

A microeconomic analysis of technology transfer

The case of licensing agreements of Japanese firms

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This paper examines investment in foreign technology by Japanese firms, using previously unexplored data on technology transfer to Japan. The relationship between the acquisition of foreign technology and firm size, liquidity and affiliation with a corporate group, or *keiretsu*, is analyzed. Our results indicate that the number of licensing agreements a firm signs is positively and strongly related to its size, although the relationship is concave. We also find that liquidity is an important consideration in the firm's decision to invest in foreign technology. *Keiretsu*-affiliated firms acquire relatively more foreign technology than independent firms, suggesting that corporate groups have played an important role in Japan's technological progress.

JEL classification: O32

1. Introduction

Japan's economic growth in the postwar period has been characterized by a very rapid growth in productivity, achieved, to a great extent, through massive borrowing of technology from more advanced countries. Japan has been making a tremendous effort to absorb foreign knowledge, and even as late as 1980, Japanese royalty payments on imported foreign technology were far higher than those of the United States, the United Kingdom and Germany [Evanson (1984)]. Nevertheless, very little is known about the microeconomic details of this technology transfer process, and the role of Japanese corporate groups (*keiretsu*) in it. In this paper we examine, to our knowledge for the first time, Japan's investment in foreign technology, using

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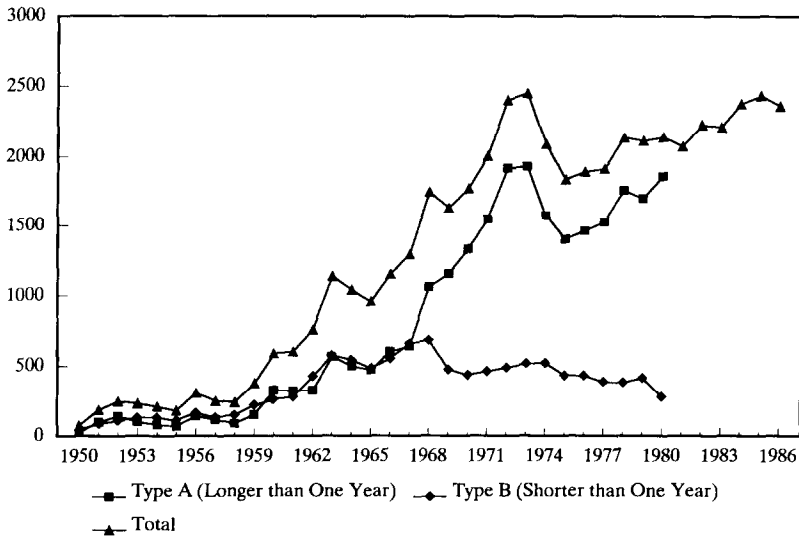


Fig. 1. Total number of licensing agreements. *Source: Gijutsu Donyu Nenji Hokoku.*

a large sample of manufacturing firms. We use previously unexplored Japanese microdata on technology transfer, in order to identify the relationship between investment in foreign technology and firm size and liquidity variables. We find that the number of licensing agreements a firm signs is positively and strongly related to its size, although the relationship is concave. We also find that liquidity is an important consideration in the firm's decision to invest in foreign technology. For the first time, we provide statistical evidence suggesting that *keiretsu*-affiliated firms acquire significantly more foreign technology than independent firms of similar size, suggesting that business groups have had an important role in Japan's technological progress.

Since 1950, the main form of technology transfer from advanced Western countries to Japan has been formal licensing agreements between Western and Japanese firms. While international technology transfer is often associated with multinational corporations [Bonin (1981), Contractor (1981)], foreign direct investment in Japan was restricted by the Foreign Investment Law of 1950, and thus relatively few multinationals were present prior to 1980 [Krasner (1988), Komiya and Itoh (1988)]. The number of licensing agreements increased steadily between the mid-1950s and 1973 (fig. 1), and during the rapid growth of the 1960s and early 1970s hundreds of contracts for the purchase of technology were signed annually. Following the Oil Shock of 1973, the number of agreements sharply declined, although the trend was reversed in 1976. Investment in foreign technology surged again in

Table 1

Percent of duplicate agreements
out of total type A agreements.

1963	35.64
1965	54.51
1966	56.46
1967	64.26
1968	70.38
1969	72.89
1970	73.64

Source: Peck and Tamura
(1976).

the late 1970s, and reached a level of approximately 50% of R&D spending in some industries.¹ The majority of firms supplying the technology have been American, followed by German, British and other European firms. The contracts typically include the transfer of patents, production processes, knowhow and the like,² usually associated with incremental improvements in production processes, rather than basic technological breakthroughs.³ The terms of the agreements vary, but often include a combination of fixed up-front payments, 'running royalty' (a percentage of sales), fixed annual fees, and an item involving export restrictions and/or exclusive dealing for the recipient Japanese firm. Agreements vary also in length, from short-term agreements of less than one year to agreements of over 15 years. The contractual complexity makes it virtually impossible to evaluate the actual cost of each agreement, and therefore we will subsequently use the number of agreements signed by the firm as an indicator of its imported technology.

