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04. October 2006

Online at <http://mpa.ub.uni-muenchen.de/98/>

MPRA Paper No. 98, posted 07. November 2007 / 00:47

Domestic and International Knowledge Spillovers in Manufacturing Industries in South Korea

This paper explores the relationship between the productivity growth and both domestic and international knowledge spillovers in the Korean manufacturing industries, using panel data for 28 industries over the period 1970-2000. To empirically verify the extent of domestic and international knowledge spillovers we have followed endogenous growth approach and wisdom from new international trade theory. We find strong productivity effects from industry's own R and D as well as domestic and foreign knowledge spillovers. International knowledge spillovers transmitted by trade played dominant role in explaining productivity growth in the Korean manufacturing industries during the 1970s and 1980s, but the international knowledge spillovers did not play any significant role in the 1990s. This empirical finding has strong implications for the Korean technology policy as well as for the strict intellectual property rights regime enacted by the WTO.

LAKHWINDER SINGH

Introduction

Knowledge accumulation and its progress have been recently recognised as the engine of economic growth [Jones 2002]. The application of knowledge in economic activities explains substantial part of income differential within and across countries [World Development Report, 1998-99]. It is widely recognised that the generation of knowledge is proportional to the amount of resources expended by the national economy. The peculiar characteristic of knowledge is that it is partially non-excludable as well as non-rival. Therefore the producers of knowledge cannot prevent others to make use of it howsoever the stringent property rights are enacted. However, the strict intellectual property rights regime has a capacity to reduce the extent of public knowledge along with global reduction of innovations at least in short run [Helpman 1993]. This means that the knowledge has the public good characteristic and the domestic investment which generates knowledge also adds to the global pool of knowledge.¹ Consequently, the effect on the productivity of domestic innovative investor's productivity may be accompanied by an external effect of other economic agents' innovative efforts which is popularly called as spillover effect. The knowledge spillovers has been considered recently as a fundamental source of increasing returns to scale and a determinant of persistence of productivity and income differentials across economic agents of production [Romer 1986, Lucas 1988]. The reduction of productivity differentials, therefore, requires stepping up innovative efforts which also enables the economic agents of production to draw more external public knowledge for its ends.

The externalities underlined by the endogenous growth literature as mechanism of linkages across economic agents of production are both domestic and international in scope. An important aspect of spillovers in relation to economic growth is the relative extent of national and international spillovers. If the spillovers are national in scope where knowledge creation efforts are taking place then the growth rate in each country will be

determined by country's own innovative efforts. If knowledge spillovers are purely international in scope then the domestic growth is mainly determined by the innovative efforts made in other countries in the globe. Empirical studies in general confirm the existence of spillovers within and across industries within a country [Griliches 1992, Meijl 1995]. However, the recent empirical evidence pertains to the advanced countries show that the major source of knowledge progress leading to productivity growth in these countries is not domestic but rather international [Coe and Helpman 1995, Eaton and Kortum 2001, Keller 2001]. This suggests that the countries which are have more linkages with those countries that are on the frontiers of knowledge would be the gainers in terms of enhancing productivity of their factors of production.

A striking feature of South Korea's industrial growth process is the reduction of productivity and technological gap with the global technology leaders relatively in a short span of time. Some of its productive activities, such as telecommunication have already achieved the global leader's productivity level [Baily and Zitzewitz 1998] and is very near to achieving global leader's productivity and technology levels in most knowledge intensive productive activities [Lee and Lim 2001, Baily and Zitzewitz 1998]. Obviously, this achievement is based on early period of technology import from external sources and stepping up domestic efforts in the latter period. The state, during this period, played an important role in nurturing the economic agents of production through creating a web of technology development related institutions and providing suitable human capital resource [Suh 2000]. The diffusion of technology was the central force in achieving an all around productivity growth. The contribution in the success of moving up the technological ladder of external sources such as direct purchase of technology and imports of technology intensive commodities is pretty clear [Kim 2000, Suh 2000], but the contribution of indirect flows of knowledge to productivity growth is still lacking. An attempt in this paper is made to fill this gap.

This study analyses different aspects of domestic and international knowledge spillovers. A distinction has been made between pure rent and knowledge spillovers. To empirically verify the extent of domestic and international knowledge spillovers we have followed endogenous growth approach and pooled time-series and cross-section data for 28 manufacturing industries for the period 1970-2000.

The rest of the paper is organised as follows. Theoretical and empirical literature is discussed in Section II. In Section III, we have described the analytical framework of the paper. The variables used in the analysis, their construction and sources, are stated in Section IV. The main empirical findings and discussion are reported in Section V. The final section contains summary, conclusions, and policy implications.

