivity)	4.236	0.615	−1.773	7.684	5,640
	Foreign parent	0.068	0.253	0	1	5,640
	Foreign affiliate	0.324	0.468	0	1	5,640
	ln(Advertising intensity)	−3.799	2.434	−6.908	3.235	5,640

Note: All independent variables are one-year lagged to avoid a possible endogeneity problem.

B. Correlation Matrix of Continuous Independent Variables

	ln(Size)	*ln(K/L)*	*ln(Labor productivity)*	*ln(Advertising intensity)*
ln(Size)	1			
ln(K/L)	0.179	1		
ln(Labor productivity)	0.231	0.368	1	
ln(Advertising intensity)	0.208	-0.022	0.003	1

is an MNE or not. This is plausible because MNEs can pay substantial fixed costs associated with GVC participation and R&D investment.

Panel A of table 5 reports summary statistics of dependent variables and independent variables where independent variables are one-year lagged to avoid possible endogeneity. Panel B of table 5 shows correlation matrix of continuous independent variables. Table 6 divides our sample into four mutually exclusive categories and presents average of the independent variables for each category. *None* is a group of firms which neither engage in GVCs nor R&D investment, *Only GVC* reflects those which participate in

Table 6 Comparison by Categories

Variable	*None*	*Only GVC*	*Only R&D*	*Both*
ln(*Size*)	4.636	4.930	4.855	5.297
ln(*K/L*)	4.410	4.585	4.583	4.737
ln(*Labor productivity*)	4.119	4.400	4.167	4.353
Foreign parent	0.044	0.287	0.029	0.091
Foreign affiliate	0.152	0.278	0.266	0.494
ln(*Advertising intensity*)	−4.669	−4.297	−3.820	−3.220
Obs.	1,038	338	2,327	1,937

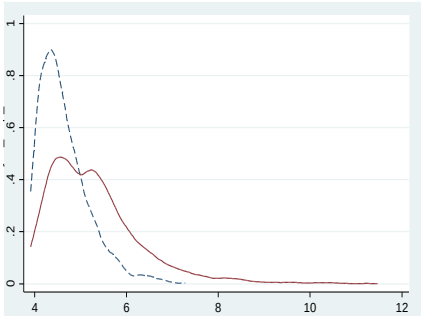
Notes: None is a group of firms which neither engage in GVCs nor R&D investment, Only GVC reflects those which participate in GVCs but do not invest in R&D, Only R&D indicates those which invest in R&D but do not engage in GVCs, and Both is those which engage in both GVCs and R&D investment.

GVCs but do not invest in R&D, *Only R&D* indicates those which invest in R&D but do not engage in GVCs, and *Both* is those which engage in both GVCs and R&D investment.

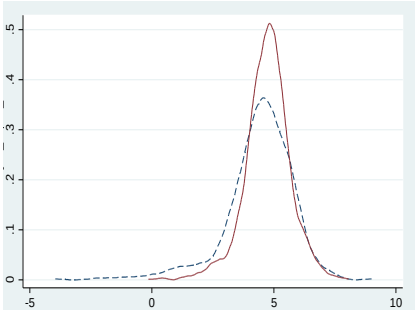
Findings that table 6 indicates can be summarized as follows. First, firms which belong to *Both* are the largest and the most capital-intensive. In particular, as GVC participation and R&D investment are subject to substantial costs, firms categorized as *Both* are very large and productive. Second, share of firms which have a foreign parent is highest in *Only GVC* and lowest in *Only R&D*. This indicates that whereas foreign firms are highly embedded in GVCs (OECD *et al*., 2014), the probability of investing in R&D is small since R&D investment generally takes place in headquarters of a firm. Third, share of MNEs among *Both* firms is the highest. This may be evidence for hypothesis 2 that MNEs participate in GVCs and R&D at the same time since they can pay substantial fixed costs associated with the two activities. Fourth, *Both* firms have the highest advertising intensity. Noting that GVC participation and R&D investment require sizeable fixed costs, firms have incentives to promote sales so that they can get ready for sizable fixed costs (Hypothesis 3). Figure 7 compares distributions of *None* firms and *Both* firms. Panel A, Panel B, and Panel C show distributions of ln(*Size*), ln(*K/L*), and ln(*Labor productivity*), respectively. Dashed lines indicate distributions of *None* firms and solid lines reflect those of *Both* firms. According to figure 7, *Both* firms are larger, more capital-intensive, and more productive, which is

