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"R&D AND TECHNOLOGY LICENSING IN BRAZIL"

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R&D and Technology Licensing in Brazil

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R&D and Technology Licensing in Brazil

Technology, or the knowledge of how to combine inputs to create a final product, has recently become a focus of attention not only among developed nations, but among less-developed nations as well. Technical knowledge can be attained by a firm in two ways: by original thought (i.e. innovation) or by acquisition of knowledge new to the firm but not to the world (e.g. licensing, training by another firm, or reverse engineering of another firm's product). Generally, either R&D or patenting activity is used as a measure of the first method, but measures are rarely available for the second. In this work we will exploit a new database which includes not only R&D by firm but payments for technology license contracts.

My dissertation investigates three aspects of technology licensing and innovative activity, focussing on the benefits which foreign technology provides to less-developed nations. While it is traditionally argued that the proximity of advanced technology helps domestic industry to learn and grow more quickly, mainly via technology transfers to host nation firms, the evidence is scattered and ambiguous. My work will specifically inquire:

1) whether licensing of foreign technology encourages future technological dependence or instead fosters within host nation firms an ability to do their own research,

2) whether licensed technology, worker education and R&D are equally productive in the creation of innovative products, and

3) what determines the contracting behaviour of firms and the pricing of licenses.

I use Brazil as a case study for this work, for theoretical as well as for practical reasons. Brazil is intriguing from a theoretical viewpoint, as a less-developed nation with a well-defined legal structure (including utility patent law, which recognizes minor adaptations of other patents) that has undergone substantial recent changes. From a practical viewpoint, Brazil has a large

industrial and consumer base to sustain many firms with R&D capability, as well as acting host to a sizable multinational corporation presence. Most critically, Brazil also has legal restrictions about technology licensing which allow the inspection of historical licensing records.

The primary question that this first chapter aims to answer is whether R&D and technology licensing are substitutes or complements in production, with the related question of whether licensing in one period encourages subsequent dependence (i.e. more licensing) or independence (i.e. lack of licensing, or even new R&D). Existing empirical evidence, as will be presented below, is mixed.

The question of R&D/licensing complementarity is critical for all firms deciding on a method for technology acquisition, but the issue is of even larger significance when considered in the context of public policy for less-developed nations. Since 1990, traditionally staunch supporters of controlled technology imports like Brazil and India have reversed course. After decades of tight license restrictions designed to foster domestic R&D, a combination of international pressure for open markets and growing dissatisfaction with low rates of technological change (Estache, 1990) has led to a flood of legislative changes easing inflows of foreign technology. So it is important to evaluate the potential reactions of domestic R&D to these policy changes.

In the first section of this chapter I review existing studies of the substitutes/complements debate, while Section II briefly explains the history of technology license law in Brazil. The third section introduces a unique new dataset on Brazilian firms. Heuristic work using the data to look at R&D and technology licensing follows in Section IV, and the fifth section outlines a

microeconomic model which I have created to explain the data. I hope to add a final section with results of my estimation by early summer.

I. Literature Review:

Heuristic studies

Early literature began with informal analysis of correlations and interviews with firms about the effects of foreign technology on domestic research and progress. Lake (1979) found that imitation in American "high-tech" (semiconductor and pharmaceutical) fields was faster when there were more newly-entered firms, and also concluded that the presence of multinationals positively affected the average R&D of each firm in the industry. However, he did not document transfers of technology between firms, so it unclear whether he witnessed firms performing R&D after learning from imitation of multinationals or merely facing more competition.

In an empirical paper by Mansfield and Romeo (1980), a survey of 70 British firms reported that two-thirds "felt the impact of transfers of American technology", with significantly greater effects in R&D-intensive industries. However, firms were not asked for their responses to these perceived impacts. A similar survey of 26 firms indicated that the mean age of transferred technology is 6 years for subsidiaries in developed nations, 10 years for subsidiaries in LDC's, and 13 years for licensed technology or joint ventures. This substantial difference hints at a difference in the ability of firms to appropriate and perhaps improve upon existing technology once it is transferred.