II Theoretical and Empirical Overview of Literature

Domestic and foreign diffusion of technological knowledge is widely recognised as a fundamental factor of long run growth. However, the moot question here is how domestic and foreign knowledge takes place and what kind of knowledge (domestic or foreign) is more important. This question is of high theoretical and practical importance. There are three strands of economic theory that explains how long run economic growth directly addresses the question of how knowledge diffusion takes place. First, the neoclassical growth theory assigned central importance to knowledge in explaining long run growth. However, it considered knowledge as exogenously determined and therefore, focused solely on the public good aspect of technology. The underlined transmission mechanism of diffusion is automatic and without incurring any cost and thus, is of little practical relevance to understand the diffusion process. Second, the technology gap theory of long run economic growth, which is essentially an appreciative theory, emphasised the advantages of technological backwardness and opportunities to catch up the technology leader by the developing countries [Fagerberg 1987, Gerschenkron 1962]. The underlined mechanism of knowledge diffusion in this stream of thought is mastery of developed country's technology by developing countries. It clearly recognised the need for building sufficient domestic capabilities for imitation of technological knowledge. In a similar vein, Abramovitz (1979) argued, while using the concept of absorptive capacity, that the existence of domestic capability is a precondition to assimilate foreign spillovers. Thus, it is quite clear that the process of imitation

of frontier technology from the advanced country entails cost and this cost varies positively with the increase in the complexity of knowledge. Obviously, the message from the technology gap theory is that the domestic and international knowledge diffusion involves huge cost. Without sufficient level of domestic capabilities, which requires massive investment, a country is unlikely to benefit from leaders' technological knowledge and face risk to continuously lag behind than catch up [Verspagen 1991]. Third, the new growth theory, which is also known as 'endogenous growth theory', however, stressed the role of innovative investment, human capital accumulation and externalities as the dominant factors that determine long run economic growth. It is important to note that the concern of new growth theory is to endogenise the growth which requires the rate of investment to be internalised. Although it is ultimately the factor accumulation that accounts for growth, yet for factor accumulation to grow, the returns to capital stock should not diminish. The new knowledge, which prevents diminishing returns on capital stock, is produced by investment in research technology which exhibits diminishing returns. Moreover, the increase in knowledge will not be appropriated solely by those who undertake investment. This implies that the investment effort gives birth to appropriable and non-appropriable growth of knowledge. The latter is called externalities or knowledge spillovers [Aghion and Howitt 1992, Grossman and Helpman 1991, Romer 1986]. Although the endogenous theory of growth identified knowledge spillovers as potential source of growth, yet the empirical support of such externalities is not yet conclusive.

The endogenous theory of growth inspired numerous scholars to examine a fresh interdependence of economic growth process and international diffusion of knowledge across countries and overtime. Seminal contribution towards this direction is of Coe and Helpman (1995). Coe and Helpman have examined the relationship between total factor productivity of a country and international technological spillovers. To verify this relationship empirically the authors selected 22 advanced countries and developed a panel data for the period 1971-90. The most striking result of the study is that the foreign spillovers are more important as a source of productivity growth in the small open economies compared with their domestic efforts in technology. However, the elasticities of domestic efforts of technology are higher in the G-7 countries compared to the international technological spillovers. This revealing new evidence generated lot of heat and scepticism and thus resulted into a spurt in empirical literature on international technological spillovers [see for detailed overview Navaretti and Tarr 2000, Keller 2001]. The sceptics re-

Table 1: Estimates of Domestic and International Knowledge Spillovers 1970-2000
(Dependent Variable Is Log TFP Index)

Variables/Industry Effects	Fixed Effects (1)	Fixed Effects (2)	Fixed Effects (1)	Fixed Effects (1)	Fixed Effects (2)	Fixed Effects (2)	Fixed Effects (1)
Industry's own R and D stock	0.0625* (13.163)	0.05772* (2.759)	0.03004**** (1.595)	0.0156**** (1.523)	0.08610* (11.192)	0.07997* (3.715)	0.00784 (0.409)
Other industry R and D stock(I-O)			0.03365**** (1.782)				0.00929 (0.481)
Other industry R and D stock(TM)		0.00433 (0.236)				0.0056 (0.305)	
Same industry international R and D stock (I-O)				0.0803* (5.138)			0.07825* (4.832)
Other industry international R and D stock(TM)					-0.0569* (-3.876)	-0.0571* (-3.879)	
Adj-R squared	0.6622	0.6618	0.6631	0.6721	0.6677	0.6674	0.6718
Hausman test	0.1935	1.6783	3.9028	1.3775	9.4546	9.4750	5.2769
AIC	0.1318	0.1321	0.1316	0.1281	0.1298	0.1301	0.1284
N	868	868	868	868	868	868	868

Notes: 1 Figures in parentheses are t-values. AIC is Akaike's Information Criterion.

