An Empirical Study of Technology Diffusion and International Trade in Korea: Using Patent Application Data

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International trade is an important conduit for international technology diffusion. Considering the endogenous growth theory, a rapid increase of foreign patent application, and international trade in Korea, it seems meaningful to study the role of international trade in the technology diffusion from foreign countries to Korea. This paper investigates the relationship between the trade and technology diffusion by using Korean patent data and trade data. We found that the international trade of Korea with foreign countries was very significant variable.

Keywords: Patent, Korea, Technology diffusion, International trade

1. Introduction

The Korean economy went into the world's rapid development process in the second half of 20th century. The quick industrialization performances and the rapid increase in exports have been noticed by the world, and this seems to have been possible mainly thanks to the imports from other advanced countries like Japan. We might think that a large number of imported high-tech capital equipment and intermediate goods improved the level of industrial capital and technology in Korea. Korea also could have enjoyed the effect of international technology diffusion and obtained higher productivity levels. From 1981 to 2005, the level of Korea productivity has been significantly affected by foreign R&D(the United States, Japan and other OECD countries) and the huge import from(and sometimes exports to) those countries. This shows that international trade is very important for Korea's rapid technology progress and economic success.

Technology diffusion from more advanced economies benefits the country in two ways. On the one side, when we import capital goods in which new technology is embodied and use them in the production as the intermediate goods, it can directly increases the productivity. On the other side, researchers or inventors in less-developed countries can utilize the new knowledge that they came to know in the process of international trade. As the matter of facts, the endogenous growth theory says that the total amount of knowledge in the world as well as that of a certain economy does matter to the productivity of that economy, if the economy is really open to the world. This is due to the technology diffusion between the countries.

There is quite large body of literature for international technology diffusion. In particular, many studies investigate the relationship between international technology diffusion and international trade. The recent development of theories of technology diffusion has triggered new research on the relation of trade and technology diffusion.

One of the most important studies in this area is Grossman and Helpman(1991). The authors studied the growth performance of small countries to which scientific and technological knowledge flew from abroad. They found that the economic development (and technology diffusion) was related to its extent of foreign trade. Particularly, they showed that policies that reduced the extent of international trade resulted in the undersupply of innovation.

Coe and Helpman(1995) examined R&D spillovers among OECD countries. They obtained that foreign R&D had beneficial effects on domestic productivity and these effects were stronger if an economy was more open to foreign trade.

Eaton and Kortum(1996) developed a model of economic growth and technology diffusion. They tested the model by using aggregate data of OECD countries. They estimated the model to explain international patterns of productivity and patenting. They found more than 50% of the growth in each country in their sample was derived from innovation in the United States, Germany, and Japan.

Keller(1998, 2000) analyzed the findings of Coe and Helpman(1995) on trade-related international R&D spillovers. A Monte Carlo based robustness test was proposed which compared the elasticity of domestic productivity with respect to foreign R&D with an elasticity based on counterfactual international trade patterns. He also showed that these randomly created trade patterns gave rise to positive international R&D spillover estimates. He said that the finding cast doubt on the claim that patterns of international trade are important in driving R&D spillovers.

Hu and Jaffe(2003) examined the patterns of knowledge diffusion from US and Japan to

Korea and Taiwan using patent citations as an indicator of knowledge flow. They estimated a knowledge diffusion model using a data set of all patents granted in the U.S. to inventors residing in these four countries. Explicitly modeling the roles of technology proximity and knowledge decay and knowledge diffusion over time, they found that knowledge diffusion from US and Japan to Korea and Taiwan exhibited quite different patterns.

Xu *et al.*(2005) investigated international technology diffusion through trade and patenting in a sample of 48 countries for the period 1980~2000. They showed that rich countries benefit the developing countries' technology. And with the foreign technology embodied in imported capital goods, middle-income countries enjoyed technology spillovers. They found that government policies on intellectual property rights protection and trade openness had large effects on foreign technology spillovers in middle- and low-income countries.