Our licensing data, as well as Peck and Tamura's (1976) historical account, suggest that Japan's rapid technological progress has been, by and large, a phenomenon driven by the private sector, with only little direct influence by the government, or MITI. In general, government subsidies to R&D in Japan are much lower than in the United States and many European countries [Okimoto and Saxonhouse (1987)] and similarly, government direct intervention in technology imports has also been limited. Although between 1950 and 1969 government approval was required in order to use foreign currency for royalty payments, the same technology was often licensed more than once by different foreign suppliers to different Japanese companies, with apparently little state guidance of the process (table 1).

Licensing as a form of technology transfer to Japan has been especially

¹The scale of royalty payments in the machinery, electronics and transportation equipment industries is between 40% and 50% of private R&D in these industries [Odagiri (1983)].

²Although the term 'technology import' in the official statistics refers to the acquisition of trademarks as well, we ignore this aspect in our analysis.

³Bonin (1981) suggests that technology transfer transactions at arm's length typically involve incremental, relatively old, technology.

important in the machinery (including transportation equipment), and electrical machinery industries, as well as in the chemical industries, and to a lesser extent, in the iron, steel and non-ferrous metals industries. These industries are among the sectors that have enjoyed the most rapid total factor productivity growth in the postwar era according to studies by Jorgenson et al. (1987) and Jorgenson (1988). A positive relation between licensing, productivity growth and Japan's export structure is suggested also by Ozaki (1972) and Tsurumi (1980).

Japanese market structure before and after World War II has been characterized by the existence of large corporate groups, and yet little is known about the role of these groups in the process of technology transfer to Japan. In order to examine the importance of group affiliation in technology transfer, we define a *horizontal group* as a group of firms that operate in different industries, and are related to each other by one or more of the following mechanisms: (a) A main bank, or a group bank which is the principal lender to group members, and owns a significant number of shares in group firms. (b) Cross shareholding between group firms and occasionally some exchange of personnel. (c) Scheduled meetings of presidents or directors of group firms at a 'Presidents Club' (*shacho-kai*). In the present-day Japan, there are six major horizontal (or financial) groups of this type: three that evolved from the prewar *zaibatsu* groups (Mitsui, Mitsubishi and Sumitomo), and three bank-centered groups (Dai-Ichi Kangyo, Fuyo and Sanwa), each with hundreds of affiliated firms. We distinguish between a horizontal group and a *vertical group*, which we define as a group of firms associated with one major manufacturer in a particular industry. Such groups typically include a large manufacturer and 'quasi-integrated' subcontractors (upstream suppliers) and retailers who are partially controlled (in terms of stocks and board of directors) by the main manufacturing firm of the group. Groups of this type are common in the auto and electronics industries, and include Toyota, Hitachi and other familiar names.

In this paper we use firm data on licensing agreements, firm performance and group affiliation in order to identify the determinants of investment in foreign technology. The paper is organized as follows. Section 2 presents a theoretical framework for the analysis of the decision to purchase foreign technology. In section 3 the data and variables are described and an appropriate econometric approach is suggested. Our main results are presented and discussed in section 4. In section 5 we examine the robustness of our results by using two more general estimation techniques. Section 6 contains conclusions and directions for further research.

2. Theoretical framework

Japanese Industrial Organization literature has devoted little direct atten-

tion to the *data* on Japan's technological imports, and hardly any empirical analyses have ever been attempted at the microeconomic level. Among the few exceptions are Blumenthal (1976) and Peck and Tamura (1976), who discuss aggregate trends in the technology transfer process, and Okimoto and Saxonhouse (1987), who emphasize the relationship between imperfect financial markets, market structure and R&D. However, no data at the firm level are used in either one of these essays. In addition, many case-study analyses have been made, focusing on particular firms or industries. Examples include Cusumano's (1985) study of the automobile industry, several studies of the shipbuilding industry, and many others. These studies often include interesting insights into particular industries, but do not attempt to analyze statistically data from an intertemporal cross-section of industries.

In this paper, unlike previous studies, we adopt a microeconomic framework, and focus on the individual firm's decision to acquire foreign technology. In this section we present a general theoretical formulation of the firm's decision to invest in foreign technology within a framework of an 'adoption game', inspired by the work of Katz and Shapiro (1987).

