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A Simultaneous Equation Tobit Analysis of Research and Development in Korean Manufacturing Firms*

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The primary focus of this paper is the empirical analysis of the interactions among domestic sales, exports, and research and development (R&D). Based on the assumption of a firm's profit maximization behavior, this paper models a microeconomic simultaneous equation system to analyze the interactions. Amemiya's generalized least squares Tobit estimation method is used for and extended to the estimation of three equation system. The estimation result shows that exports have the effect to delay R&D. It is also shown that the imported technology is closely related to the foreign markets, while R&D spending has a significantly positive effect on domestic markets. The results give a policy implication that export-promotion industrial policy should be collaborated with technology policy.

I. Introduction

Technological change is understood as one of the major factors explaining economic growth, but the processes of the technological change remain largely unknown. By what processes is technological change generated? Research and development (R&D) at the firm level is one of the principal means through which technological change occurs. Until recently, studies of R&D activity focused largely on domestic conditions. However, particularly in developing economies,

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the role of foreign conditions may be as important as that of domestic conditions. The existence of a stock of advanced technology makes developing economies take quite different development strategies from advanced economies. Developing economies can borrow foreign advanced technologies, or they can learn by various channels associated with foreign trade. In this regard, as Harberger (1990) noted, most growth in the developing countries is catch-up growth.

As a source of catch-up growth in developing countries, the importance of borrowed technology has long been well recognized by the economists and is sometimes formulated as the "Veblen-Gerschenkron hypothesis."[1] An idea usually associated with the names of Veblen and Gerschenkron is that the greater the relative disparity in development levels between countries at the outset of a process of industrialization and the already industrialized part of the world, the faster the rate at which the backward country can catch up. The Korean economy is a good example of catch-up growth. Dealing with the period from 1966 to 1978, Dollar and Wolff (1993) conclude that borrowing disembodied technology made a significant contribution to the rapid productivity growth realized by Korean manufacturing industries. Covering the period from 1962 to 1991, Suh (1993) shows that the Korean economy has tended to depend more on foreign technology as it has grown. One of the deficiencies in these studies of the role of foreign technology in the process of industrialization, however, has been conducted at the aggregate or industry levels. The role of foreign technology at the firm level has accordingly not yet been much explored.

A large volume of research has recently attempted to relate industrial organization considerations to patterns of international trade. The relaxation of the assumption of perfect competition has especially enriched the ranges of international trade theory.[2] It is said that increases in market size realized by integration into the world market allow firms to exploit increasing returns in production. Some scholars have suggested that this increased extent of the market should stimulate advances in productivity, and in related phenomenon like research and development. However, this is not always the case. For instance, imitations of product and process innovations are less costly than

1 Findlay (1978) gives a good explanation of the Veblen-Gerschenkron hypothesis.

2 Based on the single equation estimation methods, Engelbrecht (1992) provides empirical evidence on the relation between R&D and foreign trade. Jacquemin (1982) is a good survey though it does not reflect recent developments. For comprehensive treatments on the subject, see Krugman (1990) and Grossman and Helpman (1991).

original development. Therefore, a firm in a developing country which competes in the foreign markets may decide to import foreign advanced technology instead of developing its own technology. In this regard, a developing country might face a choice of whether to import and imitate foreign technologies or to develop its own technologies. From a static point of view, the importation and imitation of foreign technologies might be less costly and more efficient than the development of original technologies. Importation and imitaion of foreign technologies, however, might require the importation of more advanced technologies when already imported technologies come to be obsolescent and products made by imported technologies have lost their competitiveness in the world markets. In this case international trade can reduce dynamic efficiency.

In general, large firms tend to spend more on R&D and, in Korea, tend to export more than small firms. Therefore domestic sales, exports, and R&D expenditures of each firm tend to vary together with the firm size. These co-movements may involve interactions between the three variables which must be identified in order to understand the processes underlying technological change. Zimmermann (1987) gives much emphasis on trade as a determinant of endogenous innovations in German firms, but he gives little attention to the precise mechanisms. Entorf and Pohlmeier (1990), on which this paper relies, construct a simultaneous equation Probit model to analyze the interactions among employment, innovation and export activity. These two papers give an affirmative answer to the issue of whether trade enhances domestic efficiency or not.[3]

Based on the assumption of firm's profit maximization behavior, this paper tries to establish a microeconomic simultaneous framework to anlayze the interactions between foreign factors and R&D, and the exogenous effects of technology imports on domestic sales, exports, and R&D. Several economists have felt the necessity of a simultaneous framework to model the determinants of R&D investment. Dasgupta and Stiglitz (1980) modeled the simultaneity of R&D and market structure, and Levin and Reiss (1984) tested it. In this paper, the simultanei-

[3] Zimmermann (1987) and Entorf and Pohlmeier (1990) both use realized innovations in products and processes as variables. This paper uses R&D expenditure as a variable and, as will be explained in section II, assumes that R&D has a cost-reduction effect indirectly. Therefore, the device to channel R&D into a cost-reduction effect at the firm level will be crucial in empirical analysis. Empirical studies weakly affirm the positive role of R&D in innovation and productivity growth at the firm level. See Griliches (1984) and other papers therein.

ty comes from the interactions among domestic sales, exports, and R&D. In addition, the approach in this paper emphasizes imperfect market structure where firms can reap positive profits and firms' output activity is related to the extent of foreign demand, and R&D activity.