2 *, **** statistically significant at 1 per cent and 15 per cent level respectively.

examined the same data set introducing refinements in the construction of variables but endorsed the results of Coe and Helpman more empathically [Keller 1998, Lichtenberg and Potterie 1998]. Coe, Helpman and Hoffmaister (1997) extended the scope of their analysis to 77 developed and developing countries to examine the extent of international knowledge spillovers from developed to developing countries. The authors found that capital goods import substantial impacted international R and D spillovers from developed countries to developing countries. However, the domestic R and D stock has not been considered in the analysis on the pretext that developing countries incur little R and D expenditure. Contrary to this, Evenson and Singh (1997) have examined the impact of international technological spillovers on 11 Asian countries during the period 1970-93 and found higher elasticity of domestic R and D stock compared to that of international R and D spillovers. After introducing several refinements in the analysis, Singh (2001) re-examined the relationship between total factor productivity and international technological spillovers in Asian countries. He found that R and D elasticity in Asian countries is higher compared to that of international technological spillovers. However, the estimates of international R and D spillovers were higher than the domestic R and D stock elasticity for the east Asian countries. Somewhat similar results were reported by Kim (2000) after examining six east Asian countries covering the period 1971-93.

Empirical results reported by the studies using disaggregative data, however, present different picture on international technological spillovers. Evenson (1995) has examined the relationship between total factor productivity and domestic and foreign R and D stock, while introducing several refinements in the construction of variables and underlying concepts used such as changes in unadjusted quality improvements in total factor productivity rather than levels of total factor productivity, international R and D stock of leader industry/country by the follower industry/country and innovation generating industry to innovation receiving industry. The author has provided empirical estimates while using four observations of changes in variables for each industry between the periods 1969-89 for 11 industries for each of the seven OECD countries. On the basis of pooled regressions, he found that the capital goods impacted international R and D capital stock is positive but non-significant. The most important finding of this study is that the interaction of catch up variable (economic distance) with domestic R and D capital stock is the dominant explanation for changes in total factor productivity

growth for the OECD countries. Thus, concluded the author, the convergence effect is channelled through domestic R and D stock. Some what similar empirical evidence has been reported by Keller (2002) for G-7 countries as well as from Sweden. To examine the relative importance of domestic and international knowledge spillovers, Braconier and Sjöholm (1998) examined both national and international technological spillovers for six large OECD countries and nine industries while covering the period 1973-91. The authors found that industry's own R and D stock and domestic spillovers were significant in explaining total factor productivity. However, intra-industry international spillovers were positive but less important compared with domestic spillovers. Fagerberg and Verspagen (2000), while using the most comprehensive data set consisting of (1974-92) for 14 countries and 22 manufacturing industries, found that the domestic industry R and D stock is most important variable in explaining productivity compared with both domestic and international technological spillovers. However, the authors reported higher international R and D elasticity compared with domestic spillover R and D elasticity.

The briefly stated literature on international R and D spillovers do not show any conclusive evidence of international knowledge spillovers when disaggregation is introduced in the analysis. The diaggregative analysis of international knowledge spillovers is more or less concentrated on the advanced countries and almost bypassed the most important growth pole of the world, that is, Asia and more specifically South Korea. This paper attempts to fill this gap.

III Framework for Analysis

Interdependence among economic agents of production has been increasing over the last three decades of the 20th century at a pace unprecedented compared with earlier historical times. Interdependence is growing both across and within national boundaries. The fundamental dynamic force working behind this change is technological knowledge. Technological revolution has tremendously reduced cost of transportation and communication within and across national boundaries and thus has facilitated faster flows of goods, services, humans and of course technological knowledge. It has been increasingly argued in the globalisation literature that technological knowledge is becoming global by leaps and bounds. Although, the production of technological knowledge is largely taking place within the national

Table 2: Estimates of Domestic and International Knowledge Spillovers 1970-2000
(Dependent Variable Is Log TFP Index)

Variables/Industry and Period Effects	Random Effects (1)	Random Effects (2)	Random Effects (1)	Random Effects (1)	Random Effects (2)	Random Effects (2)	Random Effects (1)
Industry's own R and D stock	0.06796* (9.573)	0.05601* (2.822)	0.03865** (2.045)	0.0222** (1.954)	0.094950* (10.050)	0.07939* (3.930)	0.01372 (0.704)
Other industry R and D stock(I-O)			0.03223*** (1.668)				0.01074 (0.545)
Other industry R and D stock(TM)		0.01145 (0.664)				0.015264 (0.902)	
Same industry international R and D stock (I-O)				0.07932* (5.239)			0.0769* (5.043)
Other industry international R and D stock(TM)					-0.06388* (-4.270)	-0.0651* (-4.343)	
Constant	0.13356 (1.409)	0.1410**** (1.489)	0.16616*** (1.821)	-0.3779 (-0.371)	0.34934 (3.402)	0.3638* (3.485)	-0.022* (-0.215)
Adj-R squared	0.10667	0.11476	.12666	0.0846	0.0044	0.02025	.0980
Hausman test	13.8081	18.0973	49.5915	21.5322	31.6291	34.0591	44.6036
N	868	868	868	868	868	868	868

Notes: 1 Figures in parentheses are t-values.