While many papers focus on 'direct' R&D spillovers which are related to the levels of R&D produced by the trading partners, Lumenga-Nesoa *et al.*(2004) argue that 'indirect' trade-related R&D spillovers also take place between countries, even if they do not trade with each other. These 'indirect' spillovers are associated with available R&D rather than with produced levels of R&D. The results suggest that these 'indirect' trade-related spillovers are at least as important as the 'direct' ones, and strengthen the view that trade does matter for the international transmission of R&D. They also suggest that, due to the existence of these 'indirect' effects, bilateral trade patterns are relatively less important determinants of the level of foreign R&D spillovers acquired through trade.

Park(2007) estimated a patent equation to measure the effects of the trade on knowledge diffusion. He found the positive effects of trade and some preferential trade agreements like EU, EFTA and EEA on the international knowledge diffusion. Using a common language showed itself as another factor promoting the international knowledge diffusion. The effect of sharing common border was not robust. He also found that the number of patenting was increased in proportion to the market size and the absorption capacity of the reporting country and the invention capacity of the country of residence of applicant. The estimation results showed that the patenting to the member countries of international or regional patent cooperation agreements was more frequent than that to the other countries.

This paper focuses on the impact of international trade on the technology diffusion in Korea. We investigate the role of international trade or other variables in the technology diffusion from the foreign countries to Korea. We use patent data as a proxy for the degree of new knowledge creation or diffusion. We used 38 countries' patent application data to Korea from 1981 to 2005. The panel data model with time fixed effects and individual fixed effects is used in this paper.(1)

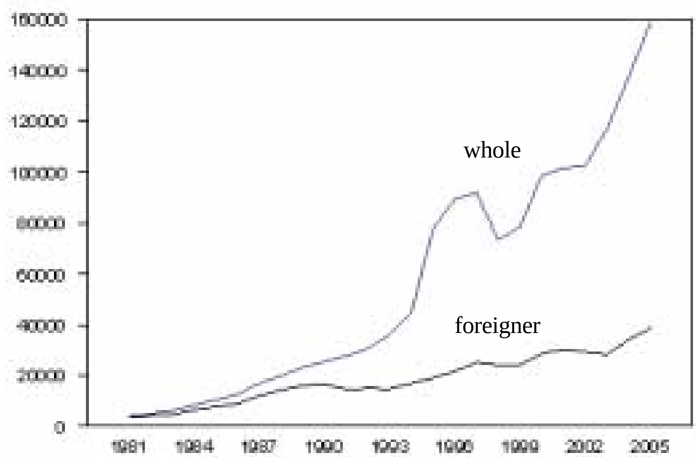
Different from the other published literature, this paper could make some new contributions in the sense that we focus on the technology diffusion of Korea and use the new panel data. We extracted the individual patent applications from raw data set of KIPO and counted the patent by the applying countries and the year.

In the section 2, we offer our econometric model and data, The results is shown in section 3 and we conclude in the section 4.