This paper is organized in the following way: Section II illustrates a theoretical model which explicitly captures the simultaneous interactions among domestic sales, foreign demands, and R&D activity. Section III presents the estimation method for the simultaneous equations with censored variables. Section IV contains estimation results and discussions on the estimation results. Section V concludes the paper.

II. Model

The theoretical model here is an extension of a competitive fringe model.[4] The market structure assumed is characterized by a number of monopolistic competitors and a competitive fringe, where the two groups of firms are assumed to behave differently. On the l-th domestic market, total demand $Q_l^d = \Sigma_{i=1}^{n} q_{il}^d + x_l^d$ will be served by n dominant firms and a competitive fringe x_l^d, and the demand on the lth foreign market is modeled the same way by $Q_l^f = \Sigma_{i=1} q_{il}^f + f_l^f$, where q_{il}^d is the output of firm i in industry l sold on the domestic market and q_{il}^f is its output sold on the foreign market. The total output q_{il} of firm i in industry l is $q_{il}^d + d_{il}^f$. Each firm can sell its products on the domestic market and on the foreign market. In addition to decisions of how much to produce and sell for the two markets, each firm is also assumed to make a decision to invest in R&D activity. Each firm's main goal is to maximize its profits by combining these three activities.

More specifically, the firm's objective is to maximize the following profit function:

$$(1) \qquad \Pi_{il} = p^d(Q_l^d)(1-\lambda_{il})q_{il} + p^f(Q_l^f)\lambda_{il}q_{il} - c(q_{il}, I_{il}(RD_{il})) - RD_{il}$$

where,

p^d: prices of the firm's output sold at the domestic markets,

p^f: prices of the firm's output sold at the foreign markets,

4 The model in this section follows Neuman, Bodel, and Haid (1985). Entorf and Pohlmeier (1990) applied the model of Neuman *et al.* to the analysis of German firm's innovation and export activity.

$\lambda_{il} = q^f_{il}/q_{il}$: the export share in total output,
C: a cost function of the firm which is assumed to be $C_q > 0$ and $C_I < 0$,
$I_{il} = I_{il}(RD_{il})$: cost reducing innovation made by R&D, and
RD_{il}: R&D expenditure.

Note that in the above specification R&D has a cost reduction effect[5] but in an indirect way. That is, cost reducing innovation is possible only through R&D activity but R&D activity does not necessarily incur cost reducing innovation. More specifically, in mathematical notations, this implies the following relations:

$$(2) \qquad \frac{\partial C}{\partial RD_{il}} = \frac{\partial C}{\partial I} \frac{\partial I}{\partial RD_{il}} < 0$$

which assumes marginal contribution of R&D to innovation to be positive ($\partial I/\partial RD > 0$) and production cost to be lowered with an additional innovation ($\partial C/\partial I < 0$).)

Now firm's maximizing behavior will yield the following first order conditions with respect to q_{il}, λ_{il}, and RD_{il}:

$$(3) \qquad \left(\frac{\partial p^d}{\partial q_{il}} q_{il} + p^d\right)(1-\lambda_{il}) + \left(\frac{\partial p^f}{\partial q_{il}} q_{il} + p^f\right)\lambda_{il} - \frac{\partial C}{\partial q_{il}} = 0$$

$$(4) \qquad p^f - p^d + \frac{\partial p^d}{\partial \lambda_{il}}(1-\lambda_{il}) + \frac{\partial p^f}{\partial \lambda_{il}} \lambda_{il} = 0$$

$$(5) \qquad \frac{\partial C}{\partial I} \frac{\partial I}{\partial RD_{il}} + 1 = 0.$$

Equation (3) shows that at the optimum marginal cost is equal to the weighted average of marginal revenues in domestic and foreign markets. Equation (4) is the decision rule of optimal export share: export will be optimal at the point where the difference beween domestic price and foreign price of the firm's output equals the weighted average of two price responsiveness where the export share λ and 1-λ behave as weights. Equation (5) says that at the optimum, R&D is determined at the point where marginal cost reduction is equal to the marginal cost of R&D. The above three equations give a simultaneous equations system with three endogenous variables, q_{il}, λ_{il}, and RD_{il}.