Figure 7 Comparisons of Distributions

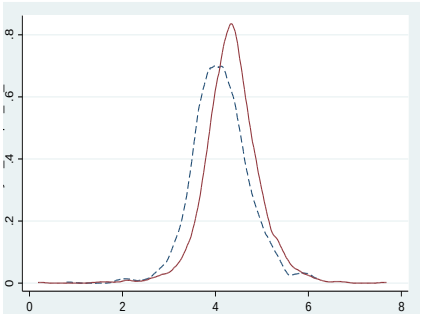
A. *ln(Size)*



B. *ln(K/L)*



C. *ln(Labor productivity)*



Note: Dashed lines indicate distributions of None firms and solid lines reflect those of Both firms.

in line with table 6.

6. ESTIMATION

6.1. Empirical Specification

Complementarity is defined as a relationship where two activities reinforce one another by making each activity more likely. To take into account the joint determination of GVC participation and R&D investment, we follow the existing literature and use a bivariate probit model, which allows the error

terms of the two probit equations to be correlated (Girma *et al*., 2008; Aw *et al*., 2011; Golovko and Valentini, 2011; Cho *et al*., 2014). However, using a panel data for a bivariate probit model could be problematic because of possible serial correlation issue. To take this into account, we use a cross-section data, instead of a panel data.

Suppose that firms' decision to participate in GVCs and to invest in R&D is determined by the following equation:

$$\begin{aligned} Y_{1ijt} &= X_{ijt-1}\beta_1 + \varepsilon_{1ijt}, & Y_{2ijt} &= X_{ijt-1}\beta_2 + \varepsilon_{2ijt}, \\ Y_{1ijt} &= 1 \; if \; Y^*_{1ijt} > 0, & Y_{2ijt} &= 1 \; if \; Y^*_{2ijt} > 0, \\ Y_{1ijt} &= 0 \; otherwise, & Y_{2ijt} &= 0 \; otherwise. \end{aligned} \tag{1}$$

In the aforementioned equation, Y_1 denotes GVC participation of a firm and Y_2 indicates whether a firm invests in R&D; X_{it-1} is a vector of one-year lagged independent variables; and ε_1 and ε_2 are error terms where *i* denotes a firm, *j* denotes an industry that a firm belongs to, and *t* denotes a year, respectively. Moreover, we include industry dummies in the above estimation to control for industry heterogeneity and use robust standard errors.

In this model, errors are assumed to have a standard bivariate normal distribution and ρ denotes the correlation between the two error terms. If this correlation coefficient is zero, this model is equivalent to two separate univariate probit models. However, if the error terms are correlated (i.e., $\rho \neq 0$), then the two dependent variables are likely to be interdependent. For example, if $\rho > 0$, then Y_1 and Y_2 could be interpreted as complementary. Moreover, it must be emphasized that if the error terms are correlated, then coefficients of the univariate probit models would be biased.

6.2. Estimation

Table 7 displays our baseline estimation results. *GVC* takes 1 if a firm exports and imports simultaneously and *R&D* takes 1 if a firm invests in R&D.

Table 7 Complementarity between GVC Participation and R&D Investment

Model	Univariate probit		Bivariate probit	
	(1) *GVC*	(2) *R&D*	(3) *GVC*	(4) *R&D*
ln(*Size*)	0.140***	0.106***	0.140***	0.105***
	(0.008)	(0.008)	(0.008)	(0.008)
ln(*K/L*)	0.015**	0.030***	0.015**	0.029***
	(0.006)	(0.006)	(0.007)	(0.006)
ln(*Labor productivity*)	0.051***	-0.001	0.051***	-0.001
	(0.012)	(0.010)	(0.012)	(0.010)
Foreign parent	0.224***	-0.183***	0.223***	-0.185***
	(0.026)	(0.021)	(0.026)	(0.021)
Rho			0.278***	
Wald test of rho=0			115.048	
Log pseudolikelihood			-6,143.872	
Industry dummies	Yes	Yes	Yes	
Obs.	5,640	5,640	5,640	

Notes: GVC is a dummy which indicates whether a firm exports and imports simultaneously and R&D is a dummy indicating whether a firm invests in R&D. Columns (1) and (2) use separate univariate probit models whereas columns (3)-(4) use a bivariate probit model. Rho is a correlation between the error terms in the bivariate probit model. All reported coefficients are average marginal effects and numbers in parentheses are robust standard errors. *, **, and *** denote statistical significance at the 1%, 5%, and 10% level, respectively.