Assume firms compete in a repeated Cournot game and have constant marginal costs of production which are determined by the stock of technology accumulated in the past. Notice that this assumption implies that current output is independent of technology acquired during the same period. Investment in additional technology is made at time intervals between quantity games, and reduces unit costs in the future. This description fits the nature of the transferred incremental technology, and is in accordance with the treatment of technology in much of the Industrial Organization literature [Suzuki (1985), Tirole (1988)]. Following Katz and Shapiro (1987), firms are assumed to observe available innovations, and choose the optimal time of adoption. Once adopted, an innovation is no longer available to other firms, and no sub-licensing or imitation are possible.

The cost of any given innovation declines exponentially over time at a given rate μ :

$$K(T) = K(0)e^{-\mu T}. \quad (1)$$

This formulation suggests the existence of a tradeoff between early adoption at a high cost, and later adoption at the risk of losing the technology, if one of the firm's rivals adopts it.

Define r_i as the discount rate of firm i , which equals its cost of capital. Japanese capital markets prior to the liberalization of the 1980s were highly regulated and immature, and firms could raise very limited amounts of external capital. Instead, firms had to rely mainly on internal and bank finance for investment funds [Hamada and Horiuchi (1987), Meerschwan

(1990), Frankel (1991)]. We view external finance as a costly source of funds to the firm due to asymmetric information problems.⁴ Following Aoki (1988), Hoshi et al. (1990, 1991), and Frankel (1991), we regard the long-term relationship between a main bank and a group firm as a solution to these problems, and therefore treat loans from a main bank as less costly funds. The effective cost of capital to the firm, then, will be lower the more cash flow (internal funds) the firm has, and the more accessible are main bank loans:

$$r_i = r(\text{Group Affiliation, Cashflow}), \quad r_1 < 0, r_2 < 0. \quad (2)$$

Define Π_i^0 as firm i 's profits before any firm adopts the innovation; Π_i^i as firm i 's profits if it is the first to adopt an innovation, and Π_i^j as firm i 's profits if the innovation is adopted by firm j .

If firm i is the first to adopt a given innovation at time T , it will enjoy discounted future profits of⁵

$$W_i(T) = \int_0^T \Pi_i^0 e^{-rt} dt + \int_T^\infty \Pi_i^i e^{-rt} dt - K(T), \quad (3)$$

which can be rewritten as

$$W_i(T) = \frac{1 - e^{-r_i T}}{r_i} \Pi_i^0 + \frac{e^{-r_i T}}{r_i} \Pi_i^i - K(T). \quad (3')$$

If firm j is the first to adopt, firm i 's profits will be

$$L_i(T) = \frac{1 - e^{-r_i T}}{r_i} \Pi_i^0 + \frac{e^{-r_i T}}{r_i} \Pi_i^j. \quad (4)$$

The date T at which firm i is willing to 'preempt' if it believes firm j would otherwise adopt the innovation, satisfies $W(T) = L(T)$, or

$$\Pi_i^i - \Pi_i^j = r_i K(T) e^{r_i T}. \quad (5)$$

Eqs. (1) and (5) imply that firm i will be the first to adopt if its adoption time (T_i) is smaller than the adoption time of its rivals (T_j):

$$T_i = \frac{1}{(\mu - r_i)} \log \frac{r_i K_0}{\Pi_i^i - \Pi_i^j} < \frac{1}{(\mu - r_j)} \log \frac{r_j K_0}{\Pi_j^j - \Pi_j^i} = T_j, \quad i \neq j. \quad (6)$$

Following Katz and Shapiro, we allow for a different effect of any given technology on the costs of different firms. The outcome of every race is

⁴For example, raising external capital may require the firm to reveal costly private information, as in Myers and Majluf (1984).

⁵This section draws heavily on Katz and Shapiro (1987).

stochastic and depends on firm characteristics as well as on δ_i , an unobserved random factor which determines the cost reduction to firm i relative to that of firm j . Define P_i as the probability that firm i will be the first to adopt a given innovation, and note that a firm is more likely to be the first to adopt the lower is its T_i . Hence, eq. (6) implies that P_i is negatively related to r_i , firm i 's cost of capital, and, by (2), positively related to cash flow and to the availability of main bank loans (i.e. *keiretsu* affiliation). P_i is also related to firm size. To see this, note that $\Pi_i^i - \Pi_j^j$ will be higher for firm i if adoption by firm i raises industry profits by more than adoption by firm j . In a Cournot game, this implies that industry leaders, or bigger firms, will have a higher incentive to adopt any given innovation, and a higher probability of winning the adoption race.