2 *, **, *** statistically significant at 1 per cent, 5 per cent, and 10 per cent level respectively.

boundaries, yet its transmission through various channels is on the rise [Archibugi and Pietrobelli, 2002]. Direct channels through which technological knowledge is being transmitted across and within national boundaries are well documented in economic literature. A growing body of economic literature suggests that the indirect transmission of technological knowledge is substantial and entails numerous channels such as trade, direct foreign investment, and communication.

Trade is the most widely accepted channel of domestic and international diffusion of technological knowledge across industries. Foreign trade boosts productivity growth, as underlined by the new developments in the theory of international trade, broadly through exposure of domestic production agents to physical characteristics of new variety of products which contain new technological knowledge and access to intermediate products. It also raises the consciousness of the producers towards quality improvements and spirit of competitiveness. This suggests that economic agents of production having trade relations with technology frontier agents of production will gain in terms of productivity growth. However, the empirical studies which examined the relationship between level of productivity and international technological knowledge transmission through trade show mixed results. A recent decomposition exercise to empirically verify the relative importance of international trade as a channel of diffusion of international technological knowledge show that trade transmits more than 50 per cent of the total international technological knowledge [Keller 2002]. Apart from this trade is the most traditional channel of international economic relations and availability of trade statistics is most up to date as well as comprehensive.

Foreign direct investment not only fills the gap of inventible resources but involves the transfer of technological knowledge from one country to another [Carr, Mrkusen and Maskus 2001]. Multinational corporations are considered as leaders in producing commercial oriented innovations and thus brings in along with investment, new technology, new varieties of products, new organisational forms that makes it a potent vehicle of international technology diffusion. Empirical studies conducted to examine the impact of foreign investment for international technology diffusion report, however, mixed results. Aitken and Harrison (1999) show negative relationship between foreign direct investment and total factor productivity of domestic plants. However, Xu (2000) in a detailed study covering 40 countries finds positive relationship between productivity growth and foreign direct investment. The impact of foreign direct investment on productivity is stronger and robust for advanced countries than less developed countries.

Recently information technology revolution opened up new possibilities of communications and monitoring abilities across long distances and made easier for multinational corporations to outsource certain stages of production. This implies that communication between distantly located persons might play an important role now than before. However, technological knowledge is becoming at the same time more complex and increasingly tacit which instead increases the importance of face to face communication. Empirical studies yet to incorporate this important source of international diffusion of technology into the analysis.

It needs to be mentioned here that channels suggested in theory are interlinked. The links between foreign direct investment, technology transfer and various trade flows will often be particularly close. Investment by a firm in a plant in other country may well involve technology transfers and exports of capital goods and services to assist in establishment of plant, while the operation of the plant requires continuous import of intermediates. Thus, foreign trade emerges as the most significant channel through which international technological spillovers can be transmitted. This transmission process will depend on the trade partners' accumulated R and D stock which is embodied in the tradable products.

Moreover, a country/industry trades with that country which is capable of providing technologically superior products and information which the importing country is in short supply. Therefore, the import weighted cumulative R and D stock of the technological superior trade partner seems to be an appropriate approximation of the channel of international technological spillovers.

Long-run growth is endogenously determined by R and D investment and knowledge spillovers transmitted through trade in intermediate inputs. To empirically examine the relationship between total factor productivity and R and D stocks, we follow the usual Cobb-Douglas extended production function approach [see for detailed derivations in Keller 2002, Meijl 1995]. The relationship between productivity and its determinants is expressed as follows:

$$\text{LogTFP}_{it} = \alpha_{it} + \beta_1 \text{logS}_{it}^d + \beta_2 \text{logDS}_{it} + \beta_3 \text{logFS}_{it} + \varepsilon_{it} \quad (1)$$

Where:

TFP is the total factor productivity;

S^d is the industry's own R and D capital stock;

DS is domestic intermediate trade weighted knowledge spillovers;

FS is the international import weighted knowledge spillovers;

ε is the random disturbance term; and

i and t index industries and time periods.

Table 3: Estimates of Domestic and International Knowledge Spillovers 1970-79

(Dependent Variable Is Log TFP Index)

Variables/Industry Effects	Fixed Effects (1)	Fixed Effects (2)	Fixed Effects (1)	Fixed Effects (1)	Fixed Effects (2)	Fixed Effects (2)	Fixed Effects (1)
Industry's own R and D stock	0.07553* (8.622)	0.09061* (2.521)	0.07095** (1.863)	0.02614*** (1.467)	0.07912* (8.351)	0.09526* (2.629)	0.04985 (1.314)
Other industry R and D stock(I-O)			0.00583 (0.124)				-0.339 (-0.708)
Other industry R and D stock(TM)		-0.01358 (-0.433)				-0.0145 (-0.462)	
Same industry international R and D stock (I-O)				0.0972* (3.166)			0.10298* (3.238)
Other industry international R and D stock(TM)					-0.0217 (-0.994)	-0.02198 (-1.006)	
AIC	.09708	0.09771	0.09778	0.09401	0.0974	0.09802	0.09551
Adj-R squared	0.4891	0.4875	0.4871	0.5068	0.4891	0.4875	0.5059
Hausman test	2.8862	3.2480	1.7408	10.6965	4.2911	3.9572	9.6374
N	280	280	280	280	280	280	280

Notes: 1 Figures in parentheses are t-values. AIC is Akaike's Information Criterion.