5 Spence (1986) discussed more in detail about the cost reduction effect of R&D spending.

Now let us investigate the nature of the partial derivatives in equation (3)-(5). It can be shown that the slope of the inverted demand curve for domestic goods is

$$(6) \qquad \frac{\partial p^d}{\partial q_{il}} = -(1-\lambda_{il})\frac{1}{\varepsilon_l^d}\frac{p^d}{Q_l^d}\left(1 + \sum_{j=1, j\neq i} z_{ijl}{}^d \frac{q_{jl}{}^d}{q_{il}^d} + \frac{\eta_l^d}{1-\lambda_{il}}\frac{x_l^d}{p^d}\frac{\partial p^d}{\partial q_{il}}\right)$$

where

$$\varepsilon_l^d \equiv -\frac{\partial Q_l^d}{\partial p^d}\frac{p^d}{Q_l^d}, \quad \eta_l^d \equiv \frac{\partial x_l^d}{\partial p^d}\frac{p^d}{x_l^d}, \quad z_{ijl} \equiv \frac{\partial q_{jl}^d}{\partial q_{il}^d}\frac{q_{il}^d}{q_{jl}^d}$$

ε_l^d is the price elasticity of total demand on the domestic market. η_l^d is the supply elasticity of the competitive fringe on the domestic market and is assumed to be positive. z_{ijl}^d represents the elasticity of conjectural reaction of the *j*-th dominant firm on the domestic market.

In order to make the model operational for econometric estimation, some assumptions are needed. First, we assume that $z_{ijl}^d = z_{il}^d$ for all j. This implies that all firms reveal the same reaction when firm i changes its sales strategy.[6] Second, we assume that the elasticity of conjectural reaction varies with the relative firm size of the *i*-th firm in the following way:

$$(7) \qquad z_{il}^d = f(rs_{il})$$

where $rs_{il} \equiv s_{il}^d/(1-s_{il}^d)$ is the relative firm size and $s_{il}^d \equiv q_{il}^d/(Q_l^d - x_l^d)$ is the market share of firm *i* among the *n* dominant firms on the domestic market. Define n-firm concentration ratio for industry *l* as $K_l^d \equiv (Q_l^d - x_l^d)/Q_l^d$. Then the slope of the inverted demand curve can be simplified by

$$(8) \qquad \frac{\partial p^d}{\partial q_{il}} = -(1-\lambda_{il})\frac{p^d}{Q^d}(1 + h(rs_{il}^d))(\varepsilon_l^d + \eta_l^d(1-K_l^d))^{-1}$$

or

$$(9) \qquad \frac{\partial p^d}{\partial q_{il}} = g_l^d(q_{il}, \lambda_{il}, Q_l^d, K_l^d, \varepsilon_l^d, \eta_l^d, rs_{il})$$

6 This assumption seems to be inconsistent with the model of a few dominant producers and a competitive fringe. This assumption, however, is inevitable to make the model operational for estimation. Actually it can be assumed that any Korean firm conducting R&D is, at the minimum, not a competitive fringe.

where $h(rs^d_{il}) = f(rs^d_{il}) / rs^d_{il}$.

The price reaction of the foreign market caused by an increase in total output by the i-th firm can be derived in the same way. However, since the foreign market is relatively large and less transparent for the competitors, we assume Cournot behavior, i.e., $z^f_{ijl} = 0$. Then the slope of the individual inverted demand curve for the foreign market reduces to

$$(10) \qquad \frac{\partial p^f}{\partial q_{il}} = -\lambda_{il} \frac{p^f}{Q^f_l} (\varepsilon^f_l + \eta^f_l (1 - K^f_l))^{-1}$$

or

$$(11) \qquad \frac{\partial p^f}{\partial q_{il}} = g^f(\lambda_{il}, Q^f_l, K^f_l, \varepsilon^f_l, \eta^f_l)$$

Inserting (9) and (11) into equations (3) to (5) yields the following system:

$$(12) \qquad F^{(1)}(q_{il}, \lambda_{il}, RD_{il}, Q^d_l, Q^f_l, \varepsilon^d_l, \varepsilon^f_l, \eta^d_l, \eta^f_l, K^d_l, K^f_l, rs_{il})$$
$$= (g^d(\cdot) q_{il} + p^d)(1 - \lambda_{il}) + (g^f(\cdot) q_{il} + p^f)\lambda_{il} + \frac{\partial C(\cdot)}{\partial q_{il}} = 0,$$

$$(13) \qquad F^{(2)}(q_{il}, \lambda_{il}, RD_{il}, Q^d_l, Q^f_l, \varepsilon^d_l, \varepsilon^f, \eta^d_l, \eta^f_l, K^f_l, rs_{il})$$
$$= p^f - p^d + q_{il}(g^f(\cdot) - g^d(\cdot)) = 0,$$

$$(14) \qquad F^{(3)}(q_{il}, \lambda_{il}, RD_{il}, I_{il}) = \frac{\partial C(\cdot)}{\partial RD_{il}} + 1 = 0.$$