2. Model and Data

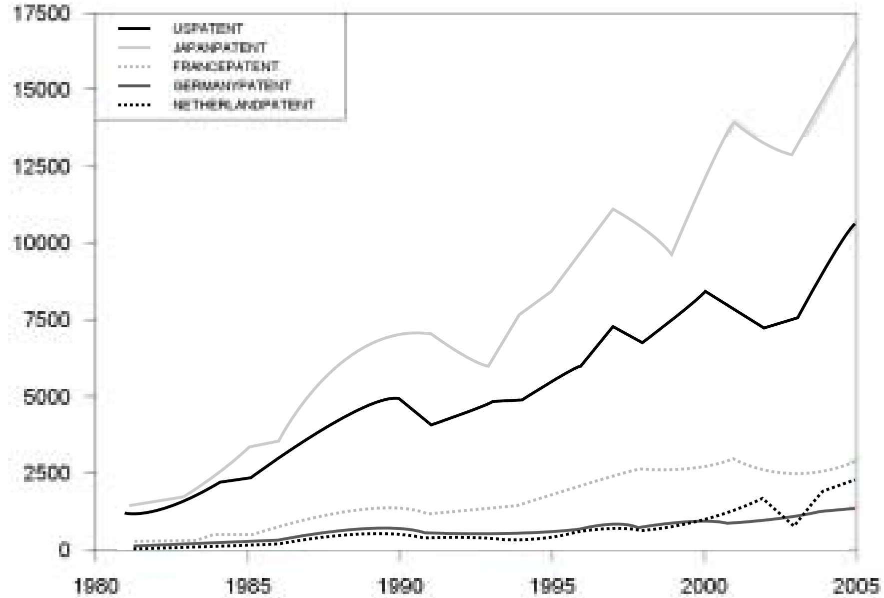
2.1. Trends of patent applications

In our patent sample, there were 3,983 total patent applications filed to Korea from worldwide in 1980. By the 2005 it increased to 40,000. The number of total patent applications got bigger than ten times in only two decades. <Figure 1> depicts the trends of foreign patent applications



<Figure 1> The trends of patent applications

(1) The countries are Argentina, Australia, Austria, Belgium, Canada, China, Chinese Taipei, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.



<Figure 2> The trends of patent applications by foreign countries

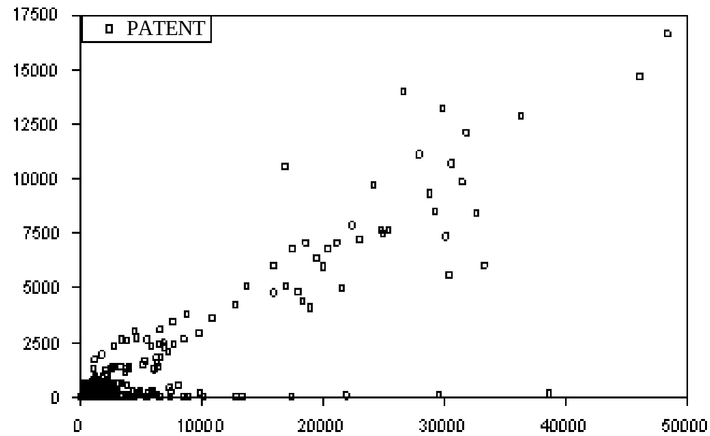
and total patent applications in Korea from 1981 to 2005. Whole patents are increasing rapidly, and the foreign patents have been increasing, too.

<Figure 2> shows the patents applications to Korea by major five partner countries; US, Japan, Germany, France, and Netherlands. Overall, there is upward trend, but the growth rate of foreign patents is comparatively low. The numbers of patent applications by Japanese and by the United States citizens ranked the first and the second, respectively. Besides, Japan has a higher number and growth rate than the United States, especially in recent years. United States' patent applications in Korea increased steadily from 1980s. France's patent applications increased steadily from 1980s, too.

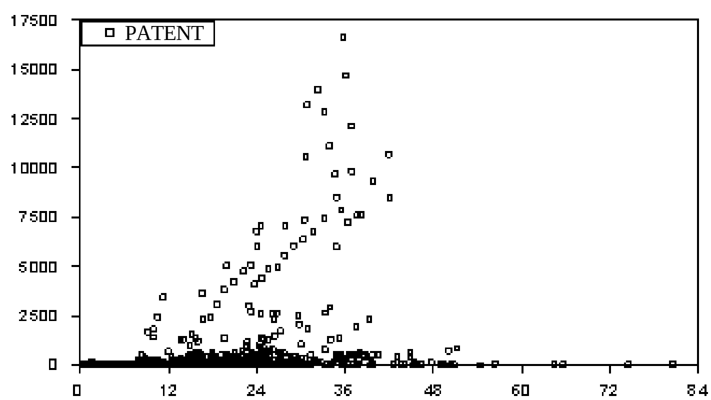
2.2. Patent applications and other variables

For a primary sketch, we plot the data of the foreign patent applications and imports in the same picture, <Figure 3>. There is clearly a positive relationship between two variables. <Figure 4> shows the data of foreign patent applications and per-capita GDP of the corresponding country. There is also a positive relationship between these variables.

Through the comparison of these figures, we guess that Korea's import from foreign country impacts on patent application more significantly than the foreign country's PGDP.