2 *, **, *** statistically significant at 1 per cent, 5 per cent and 10 per cent level respectively.

A substantial body of economic literature on knowledge spillovers has made a useful distinction between 'pure rent and knowledge spillovers [Griliches 1979, Meijl 1995, Keller 2002]. The transmission of knowledge, generated and embodied in the intermediate inputs, from the R and D performing to the recipient is being channelled through trade has been described as pure rent spillover. The equation (1) postulates the relationship between productivity and knowledge spillovers both domestic and foreign reflected through intermediate trade flows and essentially provides estimates of pure rent spillovers. Pure knowledge spillovers came into existence when ideas discovered in one sector were used in other sector without using intermediate factor inputs. It is important to note here that knowledge generated in a sector which is technologically close or similar in like sectors is expected to be more valuable than knowledge generated in sectors which draw on a completely different knowledge base. This idea of knowledge generated by an innovation of manufacture (IOM) industry and transmitted to industry of use (IOU) has given birth to pure knowledge spillovers. Thus, it is argued that technological closeness of sectors need not be related with input purchased as is the case of pure rent spillovers. Knowledge spillovers captured through innovation flow matrix are described by the equation (2). Therefore, we have proposed to estimate the following equation to quantify the magnitude of pure knowledge spillovers.

$$\log TFP_{it} = \alpha_{it} + \beta_1 \log S_{it}^d + \beta_2 \log TDS_{it} + \beta_3 \log TFS_{it} + \varepsilon_{it} \quad (2)$$

Where:

TFP is the total factor productivity;

S^d is the industry's own R and D capital stock;

TDS is the technology matrix weighted domestic knowledge spillovers;

TFS is the technology matrix weighted international knowledge spillovers;

ε is the random disturbance term; and

i and t index industries and time periods.

Our particular interest is in the econometric analysis which quantifies the domestic and international knowledge spillovers.

IV Data and Variables

This paper uses data on 28 three-digit Korean manufacturing industries covering the period 1970-2000.² The data used in the analysis is drawn from the Report of Mining and Manufacturing Survey published by the Economic Planning Board, the Republic of Korea and it covers all manufacturing establishments which are employing five or more workers. Our dependent variable is total factor productivity (TFP) estimated while using trans-log production function is as follows:

$$TFP(t) = \log V(t) - [S_l(t) \log L(t) + S_k(t) \log K(t)]$$

Where V , L , K , S_l and S_k indicate value added, labour, capital stock,³ the shares of labour and capital income in value added, respectively.

The calculations of total factor productivity employ revenue based factor shares. The appropriate price indices used to make variables at 1990 constant prices are drawn from the Korea Statistical Year Book. The total factor productivity level for all 28 manufacturing industry time series is normalised to one in the year 1970.

The industrywise research and development expenditure data, both Korea and other OECD countries, is drawn from the annual published report on the Survey of R and D in Science and

Technology by the ministry of science and technology, Korea and R and D Expenditure in Industry by the OECD.⁴ R and D stock series are derived from the real R and D expenditure data using the perpetual inventory method which is used as a proxy of technological knowledge.⁵ Knowledge spillovers, both domestic and foreign, as a determinant of productivity of an industry are captured while distinguishing its transmission either through trade or through technology of manufacture to technology of use industry. The trade impacted knowledge stocks for industry i from j industry are calculated as follows:

$$DS_i = o_{ij} R_j$$

Where O denotes the share of intermediates and R is the knowledge stock approximated by R and D capital stock. For estimation of domestic knowledge stock we have used input-output table for the years 1975, 1980, 1985 and 1990 which provides domestic intermediate inputs trade between industries while equating the diagonal elements equal to zero to avoid double counting.

The international trade impacted knowledge stock for industry i from j industry is calculated as follows:

$$FS_i = m_{ij} R_j$$

Where m denotes the share of imports. OECD industrywise trade statistics are used to estimate the values of m . This measure of knowledge stock is also described as pure rent spillovers due to the simple reason that the prices paid by the user industry for the purchase of intermediate inputs do not reflect the full price of the product.