Columns (1) and (2) report estimation results of two separate univariate probit models whereas columns (3)-(4) employ a bivariate probit model. Rho reported in columns (3)-(4) is the correlation coefficient between the two error terms in the bivariate probit model.

The coefficient of interest is rho, which investigates whether the two dependent variables are complementary or not. According to columns (3)-(4), rho is estimated to be greater than 0 (0.278) and is statistically significant at 1% level. This means that the two dependent variables (GVC participation and R&D investment) could be complementary activities. Thus, we focus on columns (3)-(4) which employ the bivariate probit model. According to columns (3)-(4), if firms' size increases by 1%, the probability of GVC participation and R&D investment increases by 14 percentage points and 10.5 percentage points, respectively. Since both GVC participation and R&D investment are subject to fixed costs, firms' size has positive effects on the

probability of engaging in GVCs and R&D investment. If capital intensity increases by 1%, the probability of GVC participation and R&D investment increases by 1.5 percentage points and 2.9 percentage points. On the other hand, when labor productivity increases by 1% the probability of GVC engagement increases by 5.1 percentage points, although labor productivity does not have significant effects on the probability of R&D investment. Moreover, although foreign firms are more likely to participate in GVCs by 22.3 percentage points, they are less likely to invest in R&D by 18.5 percentage points. This is in line with OECD *et al*. (2014) and the fact that R&D investment generally takes place in headquarters.

Next, we investigate whether there is complementarity between firm's one-way trade and R&D investment. Existing literature primarily documented complementarity between firms' one-way trade and innovation (Girma *et al*., 2008; Golovko and Valentini, 2011; Bøler *et al*., 2015). However, there are some econometric concerns that they did not take into account in their research. First, when studying relationship between export (import) and innovation, import (export) should be controlled for because export and import are complementary (Kasahara and Lapham, 2013). Second, using a panel data for a bivariate probit model could result in econometric issues. In light of these, we define two mutually exclusive groups (exporters which do not import and importers which do not export) and employ a cross-section data in our bivariate probit model.

In table 8, we use the same bivariate probit model as in table 7, but use different dependent variables. *Exporter* takes 1 if a firm exports but does not import and *Importer* takes 1 if a firm imports but does not export. *R&D* is a dummy indicating whether a firm invests in R&D. Columns (1)-(2) use *Exporter* and *R&D* as dependent variables and columns (3)-(4) use *Importer* and *R&D* as dependent variables. Rho is the correlation coefficient between the two error terms in these bivariate probit models.

According to columns (1)-(2) of table 8, rho is positive and statistically significant at 1% level, which may be interpreted as supporting evidence for complementarity between exporting and R&D investment. However, it must

Table 8 One-way Trade and R&D Investment

Model	Bivariate probit		Bivariate probit	
	(1) *Exporter*	(2) *R&D*	(3) *Importer*	(4) *R&D*
ln(*Size*)	−0.028***	0.106***	−0.022***	0.106***
	(0.007)	(0.008)	(0.004)	(0.008)
ln(*K/L*)	0.020***	0.029***	0.006*	0.030***
	(0.006)	(0.006)	(0.003)	(0.006)
ln(*Labor productivity*)	−0.020**	−0.001	0.003	-0.001
	(0.010)	(0.010)	(0.006)	(0.010)
Foreign parent	−0.125***	−0.183***	0.013	-0.183***
	(0.025)	(0.021)	(0.013)	(0.021)
Rho	0.080***		−0.064*	
Wald test of rho=0	8.468		2.725	
Log pseudolikelihood	−5,701.388		−3,902.812	
Industry dummies	Yes		Yes	
Obs.	5,640		5,640	

Notes: Exporter is a dummy which takes 1 if a firm exports but does not import and Importer takes 1 if a firm imports but does not export. R&D is a dummy indicating whether a firm invests in R&D. Columns (1)-(2) use Exporter and R&D as dependent variables and columns (3)-(4) use Importer and R&D as dependent variables. Rho is a correlation between the error terms in each bivariate probit model. All reported coefficients are average marginal effects and numbers in parentheses are robust standard errors. *, **, and *** denote statistical significance at the 1%, 5%, and 10% level, respectively.