Equations (12)-(14) defines firm's optimal choice in terms of three choice parameters and some exogenous variables. Comparative statics on each equation (12)-(14) will give empirically testable implications. More specifically, implicit partial differentiation of equation (12) gives the following output effects:

$$\frac{\partial q_{il}}{\partial \lambda_{il}} = -\frac{F^{(1)}_{\lambda il}}{F^{(1)}_{qil}} > 0 \text{ or } < 0, \frac{\partial q_{il}}{\partial RD_{il}} > 0, \frac{\partial q_{il}}{\partial \varepsilon^d_l} > 0, \frac{\partial q_{il}}{\partial \varepsilon^f_l} > 0,$$

$$\frac{\partial q_{il}}{\partial K^d_l} > 0 \text{ or } < 0.$$

Since $F^{(2)}_{\lambda il} < 0$, a straightforward application of the implicit function theorem for equation (13) yields the following effects on the export share:

$$\frac{\partial \lambda_{il}}{\partial q_{il}} > 0 \text{ or } < 0, \quad \frac{\partial \lambda_{il}}{\partial RD_{il}} > 0 \text{ or } < 0.$$

The effect of output increase on the export share is not deterministic. Likewise, the effects of R&D increase and the concentration ratio change on the export share are ambiguous. But the increase in the foreign demand elasticity has positive effects on the export share while the increase on the domestic demand elasticity has negative effect. Equation (14) yields the optimal choice of R&D activity with output and exports together. The empirical analysis in the following section will be based on the theoretical model developed here.

III. Estimation of Simultaneous Equation System with Censored Dependent Variables

The model for the analysis is composed of three equations in which two endogenous variables are continuous and one censored. For the system of two equations in which one endogenous variable is continuous and another censored, Nelson and Olson (1978) developed a two stage estimation method (NOLS) and Amemiya (1979) developed a generalized least squares estimation method (AGLS). Amemiya showed that AGLS is more efficient than NOLS. Lee (1981) generalized Amemiya's method to various different situations and confirmed again that AGLS is more efficient than NOLS. In this paper Amemiya's estimation method will be extended to the case of three equation system.[7]

IV. Data and Estimation

A. Data

The data set is composed of a cross-section survey conducted by the Korea Industrial Technology Association (KITA) from March 20 to

7 A more detailed exposition is presented in Suh (1993). In addition to the estimation method, Suh (1993) dealt with two more econometric issues: a test of weak exogeneity of Smith and Blundell (1986) in a limited information simultaneous limited dependent variable model and the Bowman-Shenton statistic to check the normality of sample distribution.

August 20, 1991. KITA published the summary of the survey at the aggregate level (see KITA, 1991). KITA sent a mail questionnaire to 3,210 firms in all industries which appeared in *Statistical Report of Mining and Manufacturing, 1987* published by the Statistical Bureau of the Economic Planning Board (EPB) and complemented the questionnaires by visits if necessary. The response rate was 33.0%: 1,058 firms responded. The firms in the survey are grouped into four-digit industry level. The survey items are classified into six categories: (1) general information of the firm; (2) R&D investment; (3) R&D personnel; (4) equipment for R&D, (5) the sources and application of technological information; and (6) the topics and results of R&D. This paper deals with 612 manufacturing firms from the survey which reflect all information of the variables explained below. The 612 firms are comprised of 20.6% of manufacturing firms in EPB's *Statistical Report*. The survey was mainly about Korean manufacturing firms conducting R&D.

The variables used in this paper are the following:

y^1 = domestic sales, continuous and positive in million won;

y^2 = exports, continuous and positive in million won, or censored at zero;

y^3 = R&D expenditure, continuous and positive in million won;

TI_d = technology imports dummy variable: 1 if technology is imported in the previous year; 0 otherwise;

RFS = relative firm share measured as each firm's sales divided by industry total sales;

Legal $Status_d$ = legal status dummy variable: 1 if legal status is large firm; 0 if small-medium firm;[8]

R&D personel intensity = ratio of R&D personnel divided by the total number of employees;

$Patent_d$ = dummy variable: 1 if the firm had been granted industrial property rights such as patents and utility models or acquired a Korean Standard (KS) mark for the product in the previous year; 0 otherwise;

CR3 = three-firm concentration ratio at four-digit industry level made by the Korea Development Institute;

EPI = the annual percentage increase rate of export price index at two-digit industry level; and

8 According to the law, in Korea, legal status of small-medium firms is defined as firms whose number of employees is less than 300, with some exceptions by industry. Legal status of the firm matters in making loans from a bank and getting various kinds of assistance from the government, for instance.

Top Management$_d$ = dummy variable: 1 if the top manager is professional; 0 if founder or his/her family.

Descriptive statistics for the endogenous variables are given in Table 1. Table 1-1 gives descriptive statistics of sales, exports, and

Table 1-1

DESCRIPTIVE STATISTICS:
SALES, EXPORTS AND R&D

	Mean	Std. dev.	Minimum	Maximum	Case
Sales	131,310	392,640	15	4,643,000	612
Exports	33,403	150,920	0	2,645,000	612
R&D	3,152	19,120	15	408,400	612

Note: Units of numbers except case are million Won.