<Figure 3> Patent applications and imports



<Figure 4> Patent applications and per capita GDP

2.3. Econometric models

In this paper, we investigate the role of international trade for technology diffusion in Korea from other advanced countries. Basically, we use gravity model for the international trade. In the data analysis, patent application data are used as a proxy for technology diffusion. Thus the dependent variable is the number of foreign patent application in Korea. For the independent variables, we used the distance, import, export, and trade between Korea and applying countries. In addition, per capita gross domestic product and gross domestic product are used as additional explanatory variables.

We use a couple of versions of regression. First we use the time series data of many partner countries, and give out the panel data research. For this analysis the model is as follows.

Panel regression model

(2.1) $$PT_{it} = \alpha + \beta_1 DIS_{it} + \beta_2 GDP_{it} + \beta_3 PGDP_{it} + \beta_4 TRADE_{it} + \varepsilon_{it}$$

Where i is the trading partner country and t is the year. PT_{it} is the number of patent applications by country i applied in year t in Korea. The data are extracted from the raw data set of KIPO(Korea Intellectual Property Office). We counted the number of patents country by country. DIS_{it} is the distance between Korea and foreign country i (data source: http://www.cepii.fr/anglaisgraph/bdd/distances.htm). Distance appears to inhibit the technology diffusion between countries. There are two kinds of distance measures: simple distances and weighted distances. In this paper, the simple distance measure is used.

GDP_{it} is the gross domestic product of country i in year t (data source: www.worldbank.org). GDP is in US dollar. $PGDP_{it}$ is per capita gross domestic product of foreign country i in t, which is obtained by dividing GDP with population (data source: www.worldbank.org). $TRADE_{it}$ is the trade amount between Korea and foreign country i (data source: www.kita.net). $IMPORT_{it}$ is the Korea's import value from country i in year t and $EXPORT_{it}$ is the Korea's export to country i (data source: www.kita.net). All the variables are in natural logarithm.

Next, we implemented another regression as follows.

Cross section equation

(2.2) $$PT_i = \alpha + \beta_1 DIS_i + \beta_2 GDP_i + \beta_3 PGDP_i + \beta_4 IMPORT_i + \beta_5 TRADE_i + \varepsilon_i$$

3. Regression Results

3.1. Primary statistics

A brief overview of the data is shown in the <Table 1>. The table indicates the summary statistics and simple correlations between the explanatory variables and patent applications during the period 1981~2005. Patent application is strongly and positively correlated with GDP, PGDP, import, export, and trade. It is negatively correlated with distance. Distance is also negatively correlated with other variables. Therefore we are likely to have multicollinearity problem in the regression if we use the import, export, and trade at the same time.

<Table 1> Summary statistics and correlations for variables

(a) Summary statistics

	Mean	Std Error	Minimum	Maximum
PATENT	497.145	1745.454	0.000	16633.000
GDP	583.896	1368.612	2.797	12421.880
PGDP	15.940	12.198	0.277	80.458
DIS	8614.111	3309.845	955.651	19447.350
IMT	1998.361	5534.631	0.000	48403.000
EXT	1992.124	5457.724	0.000	61915.000
TRADE	3986.177	10668.874	0.000	100563.000

(b) Correlation Matrix

	PATENT	GDP	PGDP	DIS	IMT	EXT	TRADE
PATENT	1.000	0.804	0.311	-0.207	0.887	0.6807	0.808
GDP		1.000	0.289	-0.048	0.819	0.822	0.845
PGDP			1.000	0.002	0.243	0.171	0.214
DIS				1.000	-0.281	-0.225	-0.261
IMT					1.000	0.885	0.971
EXT						1.000	0.970
TRADE							1.000

3.2. Regression for the panel data

We test the panel data model with time fixed effects and individual effects. Considering that there are 38 countries during the period 1981~2005, 950 total observations are generated. As the distance between the foreign country and Korea is a fixed value, we take off this variable when individual fixed effects model is implemented. We take logarithm for the variable in the regression.