be noted that some of the coefficients are inconsistent with economic theories. To illustrate, column (1) suggests that size and labor productivity reduce the probability of exporting. Note that the larger and the more productive, firms are more likely to export since exporting is subject to fixed costs. Since the presented result is not consistent with theories, the apparent complementarity between exporting and R&D investment is not reliable. On the other hand, according to columns (3)-(4), rho is negative and statistically significant at 10% level, implying that importing and R&D investment seem to be substitutes. However, size has negative effects on the probability of importing, as can be seen in column (3). This result is not reliable because importing is subject to fixed costs and thus larger firms are more likely to import. In summary, results displayed in table 8 are not credible as they are inconsistent with theories. From table 7, we document that GVC participation and R&D investment are complementary, but we do not find complementarity between one-way trade and R&D investment in table 8

(Hypothesis 1).

There are several reasons for why we do not find complementary relationships between one-way trade and R&D investment. First, earlier papers which showed complementarity between one-way trade and innovation could be wrong for the econometric issues mentioned above. Since export and import are complementary, import (export) should be controlled for when studying the relationship between export (import) and innovation. Second, using a panel data for a bivariate probit model could result in serial correlation problems.

Third, cost reductions through one-way trade may not be great enough to enable firms to invest in R&D, which requires sizeable fixed costs, and thus one-way trade and R&D investment may not be complementary. As discussed in section 3, either exporting or importing leads to cost savings, but they are smaller than cost reductions for GVC firms which export and import simultaneously. In addition, the amount of knowledge gained through one-way trade is also smaller than the amount of knowledge for GVC firms, which export and import at the same time. As a result, one-way trade may not make R&D investment less costly and thus we do not observe a virtuous cycle that we find in GVC participation and R&D investment.

Lastly, there is one caveat about the result on one-way trade and R&D investment. Our result could be related to the environment of South Korea. As can be seen in section 1 and 5, this country is highly embedded in GVCs and one-way trade is not common for Korean firms. According to our sample, about 65% of exporting firms import at the same time and about 89% of importing firms export simultaneously. Thus, it is also possible that our result about one-way trade and R&D investment is specific to the context of the country.

Next, we explore variables which may explain the complementarity between GVC participation and R&D investment in table 9. We use the same bivariate probit model as in table 7, but additionally control for *Foreign affiliate* and ln(*Advertising intensity*) in columns (1)-(2) and columns (3)-(4), respectively. By doing so, we can test hypothesis 2 and hypothesis 3.

Table 9 Variables which Explain the Complementarity between GVC Participation and R&D Investment

Model	Bivariate probit		Bivariate probit	
	(1) *GVC*	(2) *R&D*	(3) *GVC*	(4) *R&D*
ln(*Size*)	0.105***	0.089***	0.127***	0.087***
	(0.008)	(0.009)	(0.008)	(0.008)
ln(*K/L*)	0.010	0.027***	0.016**	0.030***
	(0.006)	(0.006)	(0.007)	(0.006)
ln(*Labor productivity*)	0.045***	−0.004	0.054***	0.002
	(0.011)	(0.010)	(0.011)	(0.010)
Foreign parent	0.259***	−0.167***	0.228***	-0.178***
	(0.025)	(0.021)	(0.026)	(0.020)
Foreign affiliate	0.163***	0.082***		
	(0.013)	(0.013)		
ln(*Advertising intensity*)			0.020***	0.029***
			(0.003)	(0.002)
Rho	0.260***		0.260***	
Wald test of rho=0	98.202		97.185	
Log pseudolikelihood	−6,062.592		−6,062.251	
Industry dummies	Yes		Yes	
Obs.	5,640		5,640	

Notes: GVC is a dummy which indicates whether a firm exports and imports simultaneously and R&D is a dummy indicating whether a firm invests in R&D. Columns (1)-(2) and (3)-(4) use bivariate probit models. Rho is a correlation between the error terms in each bivariate probit model. All reported coefficients are average marginal effects and numbers in parentheses are robust standard errors. *, **, and *** denote statistical significance at the 1%, 5%, and 10% level, respectively.