Therefore, P_i can be written as

$$P_i = P(q_i, r_i(CF_i, BANK_i)), \quad P_q > 0, P_{CF} > 0, P_{BANK} > 0, \quad (7)$$

where q is firm output, CF is cash flow, $BANK$ is affiliation with a financial *keiretsu* with a main bank, and P_q , P_{CF} and P_{BANK} are partial derivatives.

If vertical integration affects investment in technology by solving problems of transaction-specific opportunistic behavior [Williamson (1985)], eq. (6) can be modified to allow the effective cost of technology to be negatively related to affiliation with a vertical *keiretsu*:

$$K_0 = K_0(VI); \quad K_{VI} < 0. \quad (8)$$

In this case, P_i will depend positively on VI (affiliation with a vertical group) as well.

Assume firm i can participate in N_i adoption races in every period, where N_i depends on the firm's 'technological opportunity' (TO), i.e. the number of innovations available for adoption in its sector. The expected number of innovations adopted, or licensing agreements signed by firm i in any given period, is then

$$LIC_i = P(q_i, CF_i, BANK_i, VI_i) * N(TO_i) \quad (9)$$

or

$$LIC_i = G(q_i, CF_i, BANK_i, VI_i, TO_i), \quad (10)$$

where the partial derivatives of the function G are positive with respect to all elements.

3. The data and estimation procedure

Our sample consists of 461 Japanese firms in the period 1977–1981, selected according to five criteria. First, all firms are listed in the Tokyo Stock Exchange (TSE). This fact allows us to use the information contained in firm reports to the TSE. Second, only manufacturing firms in the following

major industries are included: chemicals, metals, machinery, electronics and transportation equipment. None of the firms in the sample was subject to major ownership changes (merger or takeover), or fiscal year changes during the period of observation. Finally, no foreign-owned firms or subsidiaries are included for obvious reasons.

Two main data sources are used. The dependent variable, the number of licensing agreements in each fiscal year, is taken from the *Annual Report on Technology Imports*, published by the Science and Technology Agency,⁶ and is denoted by *LIC*. The explanatory financial variables are taken from firm reports to the TSE. We use the following measures of the explanatory variables in (10):

(1) Firm size: *SALES* (hundred billion yen), and market share (*SHR*). While the volume of *SALES* is an absolute measure of size, market share reflects a relative measure of firm size within a given (three digit) industry.

(2) *S2*: sales squared. This variable is designed to allow for a non-linear relationship between *SALES* (or *SHR*) and *LIC*.

(3) Cash flow (*CF*, billion yen). Notice that cash flow does not include royalty payments for licensed technology.

(4) Cash flow of non-group affiliated firms (*REALCF*) – *CF* times a dummy variable which equals one if the firm does not belong to a group.

(5) Affiliation with a *horizontal group*, a group with a main bank (*BANK*). This variable is measured on a scale from 0 to 4, which is based on Dodwell Marketing Consultants (1984), with some modifications based on Nakatani's (1984) classification.⁷ The scale is based on loans from the group's main bank, ownership ties and participation in a 'Presidents Club'.

(6) Affiliation with a *vertical group* (*VI*), measured on a scale from 0 to 4 [Dodwell Marketing Consultants (1984)].

(7) Technological opportunity (*TO*) is defined as the number of agreements signed by other firms within the same three-digit industry. A similar approach was used by Wakasugi (1988) and Bernstein and Nadiri (1989), where an unweighted sum of R&D spending within the same industry was treated as a measure of technological environment.⁸

(8) Industry dummies are used to capture industry-specific characteristics. Industry dummies are defined at a two-digit level: *D1* – Chemicals; *D2* – Metals; *D3* – Machinery; *D4* – Electronics (and no dummy for Transportation Equipment).

Some descriptive statistics are presented in table 2. Table 3 describes the distribution of group-affiliation variables in the sample. Approximately 38% of the firms have a main bank, and about 15% have ties with a vertically-

⁶*Gijutsu Donyu Nenji Hokoku*.

⁷Nakatani's findings are based on *Keizai Chosa Kyokai, Keiretsu no Kenkyu*.

⁸An alternative approach is suggested by Suzuki (1985) and Jaffe (1986), who use a 'Euclidean distance' measure to identify the distance between research activities of firms.

Table 2
Descriptive statistics I.

Var	Mean	Std	Min	Max
LIC	1.21	3.31	0.00	42.00
SALES (¥100b)	1.23	2.90	0.008	31.98
CF (¥1b)	5.67	17.13	-33.89	261.82
TO	13.67	18.78	0.00	118.00

Table 3
Descriptive statistics II.

Value	Bank	VI
0	62.11	85.32
1	11.86	0.80
2	7.16	2.82
3	13.88	9.76
4	4.99	1.30

Table 4
Correlation matrix.