Table 1-2

DESCRIPTIVE STATISTICS:
EXPORT INTENSITY AND R&D INTENSITY BY FIRM SIZE

Number of employee		Mean	Standard deviation	Minimum	Maximum	Cases
Less than 300	Export intensity	0.0603	0.1737	0.0	0.9438	280
	R&D intensity	0.1104	0.3282	0.0024	4.267	280
300-999	Export intensity	0.1869	0.2869	0.0	0.9993	157
	R&D intensity	0.0281	0.0323	0.0006	0.217	157
More than 999	Export intensity	0.2557	0.2892	0.0	0.9600	175
	R&D intensity	0.0288	0.0335	0.0002	0.272	175
All	Export intensity	0.1487	0.2566	0.0	0.9993	612
	R&D intensity	0.0643	0.2271	0.0002	4.267	612

R&D. Table 1-2 shows export intensity, export divided by sales, and R&D intensity, R&D divided by sales. In Table 1-2 each firm is classified into three groups according to the firm size defined by the number of employees. The mean of export intensity increases as the firm size increases while the mean of R&D intensity is highest in a small firm group and very low and almost constant at large firm groups. Table 1-3 reports R&D intensity according to export intensity. The threshold value of 0.1487 is the average export intensity of all firms. According to Table 1-3, the domestic-market-oriented firm group whose export intensity is zero shows the highest R&D intensity.

Table 1-3

DESCRIPTIVE STATISTICS:
R&D INTENSITY BY EXPORT INTENSITY

	Mean	Standard deviation	Minimum	Maximum	Case
Export intensity = 0	0.0985	0.3146	0.0003	4.267	307
0 < Export intensity < 0.1487	0.0298	0.0433	0.0014	0.3433	139
Export intensity ⩾ 0.1487	0.0299	0.0394	0.0002	0.2980	166

To conform the data to normal distribution, domestic sales, exports, and R&D expenditures are transformed into logarithm. The normality test result is given in Table 2.

B. Estimation Results

The main rationale to construct a simultaneous equation system is to see the interactions among the endogenous variables. In general, large firms tend to spend more on R&D, and, especially in Korea, they tend to export more than the small firms. Hence domestic sales, exports, and R&D expenditures of each firm will show high positive correlation. Table 3 reveals high correlation among those variables: the

Table 2

NORMALITY TEST

	Domestic sales	Exports*	R&D expenditure
Bowman-Shenton statistic	0.1299	0.0726	0.3010

Note: $\chi^2(.95,2) = 5.9915$. *Non-censored samples only.

Table 3

CORRELATION MATRIX

	Sales	Exports	R&D
Sales	1.0		
Exports	0.794	1.0	
R&D	0.736	0.909	1.0

correlation between sales and exports is 0.794, the correlation between sales and R&D 0.736, and the correlation between R&D and exports 0.909. But these superficial correlations ignore and say very little about the interactions among those variables. If exports and R&D are compared in different units, for instance in terms of intensity as is shown in Table 1, the correlation shows a different pattern: the correlation between export intensity and R&D intensity is -0.0914.

The estimation results are presented in Table 4. Let us summarize the main findings.

First, regarding the interactions among domestic sales, exports, and R&D, domestic sales have a significantly negative effect on exports and weakly negative effect on R&D. The estimated coefficient show that when domestic sales increase by 10%, exports and R&D expenditure decrease by 35% (in equation (2)) and 0.8% (in equation (3)), respectively. The effect of exports on domestic sales is very high but its effect on R&D turned out to be negative: the export elasticity of domestic sales is 7.9 (in equation (1)), while the R&D elasticity of domestic sales is -4.2 (in equation (3)). R&D has statistically significant and positive effects on domestic sales but the magnitude is very

Table 4

ESTIMATION RESULTS (1)

	(1) domestic sales	(2) exports	(2–1)[a] exports	(3) R&D expenditure
y^1		−3.5169*** (−3.305)	−3.4676*** (−3.430)	−0.0790** (−2.230)
y^2	7.8746*** (5.407)			−4.1775*** (−4.063)
y^3	0.2175*** (6.208)	−9.3947 (−1.478)		
TI_d	−0.6281*** (−2.599)	3.8444*** (3.146)	3.8426*** (3.328)	0.4489*** (2.695)
RFS	3.6028** (2.378)			
CR3	−5.2122 (−1.524)			7.2531*** (3.511)
$CR3^2$	5.9100* (1.888)			−7.4580*** (−3.891)
Legal $Status_d$		4.4930*** (2.479)	4.5391*** (2.648)	
R&D Personnel Intensity			4.7018*** (3.520)	
$Patent_d$				0.2211* (1.621)
Top $Management_d$	−0.2347 (−1.254)	2.2859*** (2.518)	2.2821*** (2.662)	0.2214* (1.837)
Constant	0.4442* (1.739)	3.0061*** (4.221)	2.9521*** (4.308)	0.8610*** (9.880)

Note: Numbers in parentheses are t-statistics. [a]With the restriction that the exogeneity of R&D on exports does not exist. *significant at 10% level. **significant at 5% level. ***significant at 1% level. Number of sample = 612.

small. The effect of R&D on exports turns out to be negative, but the simultaneity test results imply no effect on exports. (Refer to Table 6).