As can be seen in columns (1)-(2), rho decreases from 0.278 to 0.260 by controlling for *Foreign affiliate*. Reduction in the magnitude of the rho indicates that this independent variable explains the complementarity between GVC participation and R&D investment. Given that both activities require substantial fixed costs, MNEs are likely to be the firms which participate in the two activities at the same time since they can pay these sizeable costs (Hypothesis 2). It is also consistent with observations that MNEs play a key role in GVCs and R&D investment is usually conducted in headquarters (i.e., MNEs).

Turning to columns (3)-(4), controlling for ln(*Advertising intensity*) decreases the size of the rho from 0.278 to 0.260, and thus advertising intensity explains the complementarity between GVC engagement and R&D

investment. Considering that GVC participation and R&D investment are both subject to fixed costs, firms may have an incentive to increase advertisement so that they can increase sales and get ready for sizeable fixed costs associated with GVC participation and R&D investment (Hypothesis 3). In addition, it also makes sense because GVC participation, R&D investment, and advertising are all highly related to intangible assets. Our result is also consistent with the existing literature (Golovko and Valentini, 2011).

6.3. Robustness Check

One limitation to using a bivariate probit model is that we only document the complementarity between GVC participation and R&D investment at the extensive margin. To investigate whether it also holds at the intensive margin, we employ a bivariate tobit model where dependent variables are *GVC intensity* (i.e., the sum of export values and import values which is divided by sales) and *R&D intensity* (i.e., R&D expenditure divided by sales). First, columns (1)-(2) only control for the independent variables used in table 7. Then, we additionally control for *Foreign affiliate* and ln(*Advertising intensity*) in columns (3)-(4) and columns (5)-(6), respectively.

Table 10 shows that the complementarity between GVC participation and R&D investment also holds at the intensive margin. According to columns (1)-(2), rho is greater than 0 (0.100) and it is statistically significant at 1% level, which means that hypothesis 1 also holds at the intensive margin. Moreover, controlling for *Foreign affiliate* reduces the magnitude of the rho to 0.089 and controlling for ln(*Advertising intensity*) decreases the size of the rho to 0.094. This implies that hypothesis 2 and hypothesis 3 hold true even at the intensive margin.

One thing that needs discussion is that the bivariate probit model is based on the correlation approach when we test complementarity between GVC participation and R&D investment. That is, we use the correlation between the two error terms in the bivariate probit model to identify whether the two activities are complementary or not. Golovko and Valentini (2011) used a

Table 10 Robustness Check 1: Complementarity at the Intensive Margin

Model	Bivariate tobit		Bivariate tobit		Bivariate tobit	
	(1) *GVC intensity*	(2) *R&D intensity*	(3) *GVC intensity*	(4) *R&D intensity*	(5) *GVC intensity*	(6) *R&D intensity*
ln(*Size*)	0.073*** (0.004)	0.003*** (0.001)	0.053*** (0.004)	0.002*** (0.001)	0.069*** (0.004)	0.002*** (0.001)
ln(*K/L*)	0.012*** (0.004)	0.001*** (0.000)	0.009** (0.004)	0.001** (0.000)	0.013*** (0.004)	0.001*** (0.000)
ln(*Labor productivity*)	0.033*** (0.008)	-0.002 (0.001)	0.030*** (0.007)	-0.002 (0.002)	0.034*** (0.008)	-0.002 (0.001)
Foreign parent	0.135*** (0.013)	-0.008*** (0.002)	0.163*** (0.013)	-0.007*** (0.002)	0.137*** (0.013)	-0.007*** (0.002)
Foreign affiliate			0.109*** (0.008)	0.004*** (0.001)		
ln(*Advertising intensity*)					0.006*** (0.002)	0.002*** (0.000)
Rho	0.100***		0.089***		0.094***	
Wald test of rho=0	41.983		33.396		36.557	
Log pseudolikelihood	1,954.249		2,049.398		2,011.325	
Industry dummies	Yes		Yes		Yes	
Obs.	5,640		5,640		5,640	

Notes: Columns (1)-(2), (3)-(4), and (5)-(6) employ each bivariate tobit model, respectively. In each model, dependent variables are GVC intensity and R&D intensity. Rho indicates a correlation between the error terms in each bivariate tobit model. All reported coefficients are average marginal effects and numbers in parentheses are robust standard errors. *, **, and *** denote statistical significance at the 1%, 5%, and 10% level, respectively.