Usually, it is expected that if two countries are far away from each other, it is reasonable to think technology diffusion to be restricted and the numbers of foreign patent application would be getting smaller. From the OLS regression results, we can see the signs in the front of distance variable are all "+", whose outcome does not coincide with our theoretical expectation. They are also not significant according to the t-values.

But here, we need to check the autocorrelation problem. Durbin-Watson test Statistics are shown in <Table 2>. We get D-W = 0.963 for the equation (1), which is smaller than critical

<Table 2> Basic OLS regression results by panel data

	Basic OLS regression results by panel data						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	-0.289	-0.183	-0.217	-0.210	-0.218	-0.225	-0.200
	(-0.970)	(-0.579)	(-0.659)	(-0.647)	(-0.732)	(-0.743)	(-0.665)
Trend	0.031	0.031	0.035	0.034	0.029	0.031	0.029
	(1.731)	(1.614)	(1.745)	(1.714)	(1.609)	(1.663)	(1.590)
DIS	0.014	0.001	0.003	0.003	0.007	0.007	0.005
	(0.486)	(0.047)	(0.086)	(0.080)	(0.236)	(0.227)	(0.155)
GDP	1.120						
	(30.210)						
PGDP					0.740	0.825	0.780
					(12.278)	(13.801)	(12.588)
IMT		0.486			0.252		
		(26.710)			(9.696)		
EXT			0.369			0.167	
			(24.552)			(8.027)	
TRADE				0.401			0.197
				(25.489)			(8.470)
D-W	0.963	0.963	0.883	0.876	1.010	0.974	0.970
$\bar{R}^2$	0.507	0.443	0.402	0.420	0.519	0.505	0.508
No of Obs	950	950	950	950	950	950	950

Note: t - Statistic is in parentheses.

value 1.370 for n = 38 and k = 2. This means there is the serious autocorrelation problem. The results from equation (2), (3), (4), (5), (6), and (7) are similar. The results of low Durbin-Watson statistics indicate that there is a serious autocorrelation in my panel analysis. Thus we use the Cochrance-Orcutt method.

From the <Table 3>, we see that the Durbin-Watson statistic is improved. The adjusted R^2 terms are also better now. From the regression results, we can see the signs of distance variables are all " — ", which is consistent with our theoretical expectation. But note that they are not significant according to the t-values.

The t-value of GDP is 13.381, appearing to be large enough to show that the foreign country's GDP impact on the foreign patent applications is significant. Now, the coefficient of GDP is 0.895, indicating that if the foreign country's GDP increases by 1%, the number of patent

<Table 3> The Cochrane-Orcutt method by panel data

	The Cochrane-Orcutt method by panel data						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	0.144	1.167	0.846	0.784	0.188	0.196	0.258
	(0.233)	(1.130)	(0.940)	(0.961)	(0.300)	(0.305)	(0.409)
Trend	0.001	-0.025	-0.021	-0.022	-0.001	-0.002	-0.006
	(0.027)	(-0.372)	(-0.365)	(-0.418)	(-0.018)	(-0.055)	(-0.150)
DIS	-0.007	-0.086	-0.059	-0.057	-0.012	-0.011	-0.017
	(-0.122)	(-0.852)	(-0.675)	(-0.719)	(-0.193)	(-0.179)	(-0.279)
GDP	0.895						
	(13.381)						
PGDP					0.739	0.667	0.627
					(8.788)	(7.472)	(6.820)
IMT		0.135			0.119		
		(4.045)			(3.514)		
EXT			0.179			0.118	
			(6.996)			(4.129)	
TRADE				0.246			0.159
				(8.346)			(4.576)
D-W	2.175	2.425	2.368	2.334	2.188	2.193	2.189
$\bar{R}^2$	0.686	0.666	0.673	0.676	0.683	0.685	0.686
No of Obs	950	950	950	950	950	950	950

application will increase about 0.895% in Korea. The PGDP also looks significant. Through the comparison of PGDP and GDP, it is clear that GDP effects more on the patent application than PGDP since 0.895 > 0.739 (the largest coefficient of PGDP).