	LIC	SALES	CF	BANK	VI	TO
LIC	1.00					
SALES	0.60	1.00				
CF	0.48	0.90	1.00			
BANK	0.16	0.11	0.05	1.00		
VI	0.17	0.28	0.27	-0.27	1.00	
TO	0.33	0.19	0.14	0.13	0.10	1.00

Table 5
Means by firm size (1981).

SALES (¥100b)	NUM	LIC	CF	BANK	VI	TO
<0.25	155	0.10	0.59	0.63	0.26	12.6
0.25-0.50	112	0.32	1.51	0.80	0.25	10.7
0.50-1.00	72	0.83	3.74	0.82	0.47	13.6
1.00-2.00	46	1.13	6.30	1.19	0.37	9.7
2.00-4.00	34	2.35	9.56	1.17	0.85	16.9
>4.00	42	7.35	46.82	1.47	0.92	22.6

integrated group. These figures resemble *keiretsu* affiliation figures in other, larger, samples [Weinstein and Yafeh (1992)]. Table 4 indicates that simple correlations between pairs of variables are generally low, except for the case of sales and cash flow. Table 5 presents sample means arranged by firm size in 1981.

In order to estimate (10), note that the dependent variable *LIC*, the number of licenses, is discrete and non-negative, and therefore the use of a method which takes these properties into consideration is necessary. In addition, the dependent variable very often takes a value of zero (67.5% of the observations). Poisson regression is a possible approach to deal with data of this type. It is designed explicitly to examine the relationship between a dependent variable representing the number of times an event occurs within a given period and the exogenous variables that determine its frequency [Hausman et al. (1984)]. The Poisson density function is

$$\Pr(Y_{it} = y_{it}) = e^{-\lambda_{it}} \lambda_{it}^{y_{it}} / y_{it}!, \quad (11)$$

where y_{it} represents, in our case, the number of licenses. The average of this process is specified as an exponential function of the vector of explanatory variables X_{it} defined in (10):

$$\lambda_{it} = e^{X_{it}\beta}, \quad (12)$$

and the log-likelihood (for a sample of N firms over T periods) is

$$L(\beta) = \sum_{t=1}^T \sum_{i=1}^N (y_{it} X_{it}\beta - e^{X_{it}\beta}), \quad (13)$$

suppressing terms which do not depend on β .

4. Results and discussion

The determinants of investment in foreign technology are presented in table 6 (Poisson regressions using pooled data). The estimated relations seem stable over time, and are not sensitive to specification changes.

First, we observe that the *number of agreements is strongly and positively related with firm size* (measured by either *SALES* or *SHR*). This finding is consistent with Schumpeterian theories that relate with firm size, and also with empirical findings on the role of large firms in Japanese R&D [Yoshikai (1986)]. Nevertheless, the negative coefficient of *S2* may imply that there are some 'diseconomies' in the absorption of a large number of new technologies in a given year. The concavity of the relationship between licenses and firm size is quite significant: if, for example, average firm sales doubled, the total number of licenses would increase by about 18%, suggesting a rather low elasticity of licenses with respect to sales (evaluated at the means).⁹

⁹Note that even though our sample is drawn from among firms listed on the TSE, it includes many small firms. Table 2 indicates that sales by the smallest firm were only 800 million yen (approximately 4 million dollars). It is therefore unlikely that our coefficients are biased due to sample selection by firm size. Moreover, since our results hold when firm size is measured by market share, it is fair to say that the results are not driven by the absolute size of firms in the sample.

Table 6
Poisson regressions.^a

	6.1	6.2	6.3	6.4	6.5	6.6
<i>CONS</i>	-0.531 (0.049)	-0.61 (0.05)	-0.920 (0.059)	-0.909 (0.059)	-1.02 (0.06)	-0.89 (0.06)
<i>SALES</i>	0.481 (0.009)	0.45 (0.01)	0.403 (0.011)	0.450 (0.012)	0.43 (0.01)	
<i>S2</i>	-0.015 (0.0005)	-0.014 (0.0005)	-0.015 (0.0005)	-0.017 (0.0006)	-0.014 (0.0005)	
<i>SHR</i>						52.45 (1.34)
<i>SHR2</i>						-234.33 (9.33)
<i>CF</i>			0.009 (0.001)	0.004 (0.001)		0.006 (0.001)
<i>VI</i>					0.09 (0.018)	
<i>BANK</i>		0.11 (0.01)	0.077 (0.013)		0.11 (0.016)	0.076 (0.013)
<i>TO</i>			0.013 (0.0009)	0.014 (0.0009)	0.012 (0.0009)	0.012 (0.0008)
<i>REALCF</i>				0.007 (0.001)		
<i>D1</i>	-0.559 (0.059)	-0.60 (0.06)	-0.244 (0.067)	-0.200 (0.066)	-0.21 (0.068)	-0.18 (0.07)
<i>D2</i>	-0.809 (0.073)	-0.82 (0.07)	-0.814 (0.094)	-0.742 (0.092)	-0.46 (0.078)	-0.75 (0.08)
<i>D3</i>	-0.094 (0.070)	-0.06 (0.07)	0.191 (0.076)	0.194 (0.076)	0.27 (0.076)	-0.32 (0.007)
<i>D4</i>	0.126 (0.05)	0.13 (0.05)	0.056 (0.051)	0.01 (0.042)	0.09 (0.05)	0.05 (0.05)
<i>MLL^b</i>	0.067	0.084	0.134	0.135	0.128	0.165