Second, the imported technology has positive effects on both exports and R&D but a negative effect on domestic sales: the effect of the imported technology on exports is the strongest. To begin with, these estimation results imply that, in competing in the foreign market, there are two sources of technology: foreign technology and domestic technology. However, the positive effect of technology imports on R&D also imply that domestic R&D is closely related to imported technology. In other words, some part of R&D is devoted to adapt and assimilate imported technology. That the effect of imported technology on domestic sales is negative refutes the criticism that the imported technology targets mainly the domestic market. On the contrary, in the case of Korea, the imported technology is closely related to the foreign markets while R&D has a significant effect on the domestic market.

Third, relative firm share (RFS) and three firm concentration ratio (CR3) are used as proxies for the price elasticity of domestic sales. The estimation results are significant, but it is not easy to draw strict conclusions on the relation between price elasticity and domestic sales.

Fourth, industry structure has a significant effect on R&D: the more concentrated the industry the higher the R&D expenditure but at a decreasing rate. This estimation result is consistent with the Schumpeterian hypothesis[9] that since seller concentration enhances the appropriability of the returns to R&D, larger firms tend to spend more on R&D than small firms.

Fifth, large firms show significantly different behavior on exports: they tend to export more than small firms. In Korea, the legal status of a firm has different effects on the firm's activity, especially in relation to exports. For instance, small firms are relatively disadvantaged in acquiring bank loans for export, and the government targets mainly large firms to accomplish export goals. Hence, Legal Status_d reflects the institutional factors in export activity.

Sixth, R&D personnel intensity is used as a proxy for a device through which cost-reduction innovation is made by R&D. It is expected that higher intensity will enable a firm to connect R&D activity to a cost-reduction effect in production process more effectively. However, here arises a statistical problem: R&D personnel intensity may be positively related with R&D spending. This means a collinearity problem in estimation process. But since the correlation between R&D personnel intensity and R&D spending is -0.0002, this issue can be ignored. The estimation result is that the coefficient of R&D per-

9 Mowery (1986) distinguishes two variants of Schumpeterian hypothesis: the relationship between market structure (primarily industry concentration) and R&D investment and the relationship between firm size and R&D investment. The discussion in the text refers only to the former variant of the Schumpeterian hypothesis. Later in this paper both of these will be discussed.

sonnel intensity is statistically significant and positive. In other words, the higher the intensity, the higher the R&D expenditure.

Seventh, industrial property rights can be interpreted as a device to appropriate the returns to R&D. Note that $Patent_d$ variable is the record of the previous year. The assumption here is that since patents are a product of R&D or related investment, if any firm harvested the fruits of R&D in the previous year, they will invest more in R&D this year. The estimation turn out to be weakly positive. In other words, the higher the appropriability, the higher the R&D expenditure.

Eighth, the types of top management do not have any influence on domestic sales. It should be noted that, in relation with export activity, professional managers show significantly different behaviors from the founders or their families. In other words, professional managers are more foreign-market-oriented than the founders or their families. It is possible to interpret the management type as the age of the firm since, in general, a firm is managed by its founders in the beginning while it will be managed by professionals as it ages. Based on this interpretation, the estimation result also implies that as the firm ages it tends to enter the foreign markets. The estimation result shows that professional managers show a little more affirmative attitude toward R&D.

The estimation results reveal some interesting aspects of the behaviors of the Korean firms. The interaction between domestic sales and exports is one of them: exports have significantly positive effects on domestic sales while domestic sales have significantly negative effects on exports. This is also consistent with the estimation results that R&D spending has almost no effect on exports while imported technology has significantly positive effects on exports. Ito and Pucik (1993) report that in the case of Japanese firms domestic competition enhances international competitiveness. The Korean firms show quite an opposite effect. Many Korean economists have observed that instead of developing original technology the Korean firms have tended to depend more on foreign technology as they have entered into foreign markets. Analyzing the reasons of the sharp decreases in the growth rate of total factor productivity in the Korean manufacturing sector after the late 1970s, Kim and Hong (1992) conclude that imitating foreign technology was not as effective as before the late 1970s. In this regard, even though it is more costly, developing original technology is one of the prerequisites for long-term economic growth.

What determines R&D at the firm level? Griliches (1984) summarized some problems in studying productivity and technical change.[10] One of the suggestion to remedy the problems is to consider the R&D decision within some simultaneous framework. This paper tries to show the simultaneous nature of R&D with domestic sales and exports, but this paper still suffers from some of the problems Griliches pointed out. Despite this limitation, some important implications can be drawn from the estimation results.