A recent paper by Blomstrom et al. (1994) used 1970-75 data from US firms in Mexico aggregated into 144 industries. They find a positive relation between royalty fees (or technology

licensing) and patent renewal fees (a rough proxy for own innovation) in the same industry, a generally unsurprising result. They find the same result for industries separated into domestic and foreign components, but the aggregation of large state-owned firms with smaller privately-owned Mexican firms may have biased their domestic correlations towards the behaviour of state-managed enterprises. They offer little theoretical explanation for their results, presenting merely a positive analysis of the data.

An interesting qualitative paper by Christensen and Rocha (1988) brought to light some evidence from Brazilian industry. Fifty executives of large chemical firms were surveyed for ratings of foreign and domestic technology on qualities like adaptability to the user's environment, innovativeness of the technology, affordability, and reliability of product and service. They found that the most important qualities to potential licensees were appropriateness to the market environment and to the inputs available. Using weights suggested by the survey, domestic technology held a significant edge. Inexplicably, in the last five years, 40 percent of the respondents had purchased or licensed *foreign* technology but only 26 percent had used *domestic* technology. While the authors attributed the behaviour to irrational stereotypes, I suggest that this evidence indicates a lock-in phenomenon, where firms continue to buy or license from the same foreign supplier which fathered the industry, because the fixed costs of switching to a domestic technology would be prohibitive despite the lure of a more attractive and appropriate technology.

Microeconomic modelling

Recently, several papers have approached the issue from a more rigorously modelled base, almost exclusively using industry-level data instead of firm-level data. While modelling at

the industry level avoids many data difficulties, it also lacks the explanatory power which I try to harness. Nevertheless, it is useful to briefly review the "industry-level" literature and to summarize their chief findings.

Mohnen et al. (1986) were not interested in technology licensing, but rather in the relationship between R&D and other inputs. Using aggregate manufacturing sector data for the US, Germany and Japan, they fitted input demand equations derived from a normalized cost function, finding generally small own-price elasticities for R&D (-0.15 for US, -0.28 for Japan, -0.55 for Germany). Cross-price elasticities tended to be very low, showing R&D to be a substitute for labour (0.05, 0.02, and 0.01 respectively) and a complement for capital in the US (-0.19) and Japan (-0.02) but a substitute in Germany (0.05).

The standard translog cost function approach was used by Bernstein (1988) to estimate share equations for inputs of labour, materials, physical capital and R&D. He used a sample of firm-level data for seven Canadian industries and included spillover variables as lagged R&D by other firms in the sample. While not reported in his paper, I have calculated the own-price elasticity of R&D for his sample in the Electrical Products industry to be -1.55, where R&D is a substitute for labour (3.4), capital (1.14) and materials (0.95). Spillover variables were significant for most input demands, at both the intra-industry and inter-industry levels, generally acting as a substitute for own R&D. A working paper by Bernstein (1995) furthers these results and indicates that R&D spillovers from the electrical and electronics industry alone give cost reductions in five of nine major industry groups, pushing two towards more R&D-intensive production and the other three towards more capital-intensive production.

Deolalikar and Evenson (1989) was the first paper to directly address the relationship between R&D and technology licensing. They estimated input demand equations for labour, non-production labour, fuel, patenting by nationals, and licensing of foreign technology using three aggregate Indian industries (light manufacturing, chemicals, and engineering). Patenting was used as a proxy for R&D due to problems of data availability. Estimating a SUR system, they found that international inventive activity had a positive effect on both technology imports and domestic patenting, concluding that domestic R&D and licensed foreign technology are complements. Results also indicated that average firm size had a counter-intuitive negative relationship with patenting (perhaps due to a reporting difference for large firms who perform R&D but do not patent) but only affects licensing in the engineering sector, where its effect is positive.

Mohnen and Lepine (1991) used the familiar translog cost function, this time exploring labour, materials, technology payments, physical capital and R&D as inputs for twelve Canadian industries. They employed an R&D spillover variable as well, and find substitutability for own R&D as Bernstein did earlier. Contrary to the Bernstein paper, labour and R&D are found to complements, and they cannot reject the possibility that capital and R&D are substitutes. Most importantly, they concur with Deolalikar and Evenson, finding R&D and technology payments to be complements, suggesting that perhaps Canadian firms must do some R&D themselves in order to benefit more from foreign technology.