^aAll the estimations are performed in Gauss. Starting values are obtained from the associated log-linear model, and Newton's algorithm is used in order to maximize the likelihood function. Often, this procedure is too demanding, and the initial two iterations are performed using the 'steepest descent' algorithm, and Newton's algorithm afterwards. The analytical gradient and Hessians are used when the model is simple. In general, numerical gradients and Hessians are obtained. All tables include heteroscedastic-consistent standard errors of the parameters.

^b*MLL* is the mean log-likelihood value at the maximum.

Second, in view of Japanese imperfect capital markets discussed in section 2, *liquidity matters* in the firm's decision to acquire technology. Cash flow has a positive impact, and *REALCF* (cash flow of firms with limited access to main bank loans) is always positive and significant. Furthermore, the coefficient of *REALCF* is much higher than that of cash flow, implying that non-*keiretsu* firms are more liquidity constrained than group-affiliated firms (regression 6.4 in table 6). This result is consistent with the literature on

Japanese financial markets discussed above, and especially with Hoshi et al.'s (1991) results on liquidity constraints of Japanese firms. More specifically, *affiliation with a horizontal group raises the probability of purchasing technology*: the coefficient of *BANK* is positive and significant in all specifications.¹⁰ Again, *keiretsu* firms may be less liquidity-constrained (or have 'longer horizons' due to lower effective cost of capital); however group affiliation is important even when cash flow is controlled for. Hence, additional arguments relating the profitability of new technologies and group affiliation are needed. Aoki (1984, 1988) regards postwar horizontal groups as a mechanism of insurance, or risk-sharing. If importing technology involves some risk, then 'insured' firms may tend to import more of it. Alternatively, if main banks maximize their profits from loans, and group-affiliated firms are influenced by their main banks, it is possible to show that banks will have an incentive to induce affiliated firms to invest more in technology, since such investment would benefit the main bank through increased loans [Weinstein and Yafeh (1993)].

We attempt to distinguish between the '*zaibatsu* descendants' (groups based on the prewar *zaibatsu*), and groups centered around a city bank, and allow for group-specific differences. However, we find no evidence of different behavior (or different degrees of cohesiveness) between the 'old' and 'new' groups, although some groups seem to be more active in technology acquisitions than others.¹¹

Affiliation with a vertical group has a positive impact on the amount of technology acquired. This result is consistent with theories of vertical integration as a solution to transaction-specific opportunism [Williamson (1985)], and with Goto's (1982) view of opportunistic behavior as an acute problem during periods of rapid growth and massive technological imports. This result also tends to support Caves and Torii's (1991) findings, according to which vertical subcontracting relations tend to raise productivity in Japan.

It is interesting to note that horizontal and vertical groups may also induce higher investment in technology because of their ability to internalize some pecuniary and network externalities. For example, consider two firms that belong to the same group, cross-sharehold and trade with each other. When deciding on investment in cost-reducing technology, each firm will take into consideration the expected change in its own profits, and, to some extent, will also consider the effect of its investment on the (costs and) profits

¹⁰This result is quite robust, and does not change even if the variable *BANK* is measured as a 0-1 dummy (regardless of 'degrees of affiliation'), or in the form of four dummy variables describing the affinity of a firm to a group. In both cases, the coefficients of *BANK* variables are positive and significant.

¹¹If a dummy for each group is included, the *zaibatsu*-descendant Mitsui group is the most active in technology transfer, while the other major prewar group, Mitsubishi, seems to be the least active.

of the other. Alternatively, if the two firms operate in related markets with some network externalities, investment in some technologies may not be profitable for one firm alone, but may well be profitable if accompanied by investment in a compatible, complementary technology by another group firm. To the extent that groups can coordinate investment decisions in related markets, group-affiliated firms will tend to purchase more foreign technology.