The pure knowledge spillovers both domestic and foreign for an industry i are approximated by the knowledge stocks estimated while using the weights drawn from the technology flow matrix as follows:

$$TDS_i = \omega_{ij} R_j$$

and

$$TFS_i = \omega_{ij} R_j$$

Where ω is the weights from the sectoral Technology Flow Matrix (TM hereafter) and are taken from Verspagen (1997).⁶

V Econometric Specification and Empirical Results

To quantify the impact of domestic and foreign knowledge spillovers on the productivity growth of Korean manufacturing industries, we have developed a balanced panel data set covering 28 three-digit manufacturing industries for the period 1970-2000. The estimates of the parameters of equations (1) and (2) will crucially depend upon whether the coefficients are assumed to be fixed or random effects. The specifications of equations assume that the intercept can vary across industries and over time. By assuming industry and time specific fixed effects the intercept can be defined as follows:

$$\alpha_{it} = \alpha + \mu_i + \gamma_t$$

The industry and the specific constant terms may capture unmeasured disturbances to the total factor productivity growth. It is important to note here that the omitted factors which influence the dependent variable can assume the characteristics of a random variable. The underlying assumption is that the regression disturbances are composed of three independent components: one component associated with time, another with cross-sectional units, and the third varying with both the dimensions such as

$$\alpha_{it} = \mu_i + \gamma_t + \omega_{it}$$

The choice treating effects as fixed or random is difficult one. There is a trade-off between efficiency and consistency in the fixed and random effects models. This trade-off provides an

empirical basis on which to make the decision between them. Hausman provided a method to test whether the bias from random effects model exceeds the gain in efficiency. On that basis, the results of the Hausman test clearly reject the random effects model in one way panel estimates but rejects the fixed effects models when we estimate the parameters taking into consideration the time period as well. The parameters estimated from equation (1) and (2) for the whole period 1970-2000 which has only fixed effects are reported in Table 1. The estimated parameter, that is, β_1 obtained from equation (1) is 0.0625 which is positive and highly significant. This coefficient as reported in other studies normally lies in the range of values between 0.06 and 0.1 for the advanced countries [Griliches 1995]. When we have included the domestic knowledge spillover variable in the equation (1), the value of the parameter of the domestic knowledge spillover is higher than that of the industry's own R and D stock. When both the domestic and foreign import impacted R and D stocks along with industry's own R and D stock are included in the regression, the coefficients obtained from equation (1) are positive but only the foreign knowledge spillover parameter is significant.

On the contrary, when we estimated the equation (2) with same three variables based on TM, the industry's own R and D stock parameter is higher and significant but the foreign knowledge parameter is negative and highly significant. However, domestic knowledge spillover parameter is positive but statistically non-significant. If we use the selection criterion to choose the best regression equation on the basis of adjusted R square then the gain in R square is maximum in the (2) equation which includes knowledge spillover variables weighted by technology flow matrix. In this equation the industry's own R and D stock turns out to be the most dominant explanatory variable.

One way or one factor model considers either industry or period effects at a time in the model estimation only. The two way or two factor model has an overall constant as well as an industry effect for each group and a period effect for each time period. The two-way panel estimation do not fix either the number of time periods observed for each group or the number of industries observed in each time period. The estimates of the two-way panel analysis, that is, industry and period effects for the Korean manufacturing industries for the period 1970-2000 are presented in Table 2. Random effects parameter estimates from equation (1) and (2) selected on the basis of Hausman model selection criteria show higher magnitude of industry's own R and D stock compared than that of a one-way panel analysis. The estimated coefficients from equation (1) which include variables such as industry's own R and D stock and import impacted other industry

R and D stock are positive and highly significant. It is important to note here that the industry's own R and D stock parameter recorded higher magnitude in relation to the inter-industry domestic knowledge spillovers. However, the magnitude of the same industry foreign knowledge spillover coefficient is amazingly high and also reduced the importance of the industry's own R and D stock. When domestic and foreign import impacted knowledge spillover variables are estimated from equation (1), all the coefficients are having the expected positive sign but only foreign knowledge spillover parameter comes out to be significant. Contrary to this, the same parameter estimates from equation (2) which uses TM impacted variables show industry's own R and D stock not only as having higher magnitude but is statistical significant at 1 per cent level. This finding from our empirical analysis is quite close to the studies which have used technology matrix to estimate the extent of domestic and international pure knowledge spillovers [Keller 2002].

When we select the model applying the traditional R square criteria for the model selection, the results from equation (1) that includes the two variables- industry's own R and D stock and domestic spillovers are outstanding and meaningful. The value of the parameters obtained from equation (1) for $\beta_1 = 0.0386$ and for $\beta_2 = 0.0322$, are statistically significant. This simply means that the industry's own R and D stock is most important and thus is a symbol of industry's own capabilities. This clearly shows the importance of linkages across industry within the country. Furthermore, this implies that trade is the most potent channel of technology transmission across industries.

A noteworthy feature of Korean industrialisation is its relatively faster movement in closing the productivity gap with the advanced countries. The reduction of productivity gap essentially involves the complex process of technological learning and reverse engineering. During this process, domestic technological development efforts and foreign technological influences may have undergone substantial changes. To shed light on how domestic and international influences of technological changes affected the productivity growth, we have estimated separately the domestic and international knowledge spillovers for three sub-periods while splitting the whole period, that is, 1970-79, 1980-89 and 1990-2000. The results obtained from the three sub-periods while using fixed effects models are presented in Tables 3, 4 and 5.