First of all, the estimation result that exports elasticity of R&D is negative implies that increases in domestic sales and export activity have the effect of delay in R&D. Note that the magnitude of the elasticity is far bigger than minus one. The implication of this result is the following: if the production of a firm occurred at the point which lies before the trough of U-shaped cost curve, increased production due to increases in exports will have a cost-reduction effect.[11] In this case, increases in exports will have the same cost-reduction effect as R&D does.

Secondly, the estimation result shows that the imported technology has significantly positive effects on R&D. This implies that some part of R&D expenditures is devoted to adapt and assimilate imported technology. In connection with domestic sales and exports, the estimation results reveal very interesting patterns of Korea firms' behavior: the imported technology is closely related to the foreign markets while R&D has a significant effect on domestic markets.

Thirdly, the estimation results are consistent with the Schumpeterian hypothesis that monopolistic industry structures tend to enhance R&D expenditures at firm level. As noted earlier this is valid only in the case of the first variant of the Schumpeterian hypothesis, the relationship between industry structure and R&D investment. Regarding the second variant of Schumpeterian hypothesis, the relationship between firm size and R&D investment, the estimation results are inconclusive. In this paper the volume of domestic sales can be interpreted as the firm size. The estimation results show that the domestic sales elasticity of R&D is near to zero. This implies that firm size does

10 They are (1) the ambiguities of the patent data: (2) the aggregation level at which the R&D process should be studied; (3) the absence of data on what really drives R&D; (4) the low quality and the dubious relevance of the available productivity data; and (5) the difficulties in and the importance of modeling the spillover of knowledge and technology from one firm or industry to another. (Griliches, 1984, p. 14)

11 In order for this argument to hold, the existence of the economies of scale at the firm level is the crucial issue. Empirical studies of the existence of the economies of scale in Korea are few and not readily available. Yoo (1990) estimated the technical efficiency in Korean industries and showed that the scale of production is positively related to the technical efficiency. His estimation results may indirectly indicate the existence of the scale economies.

not make any differences in R&D investment. This finding is contradictory to the recent study by Kim and Cho (1989) who find that the Schumpeterian hypothesis is not valid in the case of Korean manufacturing. The discrepancy between Kim and Cho and this paper arises from the fact that the study by Kim and Cho mainly depends on the single equation estimation method and ignores the simultaneity of R&D and other activities of the firm. The other difference is that the data set in Kim and Cho includes time series at the aggregate level and cross-section at firm level. The data set in this paper, which is cross-section only, reveals mainly short run behavior of the firm.

Lastly, although the estimation result implies the appropriability of the returns to R&D matters, it is not clear how well $patent_d$ variable reflects the appropriability. This is also the case of the R&D personnel intensity as a device of cost-reduction innovation.

C. Sensitivity Analysis

The variables in Table 4 do not cover all the variables that theory in Section II requires. The most fatal missing variable is the foreign price elasticity of exports at the firm level. Since, however, the foreign price elasticity is not given in the data set of KITA, EPI is used as a proxy for the foreign price elasticity of exports. The problem is that since EPI is measured at two-digit industry level, it does not match well with the endogenous variables which are grouped in four-digit industry level. The estimation results turn out to be weakly significant. The estimation results are summarized in Table 5.

Adding one more exogenous variable does not influence the estimation results: only the magnitudes of coefficients change a little. The interactions among the endogenous variables adding EPI are similar to the patterns revealed in Table 4. Therefore the estimation results in Table 4 are robust to adding one more exogenous variable, EPI.

D. Exogeneity Test

Table 6 shows the exogeneity test of domestic sales and R&D in exports equation. The test results strongly reject the hypothesis of no exogeneity of domestic sales but do not reject the hypothesis of no exogeneity of R&D. Third columns of Table 3 and Table 4 contain the estimation results with restriction of no exogeneity of R&D. The estimation results with restriction does not show any great difference from those without restriction; only the variance of each coefficient decreases.

Table 5

ESTIMATION RESULTS (2)

	(1) domestic sales	(2) exports	(2-1)[a] exports	(3) R&D expenditure
y^1		-2.3141*** (-2.429)	-2.2917*** (-2.458)	-0.0050 (0.194)
y^2	9.6187*** (6.607)			-2.4388*** (-3.135)
y^3	0.2525*** (6.940)	-10.433* (-1.713)		
TI_d	-0.5025** (-1.948)	3.1345*** (2.774)	3.1320*** (2.841)	0.3064*** (2.332)
RFS	5.4788*** (3.630)			
CR3	-3.5771 (-0.977)			6.9426*** (4.253)
$CR3^2$	4.4015 (1.315)			-6.9084*** (-4.567)
Legal $Status_d$		4.4706*** (2.554)	4.5003*** (2.631)	
R&D Personnel Intensity				6.5473*** (6.740)
$Patent_d$				0.1490 (1.380)
EPI		-0.2055** (-1.696)	-0.2037* (-1.722)	
Top $Management_d$	-0.1109 (-0.589)	1.9808** (2.306)	1.9805** (2.361)	0.1271 (1.341)
Constant	0.0793) (0.322)	2.3953*** (3.635)	2.3656*** (3.649)	0.6718*** (10.491)

Note: Numbers in parentheses are t-statistics. [a]With the restriction that the exogeneity of R&D on exports does not exist. *significant at 10% level. **significant at 5% level. ***significant at 1% level.