The overall effect of group affiliation on technology imports is quite significant. For example, a hypothetical removal of all horizontal (main bank) ties would lead to a fall of about 10% in number of licensing agreements signed. Absent any vertical ties, the number of agreements would fall by 5% (evaluated at the means).

As for the *technological environment*, our findings suggest, as expected, that firms in an 'innovative environment', measured by the number of agreements purchased by 'close competitors', tend to purchase more foreign technology. Wakasugi (1988) obtains a similar result with respect to R&D in the semiconductor industry. We do not regard this environmental effect as a *spillover*, as in Jaffe (1986): if imported technology is less than fully appropriable, a positive correlation between a firm's investment and its technological environment will not necessarily appear.

Generally, the effects of firm size, cost of capital and technological opportunity are in accordance with the prediction of the model. Group affiliation, however, may influence the decision to acquire technology in several ways in addition to the liquidity effect captured in the model.

One should be cautious about applicability of our results to the entire Japanese economy. Our sample is drawn from among industrial manufacturing firms and does not include firms in service or light industries such as textiles or food processing. Overall, firms in these industries are small, less often affiliated with a *keiretsu* and, in general, sign fewer licensing agreements, as our model predicts. We cannot, however, be certain about intra-industry differences between firms in non-sampled sectors.

5. More general specifications

The Poisson specification requires fairly strong assumptions, namely that events in any two disjoint intervals of time are independent of each other, that the conditional mean and variance of the dependent variable are equal, and that the probability of an occurrence during any particular time interval is proportional to its length. In our sample, however, the variance seems to be much higher than the mean (table 2). Since the assumption that the conditional mean and variance of the dependent variable are equal could produce spuriously small estimated standard errors of the parameters, we examine the robustness of our results by using more general functional forms

which do not impose the equality of conditional variance and conditional mean.

One alternative is based on the *negative binomial* distribution. The relationship between the dependent variable and the explanatory variables in this model takes the form

$$\lambda_{it} = e^{X_{it}\beta + \varepsilon_i}, \tag{14}$$

where ε is white noise.¹²

Following McCullagh and Nelder (1989), we examine two possible specifications of the negative binomial model, one where the mean-to-variance ratio is constant but possibly different than one, and the other a linearly increasing ratio:¹³

$$k=1: V(Y_{it}) = (1 + \alpha)E(Y_{it}), \tag{15}$$

$$k=2: V(Y_{it}) = E(Y_{it})(1 + \alpha E(Y_{it})).$$

On the basis of (15), it is possible to construct a score test of the Poisson model against the negative binomial. Under the null hypothesis (Poisson) $\alpha=0$. By calculating the efficient scores under the null hypothesis, the following test statistics are obtained as a function of k :

$$P_1 = \frac{1}{\sqrt{2}} \sum_{t=1}^T \sum_{i=1}^N \left[\frac{(Y_{it} - \hat{\mu}_{it})^2 - Y_{it}}{\hat{\mu}_{it}} \right] \text{ for } k=1,$$

$$P_2 = \frac{\sum_t \sum_i [(Y_{it} - \hat{\mu}_{it})^2 - Y_{it}]}{\sqrt{2 \sum_t \sum_i \hat{\mu}_{it}^2}} \text{ for } k=2,$$

which are asymptotically standard normal statistics. The formal score test rejects the Poisson specification in favor of the Negative Binomial,¹⁴ yet table 7 indicates that our results hold under this specification as well.¹⁵

Another possible specification of a model which does not impose the equality of the mean and the variance is the *Hurdle Poisson model*. It is possible that the decision whether to buy foreign technology or not to buy at

¹²For a detailed derivation of this model, see Hausman et al. (1984) or Cameron and Trivedi (1986).

¹³Notice that these two assumptions have very different implications regarding the form of heteroscedasticity in the model and will lead, in general, to different parameter estimates.

¹⁴In table 7, for regression NEGBIN I $P_1=47.5$ and for NEGBIN II $P_2=37.2$.

¹⁵Note that the standard deviations of the coefficients in the negative binomial model are larger than in the Poisson model, and the effect of technological opportunity (*TO*) on the number of licensing agreements is somewhat smaller. When the variance in the negative binomial model is allowed to depend on *SALES*, we find that the effect of *SALES* on the variance is positive and significantly different from zero.

Table 7
Comparison of the different models.