The perusal of Table 3 clearly shows that the industry's own research and development efforts were quite significant during the period 1970-79. However, the inter-industry knowledge spillovers were non-existent. This is quite understandable because of the fact that the nature of industrial structure which was biased towards

Table 4: Estimates of Domestic and International Knowledge Spillovers 1980-89
(Dependent Variable Is Log TFP Index)

Variables/Industry Effects	Fixed Effects (1)	Fixed Effects (2)	Fixed Effects (1)	Fixed Effects (1)	Fixed Effects (2)	Fixed Effects (2)	Fixed Effects (1)
Industry's own R and D stock	0.11247* (8.218)	0.0995* (2.430)	-0.0171 (-0.485)	0.07499* (4.391)	0.10276* (2.791)	0.09628* (2.105)	-0.0271 (0.772)
Other industry R and D stock(I-O)			0.12715* (3.953)				0.1075* (3.310)
Other industry R and D stock(TM)		0.01164 (0.335)				0.00913 (0.239)	
Same industry international R and D stock (I-O)				0.0841* (3.533)			0.06709* (2.807)
Other industry international R and D stock(TM)					0.01551 (0.284)	0.00966 (0.161)	
AIC	0.03546	0.0357	0.03362	0.03402	0.03571	0.03596	0.03282
Adj-R squared	0.9237	0.9235	0.9279	0.9271	0.9235	0.9232	0.9299
Hausman test	0.01106	0.7843	2.27655	1.74397	2.0206	2.2643	2.9337
N	280	280	280	280	280	280	280

Notes: 1 Figures in parentheses are t-values. AIC is Akaike's Information Criterion.
2 * statistically significant at 1 per cent level.

large sized industrial houses called chaebols as well as technology dependence were mainly based on the external sources. On the basis of adjusted R square, which is a model selection criterion, underline the importance of import impacted international knowledge spillovers as technology transmission mechanism.

A significant technology policy feature of the South Korea during the 1980s was that it concentrated on strengthening of indigenous R and D base through creating web of public institution and also encouraged to establish in-house research and development. This government policy amazingly raised the level of innovative efforts during the eighties. Thus, the rising of industry's own R and D efforts has the significant effect on raising the level of productivity. The magnitude of the estimated parameters from equation (1) is 0.11 (Table 4). However, the import impacted domestic knowledge spillover parameter's value is very high and it reduced the importance of industry's own R and D stock. This is because of the high degree of correlation among both the variables. It is important to note that the parameter from equation (1) which includes industry's own R and D stock and foreign import impacted knowledge stock are positive and highly significant. The magnitude of foreign knowledge spillover was marginally higher than the industry's own R and D elasticity. This shows that both domestic and foreign technological efforts played an important role in raising the level of productivity during the 1980s. However, the estimated parameters from equation (2) which includes domestic and foreign knowledge spillover variables, which are based on technology matrix weights, are positive and non-significant. This is a clear pointer towards the importance of industry's own technological efforts to explain in raising the level of productivity.

The perusal of the Table 5, which presents the estimates of knowledge spillovers for the period 1990-2000, reveals that the parameter estimate of industry's own R and D stock has emerged the most dominant explanatory variable in explaining productivity growth. It is significant to note here that the foreign knowledge spillovers are positive but statistically not different from zero. However, the parameter estimates from equation (2) show negative coefficients both of the domestic and foreign knowledge spillovers (Table 5). The parameter estimates selected on the basis of Hausman test and also of adjusted R square show that industry's own R and D stock is highly significant and the international import impacted R and D stock is non significant. This finding from the empirical analysis is a clear pointer towards the fact that when the nature of knowledge becomes more and more complex and tacit, trade no longer serves as a good carrier of technological knowledge transfer. This finding from the 1990s empirical analysis

also has severe implications for the strict intellectual property rights regime imposed by the World Trade Organisation.

Conclusion

This paper has examined the impact of R and D and both domestic and international technological diffusion on productivity growth, using panel data for 28 Korean manufacturing industries over the period 1970-2000. Our empirical analysis confirms earlier evidence relating to advanced countries that R and D investments are positively related to productivity at the industry level. There is also evidence that productivity growth of an industry also benefits from other industries' research and development efforts. To distinguish the importance between different channels of domestic and international technological knowledge diffusion, we have used import impacted and technology matrix weights for domestic and international knowledge spillovers. On an average, import impacted knowledge spillover specification performed quite well implying that the trade is the dominant channel for the diffusion of technology both domestically and internationally. However, the sub-period empirical evidence endorses this finding only for the two-sub periods, that is, 1970-79 and 1980-89. The empirical evidence for the 1990s does not lend support to the diffusion through trade. This finding from the empirical analysis is a clear pointer towards the fact that when the nature of knowledge becomes more and more complex and tacit, trade no longer serves as a good carrier of technological knowledge transfer. This finding from the 1990s empirical analysis also has severe implications for the strict intellectual property rights regime imposed by the World Trade Organisation. [\[E\]](#)