bivariate probit model and another alternative methodology when investigating complementarity, so we will employ the alternative approach. Note that one common effect of GVC participation and R&D investment is cost savings, as table 2 mentions. GVC participation leads to cost savings through cheaper imported inputs, economies of scale, and reduction in the fixed costs by exporting and importing simultaneously (Kasahara and Lapham, 2013). R&D investment also decreases costs of firms through process innovation. Let us define a cost function of a firm, $f(x_1, x_2)$ where x_1 takes 1 if a firm participates in GVCs and 0 otherwise, x_2 takes 1 if a firm invests in R&D and 0 otherwise, and f denotes operating expenses of a firm. If GVC participation and R&D investment are complementary activities, then the following equation must hold:

Table 11 Robustness Check 2: Alternative Approach to Testing Complementarity

Model	OLS
	ln(*Cost*)
Only GVC (b_1)	0.158***
	(0.037)
Only R&D (b_2)	0.043*
	(0.022)
Both (b_3)	0.094***
	(0.024)
Prob>F (H_o: $b_1 + b_2 - b_3 = 0$)	0.0072
R-squared	0.808
Obs.	5,640

Notes: The dependent variable, ln(*Cost*), is the logarithm of operating expenses. b_1 is the difference between the coefficient on Only GVC and the coefficient on None, b_2 is the difference between the coefficient on Only R&D and the coefficient on None, and b_3 is the difference between the coefficient on Both and the coefficient on None. Though not reported, one-year lagged independent variables listed in table 3 and industry dummies are controlled for. Numbers in parentheses are robust standard errors. *, **, and *** denote statistical significance at the 1%, 5%, and 10% level, respectively.

$$f(1,\ 1) + f(0,\ 0) < f(1,\ 0) + f(0,\ 1). \tag{2}$$

Table 11 examines whether equation (2) holds. The dependent variable is the logarithm of operating expenses of firms. *Only GVC* indicates whether a firm participates in GVCs but does not invest in R&D; *Only R&D* reflects whether a firm invests in R&D but does not engage in GVCs; and *Both* indicates whether a firm participates in GVCs and R&D investment simultaneously. The reference case, *None*, indicates whether a firm engages neither in GVCs nor in R&D investment. Thus, b_1 is the difference between the coefficient on *Only GVC* and the coefficient on *None*, b_2 is the difference between the coefficient on *Only R&D* and the coefficient on *None*, and b_3 is the difference between the coefficient on *Both* and the coefficient on *None*. Moreover, we include one-year lagged independent variables listed in table 3 and industry dummies in the regression.

If GVC participation and R&D investment are complementary, then the null hypothesis $(b_1 + b_2 - b_3 = 0)$ must be rejected. As can be seen in table 11,

Table 12 Robustness Check 3: Investigating Complementarity Using A Panel from 2006 to 2014

Model	Bivariate probit		Bivariate probit		Bivariate probit	
	(1) *GVC*	(2) *R&D*	(3) *GVC*	(4) *R&D*	(5) *GVC*	(6) *R&D*
ln(*Size*)	0.138*** (0.003)	0.124*** (0.003)	0.100*** (0.003)	0.105*** (0.003)	0.128*** (0.003)	0.104*** (0.003)
ln(*K/L*)	0.024*** (0.002)	0.029*** (0.002)	0.020*** (0.002)	0.027*** (0.002)	0.025*** (0.002)	0.031*** (0.002)
ln(*Labor productivity*)	0.044*** (0.004)	0.013*** (0.004)	0.036*** (0.004)	0.009** (0.004)	0.044*** (0.004)	0.012*** (0.004)
Foreign parent	0.231*** (0.010)	−0.177*** (0.008)	0.271*** (0.009)	-0.155*** (0.008)	0.236*** (0.009)	-0.169*** (0.008)
Foreign affiliate			0.185*** (0.005)	0.097*** (0.005)		
ln(*Advertising intensity*)					0.017*** (0.001)	0.032*** (0.001)
Rho	0.292***		0.270***		0.276***	
Wald test of rho=0	1,023.930		848.872		879.538	
Log pseudolikelihood	−47,548.236		−46,762.445		−46,885.514	
Industry dummies	Yes		Yes		Yes	
Year dummies	Yes		Yes		Yes	
Obs.	42,521		42,521		42,521	

Notes: Columns (1)-(2), (3)-(4), and (5)-(6) employ each bivariate probit model, respectively where we use an unbalanced panel of manufacturing firms from 2006 to 2014. In each model, dependent variables are GVC and R&D where GVC is a dummy which indicates whether a firm exports and imports simultaneously and R&D is a dummy indicating whether a firm invests in R&D. Rho indicates a correlation between the error terms in each bivariate probit model. All reported coefficients are average marginal effects and numbers in parentheses are robust standard errors. *, **, and *** denote statistical significance at the 1%, 5%, and 10% level, respectively.

the null hypothesis is rejected at 1% level. Even when we use an alternative method, we find that GVC participation and R&D investment are complementary.