	Poisson	NEGBIN I	NEGBIN II	HUR I	HUR II
CONS	-1.02 (0.061)	0.96 (0.097)	-1.02 (0.103)	-1.74 (0.133)	0.09 (0.072)
SALES	0.43 (0.010)	0.421 (0.018)	0.45 (0.022)	0.43 (0.026)	0.27 (0.010)
S2	-0.014 (0.0005)	-0.014 (0.001)	-0.015 (0.001)	-0.014 (0.001)	-0.008 (0.0005)
BANK	0.11 (0.016)	0.11 (0.026)	0.13 (0.026)	0.14 (0.031)	0.04 (0.017)
VI	0.09 (0.018)	0.10 (0.030)	0.10 (0.031)	0.11 (0.043)	0.04 (0.020)
TO	0.012 (0.0009)	0.009 (0.001)	0.009 (0.001)	0.007 (0.002)	0.011 (0.001)
D1	-0.21 (0.068)	-0.12 (0.103)	-0.12 (0.106)	0.01 (0.142)	-0.21 (0.078)
D2	-0.46 (0.078)	-0.47 (0.125)	-0.50 (0.130)	-0.33 (0.167)	-0.31 (0.088)
D3	0.27 (0.076)	0.15 (0.158)	0.15 (0.122)	0.22 (0.149)	0.38 (0.086)
D4	0.09 (0.050)	0.14 (0.087)	0.12 (0.092)	0.25 (0.14)	0.12 (0.053)
α		0.81 (0.078)	0.62 (0.100)		
SALES*			0.055 (0.018)		
MLL	0.128	0.364	0.371		0.332

Notes: α and SALES* define the relationship between the conditional mean and the conditional variance. MLL is the mean log-likelihood value at the maximum.

all is related to the explanatory variables in a different way than the decision to acquire a certain number of licenses, once the decision to buy at least one has been made. This suggests that existence of some ‘threshold’ that can be analyzed using a model that separates these two decisions.

We specify a more general model as

$$f_b(0, \beta_1) + \sum_{y \in \mathbf{R}_+ \setminus \{0\}} f_n(y, \beta_2) = 1, \tag{16}$$

where f_b is the density function describing the decision to buy technology at all, and f_n determines how many of the licenses are purchased. Note that the Poisson specification is just a restricted form of the last equation where

$$f_b(y, \beta_1) = f_n(y, \beta_2) \Rightarrow \beta_1 = \beta_2 = \beta. \tag{17}$$

The advantage of this kind of model, apart from its intuitive appeal, is that it allows for estimation under conditions of over- and underdispersion. Estimation results using this specification are reported in regressions HUR I and HUR II of table 7. A formal Hausman-type test of the Hurdle Poisson against the restricted Poisson model takes the form:

$$h = (\tilde{\beta}_{\text{HUR}} - \tilde{\beta}_{\text{POI}})' (\tilde{V}(\tilde{\beta}_{\text{HUR}}) - \tilde{V}(\tilde{\beta}_{\text{POI}}))^{-1} (\tilde{\beta}_{\text{HUR}} - \tilde{\beta}_{\text{POI}}) \rightarrow \chi^2_{0.5k}$$

where k is the number of coefficients and HUR and POI refer to the coefficients of the Hurdle and Poisson models, respectively.

Even though the value of h indicates that the Poisson model should be rejected when compared with the Hurdle Poisson ($h = 527.35$), the signs of the coefficients in HUR I and HUR II are still as predicted in the theoretical model. Notice, however, that while the negative binomial results are generally very similar to the Poisson regression results, the coefficients are somewhat different in the Hurdle Poisson model. The effect of *SALES* in the first stage (the decision whether to buy one license or none at all) is very important. In the second stage (the number of licensing agreements to be signed), the coefficient on *SALES* is much smaller. A similar pattern is observed with respect to *BANK*, and vertical integration (*VI*), which tend to be more important in the decision whether to buy technology at all. Note, however, that the importance of technological opportunity (*TO*) is bigger in the second stage (the number of licensing agreements) than in the first stage. We interpret this as evidence that large, less liquidity constrained firms are more likely to invest in technology, but the actual number of licenses purchased depends, to a great extent, on the firm's technological environment.

7. Conclusions and suggestions for further research

This paper provides a first look at the characteristics of recipient firms in a process of technology transfer. For the first time, a microeconomic framework and a statistical analysis of a large sample of firms in several major industries are used. We find that much of the technological catch-up during the period examined is driven by large enterprises, although the relationship between licensing agreements and firm size is concave. We find evidence on the importance of liquidity for investment in foreign technology. We also find that both horizontal and vertical *keiretsu* groups play a large role in the process of technology transfer. These results seem robust, and hold under several different distributional assumptions.

In the future we intend to extend our sample and conduct further experiments using earlier Japanese data in order to understand better the process of technology transfer to Japan and the role of the *keiretsu*

institution in it. Some extensions of our empirical analysis, using several novel panel data techniques, and allowing for simultaneous determination of both output and investment in technology are included in Montalvo's (1992) companion paper.

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