The most ambitious and impressive study to date, Fikkert (1994), used data on technology licensing, patents and R&D for 571 Indian firms over the 1970's to estimate simultaneous demand curves for R&D and technology purchases. His work contradicts the

industry-level results, declaring them to be substitutes but with very little effect on each other. In fact, in the welfare analysis which follows, the spillover effects of R&D on other firms is enough to overwhelm the substitution effect so his conclusion advocates an open technology policy. He also found evidence that firms with histories of direct foreign investment have lower costs of obtaining foreign technology, perhaps because of better access to financing or experience still present in the firm. His analysis is innovative in that it makes use of firm-level data, which traditionally have many observations with corner solutions (i.e. R&D and /or technology licensing of zero by a given firm), a problem which aggregated industry data do not share. Using Kuhn-Tucker conditions to construct a likelihood function, he estimated demand functions which indicate that technology spillovers both encourage R&D and licensing (at least in nonscientific firms).

Arora (1995) made the interesting theoretical point that the moral hazard problems of licensing can be overcome if the supplier of technology bundles the information with another more tangible input like capital goods. Then licensing will occur if the supplier has a cost advantage in supplying the physical input, or if the information technology and the input are complements. So it will be interesting to determine whether licensed technology and other physical inputs are complements for Brazilian firms, making it easier to overcome the moral hazard problems.

To summarize, heuristic studies tended to find complementarity between the presence of foreign firms (or technology transfer) and domestic R&D, although there is some evidence supporting the opposite conclusion. More careful modelling on the industry level supports the complementarity result while presenting conflicting opinions on the relationship between R&D

and other inputs like capital and labour. However, the only firm-level study to date declares R&D and technology contracts to be substitutes, despite R&D spillovers which could cloud the true relationship at a more aggregated level.

II. Background: History of Contracting Law in Brazil

Since 1962, any contract concerning a piece of intellectual property has been required by law to have a license. Law 4.131 required this contracting procedure for the use of patents or trademarks by anyone other than the registered owner, as well as for any other supply of technology, technical or scientific assistance between firms.

Concerns in the 1970's about excessive payments abroad led to stricter legislation about technology licensing, including Law 5.772 which dictated that remuneration would be fixed in accordance with instructions issued by the Central Bank which is responsible for finance and exchange (Section I.XI.29.1).

Normative Act 015 in 1975 further strengthened the law, setting a maze of guidelines for contracts including rules for remuneration amounts and types. Subsections ensured that contracts did not require the purchase of raw materials or components from the licensor (2.5.2.ii), and that contracts did not contain provisions liable to limit or hinder the research and technological development policy or activities of the licensee (2.5.2.b.iv). They also dictated the use and diffusion of new knowledge springing from the license, stating that the licensee will own the rights to all improvements or developments that he may introduce into the product or process covered by the license (2.5.1.d) and that the licensor is obliged to supply immediately to the licensee detailed information about improvements in the product or process covered by the license (2.5.1.e). All of these requirements were obviously aimed at fostering technological

independence and domestic R&D capability. On the topic of remuneration, Normative Act 015 took a tough stand, setting a fixed ceiling payment for a license, and basing acceptable payments on a weighted measure of a host of characteristics including complexity and innovativeness of the product or process, and the importance and innovative capacity of the supplier.

The 1990's saw a waning of the protectionist tide, and movement towards liberalization of technology flows. Still, initial efforts aimed mainly at streamlining the application process required for a contract's approval. Normative Act 022 promised a 10-day approval process for small contracts and a 20-day process for large contracts, but provided for 45-day extensions should more information or external verification be required. Otherwise, the 1975 legislation held firm.