Another possible threat to our results is that the complementary relationship between GVC participation and R&D investment may not hold in different time periods. We expand our sample to an unbalanced panel data from 2006 to 2014 and use the same bivariate probit model in table 12. This methodology could be disadvantageous considering possible serial correlation, but it may give us insight about results in different time periods. We still document the complementarity relationship (related to Hypothesis 1). According to columns (1)-(2), rho is greater than 0 (0.292) and statistically significant at 1% level. We also find that Hypothesis 2 and Hypothesis 3 hold

Table 13 Robustness Check 4: Multinomial Logit Model

Model	Multinomial logit		
	(1) *Only GVC*	(2) *Only R&D*	(3) *Both*
ln(*Size*)	−0.001	−0.022**	0.101***
	(0.004)	(0.010)	(0.008)
ln(*K/L*)	−0.004	0.014**	0.014**
	(0.003)	(0.007)	(0.006)
ln(*Labor productivity*)	0.013**	−0.033***	0.034***
	(0.006)	(0.012)	(0.011)
Foreign parent	0.112***	−0.254***	0.131***
	(0.009)	(0.033)	(0.026)
Foreign affiliate	0.007	−0.071***	0.147***
	(0.007)	(0.015)	(0.012)
ln(*Advertising intensity*)	−0.006***	0.005	0.024***
	(0.001)	(0.003)	(0.003)
Industry dummies	Yes	Yes	Yes
Obs.	5,640	5,640	5,640

Notes: In this multinomial logit model, the reference group is None, a group of firms which neither engage in GVCs nor R&D investment. All reported coefficients are average marginal effects and numbers in parentheses are robust standard errors. *, **, and *** denote statistical significance at the 1%, 5%, and 10% level, respectively.

since the magnitude of the rho reported in columns (3)-(4) and columns (5)-(6) is reduced to 0.270 and 0.276, respectively.

Lastly, Table 13 employs a multinomial logit model using *None* firms, which engage neither in GVC nor in R&D, as the reference group. We find that if a firm is an MNE, the probability that it belongs to *Both* relative to *None* increases by 14.7 percentage points. Furthermore, if advertising intensity of a firm increases by 1%, then the probability that a firm belongs to *Both* relative to *None* increases by 2.4 percentage points. These results indicate that *Foreign affiliate* and ln(*Advertising intensity*) have positive effects on the probability that a firm participates in GVCs and R&D investment simultaneously.

7. CONCLUSION

This paper examines a relationship between firm's GVC participation and R&D investment by utilizing 2014 Survey of Business Activities and a bivariate probit model. We document complementary relationships between the two activities because each activity requires substantial fixed costs, but reinforces one another through cost reductions. Contrary to earlier literature, however, we do not find complementarity between firm's one-way trade and R&D investment, and we provide careful explanations for this result. Finally, we document that the complementarity between GVC participation and R&D investment holds at the intensive margin as well as at the extensive margin.

Policy implications of this paper are as follows. Due to the complementarity between firm's GVC participation and R&D investment, policies to promote firms' trade have positive effects on firm's R&D investment. Similarly, government assistance to support firm's innovation may also affect firm's GVC participation. Thus, governments should not examine these two activities in isolation when they seek to assist firms.

We conclude by discussing limitations of this paper. One limitation is related to using a proxy for GVC participation of a firm. Due to the lack of data on exported inputs and imported inputs, we used two-way trade as a proxy for a firm's GVC participation. However, if data accessibility is enhanced, it is expected that a better measurement could be utilized in the future. Second, although the firm-level dataset used in this study contains various corporate data, information on destination countries of exports and imports are not available. If exports and imports are broken down by destination countries, one could investigate the complementarity relationship by destination countries. Due to the absence of such data, we leave this for future research.

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