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Notes

[This paper is a part of the project, Globalisation, Technology and Industrialisation under taken by the author as a Visiting Fellow, IWE, School of Economics, Seoul National University, South Korea. The author is grateful to Donghyu Yang, the Director of the Institute of World Economy, for encouragement and personal care and Seoul National University for hospitality. I am thankful to Hak K Pyo and Soohaeng Kim of Seoul National University and Joonghae Suh and Sungwook Joh of Korea Development Institute for enlightening discussions and helpful suggestions. I have also benefited immensely from conversations with Sibok Chang and MinKeung Song and their untiring support and assistance deserve more than perfunctory acknowledgement. However, the usual disclaimer applies. Financial

Table 5: Estimates of Domestic and International Knowledge Spillovers 1990-2000
(Dependent Variable Is Log TFP Index)

Variables/Industry Effects	Fixed Effects (1)	Fixed Effects (2)	Fixed Effects (1)	Fixed Effect (1)	Fixed Effects (2)	Fixed Effects (2)	Fixed Effects (1)
Industry's own R and D stock	0.06245* (2.036)	0.17754* (4.084)	0.18322* (3.295)	0.05643*** (1.765)	0.1488100* (2.675)	0.23591* (3.931)	0.17737* (3.099)
Other industry R and D stock(I-O)			-0.109* (-2.592)				-0.1069* (-2.536)
Other industry R and D stock(TM)		-0.0923* (-3.659)				-0.0874* (-3.437)	
Same industry international R and D stock (I-O)				0.01607 (0.676)			0.01045 (0.442)
Other industry international R and D stock(TM)					-0.10004** (-1.857)	-0.0747 (-1.400)	
AIC	0.03626	0.03482	0.03564	0.03644	0.03605	0.03480	0.03585
Adj-R squared	0.9308	0.93379	0.93224	0.9307	0.93145	0.9340	0.9320
Hausman test	1.12240	6.8923	9.47805	0.90185	7.45834	10.2568	8.6278
N	308	308	308	308	308	308	308

Notes: 1 Figures in parentheses are t-values. AIC is Akaike's Information Criterion.

2 *, **, ***, **** statistically significant at 1 per cent, 5 per cent, 10 per cent and 15 per cent level respectively.

support of IIE (Asian Scholarship Foundation), Bangkok in the form of fellowship is gratefully acknowledged.]

- 1 Technology has been viewed in theories of endogenous technological change as knowledge and is distinguished from rival factor inputs such as human and physical capital [Romer 1990].
- 2 We have prepared consistent data set for the period 1970-2000 for the twenty eight three-digit industries after making suitable changes required to be made because of the revision of the Korean Standard Industrial Classification in the year 1992 and 2000 (See for detail of adjustments for 1992 revision in Pyo, 1998; and 2000 revision which is applicable from 1999 is available from the author on request).
- 3 Capital stock data for the twenty eight three-digit industries is available for the period 1970-1996 in a study conducted by Pyo (1998) and these capital stock time series is extended by the author while using the perpetual inventory method.
- 4 We have used R and D data in the analysis for twenty eight three-digit Korean manufacturing industries which is estimated from the three digit industry ratios for the years 1978, 1983 and 1988. For these three years the detailed three and four digit industry level information is available in the census of mining and manufacturing of the republic of Korea. Aggregate data provided by the ministry of science and technology from 1970 onward for sub-groups of industries was reallocated according to the ratios developed from the Census of Mining and Manufacturing Survey of the Republic of Korea. This method to arrive at three-digit R and D expenditure is due to Hak K Pyo.
- 5 The industrywise estimates of R and D capital stocks are based on R and D expenditure which while using perpetual inventory method is as follows: $S_t = (1-\delta)S_{t-1} + R$ and $D \exp_{t-1}$ where S_t is the R and D capital stock in the period t; R and D is the real R and D \exp_{t-1} expenditure in the period t-1; and δ is the rate of depreciation, which is assumed to be 5 per cent. The R and D expenditure on nominal prices is converted into real R and D expenditure while using R and D deflator computed as follows: $R \text{ and } DPI = 0.35CPI + 0.25PPIM + 0.40PPI$ Where R and DPI is the R and D price deflator, CPI is the consumer price index for urban non manual workers, PPIM is producer price index for the capital goods, and PPI is the producer price index of an industry. The benchmark for S_t is computed by method suggested by Griliches (1980). The benchmark for the year 1970 is calculated as follows: $S_{1970} = (R \text{ and } D \exp_{1970}) / (g + \delta)$ Where g is the trend growth rate of the real R and D expenditure over the period 1970-2000. After making the R and D expenditure data on the 1990 constant prices we have converted it to purchasing power parity for comparability.
- 6 There are three technology input-output tables available so far. These three input-output matrixes are based on patent statistics pressed into service from patent offices of Canada, US and Europe. Verspagen (1997) has shown that the technology input-output table based on patent statistics from the European patent office is superior compared with the Canadian and US patent based technology input-output tables.

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