V. Conclusion

This paper begins with the assumption of profit maximization behavior by firms from which interrelations among domestic sales, exports, and R&D are derived. What can be inferred from the estimation

Table 6

EXOGENEITY TESTS OF DOMESTIC SALES AND R&D IN EXPORTS EQUATIONS

	(1)	(2)
TI_d	4.2116	4.1418
	(4.900)	(4.818)
Legal $Status_d$	1.8154	1.9887
	(2.229)	(2.325)
EPI		-0.1146
		(1.172)
Top $Management_d$	4.1275	4.1964
	(6.149)	(6.189)
$\hat{\varepsilon}_1$	2.6080*	2.6648*
	(8.408)	(8.487)
$\hat{\varepsilon}_3$	0.3083	0.3349
	(1.567)	(1.291)
Constant	-1.1286	-1.0568
	(-2.287)	(-2.137)
Wald Text:		
$\chi^2(2)$	88.9021	89.8083
Significance level	1.00	1.00

Notes: Numbers in parentheses are t-statistics.
*Significant at 0.1% level.
Number of sample = 612.

results? In sum, the estimation results reveal some weaknesses in the Korean manufacturing firms. Quite contrary to the Japanese firms, the Korean firms tend to depend more on foreign technology rather than developing original technology when they enter foreign markets. In this regard, the complementarity between technology imports and R&D indicates nothing more than that most of R&D spending is devoted to adapt and assimilate the imported technology. These results are contrary to the conclusions of Zimmermann (1987) and Entrof and Pohlmeier (1990): they showed that exports increase dynamic efficiency via triggering a firm's innovation activity.

What determines R&D at the firm level in a small open developing economy? A surprising finding is that increases in exports have the effect to delay R&D. This is possibly due to the cost-reduction effect of increased output when the production of a firm occurs at the point before the trough of U-shaped cost curve. This is also due to the fact that the firm's optimization behavior is based on the short run.[12] This finding, however, has very important policy implications: export-oriented industrial policies which have lasted for the past three decades in Korea may have an undesired effect on the technological development in the long run. Firm's myopic behavior of profit maximization in the short run in response to the increased foreign demand may make firms neglect to develop their own technology. From a static point of view, importation and imitation of foreign technologies might be less costly and more effective in the foreign markets than development and application of original technology. Importation and imitation of foreign technologies, however, might cause the importation of more advanced technologies when already imported technologies come to be obsolescent and products made by imported technologies have lost competitiveness in the world markets. Moreover, the problem will be exacerbated when importation of required advanced foreign technologies becomes more difficult. In this sense, the collaboration of export-promotion policy and technology policy is necessitated. These two policies are not apart.

This paper tested two versions of the Schumpeterian hypothesis. This paper affirms the Schumpeterian hypothesis that monopolistic industry structure tends to enhance R&D expenditure at the firm level. However, the Schumpeterian hypothesis as the relationship between firm size and R&D is not confirmed.

The effect of imported technology on a firm's activity is of interest. Contrary to the conventional belief that imported technology strengthens the domestic market position, this paper shows that imported technology targets mainly foreign markets. In addition, it is

12 Notice that in this paper only the short-run behavior of the firm is modeled and the data set is one time cross-section. It is well acknowledged that the cross-section data has a limit to reveal the long-run behavior. Hsiao (1986) clearly illustrated that the literal reading of the estimation results of cross-section data sometimes gives imprecise conclusions in that it is not clear whether the estimated coefficients reveal the relationship of the whole population or of selected samples. Hsiao's prescription is to use panel data which incorporates both time trend and short-run relationships. But Hsiao's prescription cannot be directly medicated since time-series data compatible with cross-section data in this paper do not exist. Fortunately, a recent study of Park (1993) can be a good complement to this paper. Using time-series data at aggregated industry level from 1968 to 1987, Park showed that technological change of Korea's manufacturing sector had been negatively influenced by exports expansion and, furthermore, the negative effect of exports expansion on technological change had been intensified during the 1979-87 period. The cross-section estimation results of this paper are consistent with the time-series study of Park.

found that imported technology increases R&D expenditure. This implies that imported technology and R&D expenditure are complementary at the firm level.

The effects of R&D on other activities of a firm are also interesting: R&D affects domestic sales in a significantly positive way but the exogeneity of R&D on exports is rejected. In connection with domestic sales and exports, the estimation results reveal a very interesting pattern of Korean firms' behavior: the imported technology is closely related to the foreign markets while R&D has a significant effect on domestic markets. This pattern is consistent with the finding that increased foreign demand has a retarding effect on R&D. In other words, instead of developing original technology, Korea firms tend to depend on the foreign technology when entering foreign markets.

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