The import variable is the main target in this paper. The t-statistics of the import appear to show that the Korea's import from foreign country impacts significantly on the patent application. The coefficients of the import are 0.135 and 0.119 respectively. If the Korea's import increases by 1%, the numbers of foreign patent application will increase about 0.119～0.135% in Korea.

Export to foreign country looks significant. The coefficients of exports are 0.179 and 0.118, meaning that if the Korea's export to foreign country increases by 1%, the number of patent application will increase about 0.118～0.179%. This shows that the Korea's export to foreign country is also important. Thus it is very easy for us to conclude that the Korea trade is an important factor for the patent application.

3.3. Causality between imports and patent

In time series econometrics, numerous methods have been developed for managing Causality problem. We use one of the most popular and reliable estimation methods to check the causality between the patents and international trade.

Considering the causal relationship of two variables X and Y, the Granger Causality test is the most common method. In one direction, advanced technology of foreign countries are said to be mostly embodied in the imports of high-technology intensive goods, and then imports leads to the technology improvement in Korea. That is, imports causes technology diffusion. On the other hands, when the patent application by foreign countries increases, this could mean that there is a promising market in Korea for the foreigners to take the share, thus foreigners are getting more exports to Korea. So we test the causal relationship between two variables: the number of patent application and Korea's import from foreign countries. Our simple model and test criteria are as follows.

(3.1) $$PT_t = \sum_{i=1}^{k} \alpha_{1i} PT_{t-i} + \sum_{j=1}^{k} \beta_{1j} IMT_{t-j} + \varepsilon_{1t}$$

(3.2) $$IMT_t = \sum_{i=1}^{k} \alpha_{2i} PT_{t-i} + \sum_{j=1}^{k} \beta_{2j} IMT_{t-j} + \varepsilon_{2t}$$

Here, we say there is a Granger causal relationship of "$IMT \Rightarrow PT$" when $\beta_{1j} \neq 0$ (for some j = 1, ..., k) and $\alpha_{2i} = 0$ (for all i = 1, ..., k). Similarly, there is a causal relationship of "$PT \Rightarrow IMT$" when $\beta_{1j} = 0$ (for all j = 1, ..., k) and $\alpha_{2i} \neq 0$ (for some i = 1, ..., k). And a causal relationship of "$PT \Leftrightarrow IMT$" exists when $\beta_{1j} \neq 0$ (for some j = 1, ..., k) and $\alpha_{2i} \neq 0$ (for some i = 1, ..., k). This is mutual causality between two variables. There is no Granger causal relationship when $\beta_{1j} = 0$ (for all j = 1, ..., k) and $\alpha_{2i} = 0$ (for all i = 1, ..., k).

Granger causality test, in essence, tests whether a variable's lagged term can be included in the equation of other variables or not. If the lagged variables are significant in the equations, then the variables are said to Granger-cause the other variable. An important issue of Granger causality test is on the value of K. When we choose K, we want to make K large enough to perfectly reflect the dynamic characteristics of the model. On the other side, for the larger K we have more parameters to estimate, and the model has fewer degrees of freedom. Here, we put K = 1 just for

<Table 4> The results of Granger Causality test

Null Hypotheses	F-statistic	P-value	results
IMT dose not Granger cause PT	48.4039	0.0000	reject
PT dose not Granger cause IMT	17.6524	0.0000	reject

convenience. Granger causality test results of the two variables are shown in <Table 4>. We got the results of mutual causality, which means we can not say there is one way causality from imports to technology diffusion.

3.4. Cross section analysis for the selected year

We employed the panel data model with time fixed effects and individual effects in the previous section. Recall that there are 38 countries over the period 1981~2005, generating 950 total observations. Now we use cross section analysis to study the selected years (such as: 1985, 1990, 1995, 2000, and 2005 year) in the data sample. We employ two equations with and without some variables among distance, GDP, PGDP. The results are shown in <Table 5>.

From the table we see that the import's impact on the patent application has been continuously strengthened from 1985 to 2005, which can also reflect that the import effect on the knowledge diffusion is becoming increasingly large and getting more important along with the expansion of Korea's imports recently.

4. Conclusions

This paper examined whether there is any relationship between the international trade and international technology diffusion. We used the number of patent applications by foreigners as an indicator of the technology diffusion in Korea. There was an autocorrelation problem when we took the panel OLS regression with time fixed effects and individual effects. In order to overcome the autocorrelation, Cochrane-Orcutt method is used. Besides, we also try another way to tackle this problem. We choose to study the selected years (such as: 1985, 1990, 1995, 2000 and 2005 year) in the data sample and try to get the cross section regression results. The empirical results show that Korea's international trade has clearly a positive effect in the process of international technology diffusion in the sense that the patent application by foreigners has positive relation with the trade variables. At the same time, Korea's trading partner country's

<Table 5> Cross section analysis for the selected year

	1985		1990		1995		2000		2005	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
상수	-2.175	2.356	-4.293	-3.481	-5.195	-5.108	-1.365	-2.699	1.729	-3.825
	(-0.508)	(0.609)	(-1.076)	(-0.804)	(-1.263)	(-1.658)	(-0.317)	(-0.779)	(0.353)	(-1.245)
DIS	-0.017	-0.516	0.100	0.093	0.182	0.108	-0.098	-0.063	-0.478	-0.183
	(-0.037)	(-1.205)	(0.811)	(0.197)	(0.430)	(0.331)	(-0.222)	(-0.174)	(-0.967)	(-0.579)
GDP	1.139				1.303		1.158		1.157	
	(5.753)				(7.490)		(6.452)		(5.420)	
PGDP		1.383	1.316	0.831		1.067		1.055		1.287
		(4.503)	(7.300)	(3.024)		(5.960)		(4.960)		(6.731)
IMT		0.559		0.741		0.791		0.733		0.875
		(4.676)		(5.627)		(8.487)		(7.043)		(9.503)
$\bar{R}^2$	0.492	0.639	0.612	0.658	0.602	0.805	0.547	0.748	0.475	0.832
# obs	38	38	38	38	38	38	38	38	38	38

GDP and PGDP were also shown to be significant in the regression. The distance between foreign countries and Korea does not seem to be very significant.

It seems reasonable to conclude that technology diffusion from developed economies, such as Japan, U.S, and EU, was possible through international trade with those countries. Many economists have proposed various channels through which technology diffusion may be facilitated, such as foreign direct investment, scholarly exchange, international trade, and on. This paper seems to confirm the international trade as a good channel.

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Appendix

<Table A-1> Patents by major countries

year	foreign total	US	Japan	Germany	France	Netherland
1981	3,627	1,261	1,423	158	228	77
1982	4,072	1,315	1,680	193	270	89
1983	4,653	1,564	1,808	221	302	111
1984	6,548	2,288	2,430	263	505	182
1985	7,831	2,446	3,446	283	503	176
1986	9,045	3,092	3,639	315	667	251
1987	12,105	3,801	5,063	476	964	375
1988	14,285	4,208	6,039	582	1,228	543
1989	16,191	4,781	6,796	653	1,400	647
1990	16,602	5,084	7,068	679	1,389	561
1991	14,764	4,106	7,076	503	1,160	464
1992	15,004	4,402	6,383	545	1,298	471
1993	14,914	4,839	5,974	472	1,355	437
1994	17,009	4,997	7,639	554	1,492	354
1995	19,136	5,576	8,445	652	1,847	396
1996	21,727	6,050	9,850	666	2,076	631
1997	25,269	7,361	11,116	845	2,325	730
1998	24,276	6,814	10,547	758	2,648	686
1999	24,284	7,473	9,679	876	2,623	785
2000	28,672	8,521	12,127	999	2,730	947
2001	30,493	7,865	13,978	927	3,026	1,321
2002	29,286	7,252	13,200	1,051	2,647	1,712
2003	28,387	7,620	12,883	1,053	2,483	798
2004	34,348	9,314	14,685	1,299	2,653	1,947
2005	38,823	10,690	16,633	1,387	2,940	2,314

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