Real liberalization began in 1992 with Normative Act 034, giving public and research institutions an eighty percent reduction in application fees for contract approval. Normative Act 120 in 1993 was the true watershed, restricting INPI (Instituto Nacional da Propriedade Industrial) to the formal examination of contracts with no power to refuse licenses. It stated specifically that the recording of contracts must not constitute an obstacle to the access of the national industry to the technology and R&D sources existing in Brazil and abroad (limiting the recording process to a maximum of 30 days) and that the provisions of the contract, including payment and other contract terms, are not to be the object of analysis by INPI. In fact, the Directorate of Technology Transfer has a new mandate to render support services to Brazilian firms interested in the acquisition of new technology.

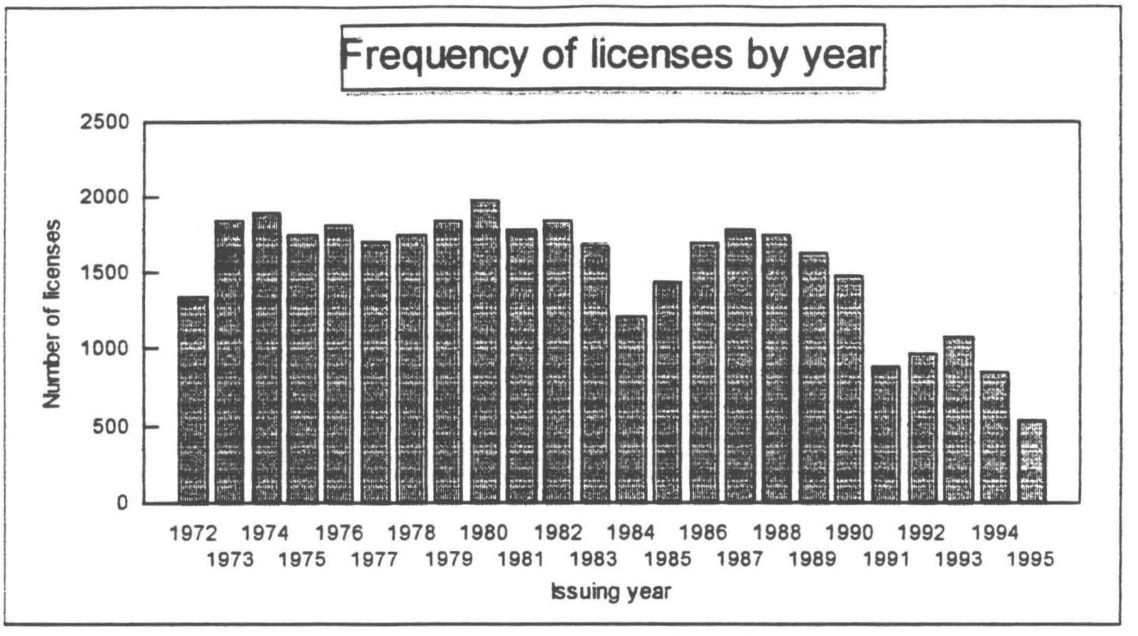
III. Data

With the cooperation of INPI and the Ministerio da Fazenda (MF), I have been able to compile a unique dataset for the study of Brazilian firm-level activity in R&D and technology licensing. While tax records are confidential, INPI agreed to attach to their records of technology contracts (a dataset referred to hereafter as DIRTEC) a code number representing the licensee firm. The code list was then transmitted to MF, which matched the numbers with a corresponding list and allowed me access to the firm-level tax records (a dataset called CADEC) for the licensee firms with no breach of confidentiality since no firm names were divulged. Unfortunately, data from CADEC had to be hand-copied into a database from printed files, restricting the number of observations which I could collect.

DIRTEC: Technology licenses

The DIRTEC dataset includes information on 36630 technology licenses registered with the government between 1972 and mid-1995. Since legal restrictions required registration of all contracts over this period, we can be assured of complete coverage of these agreements. The database includes variables indicating the license number, the object of the license, the sector of use, financial details, the duration, whether the technology is imported or domestic, and the name of the supplier.

The licenses are spread quite evenly across years, as shown in the graph below. There were sizable drops in 1984 and in the 1990's, but I have not yet determined whether they are due to behavioural or reporting practice changes. 1972 and 1995 are exceptionally low because only partial years are included.

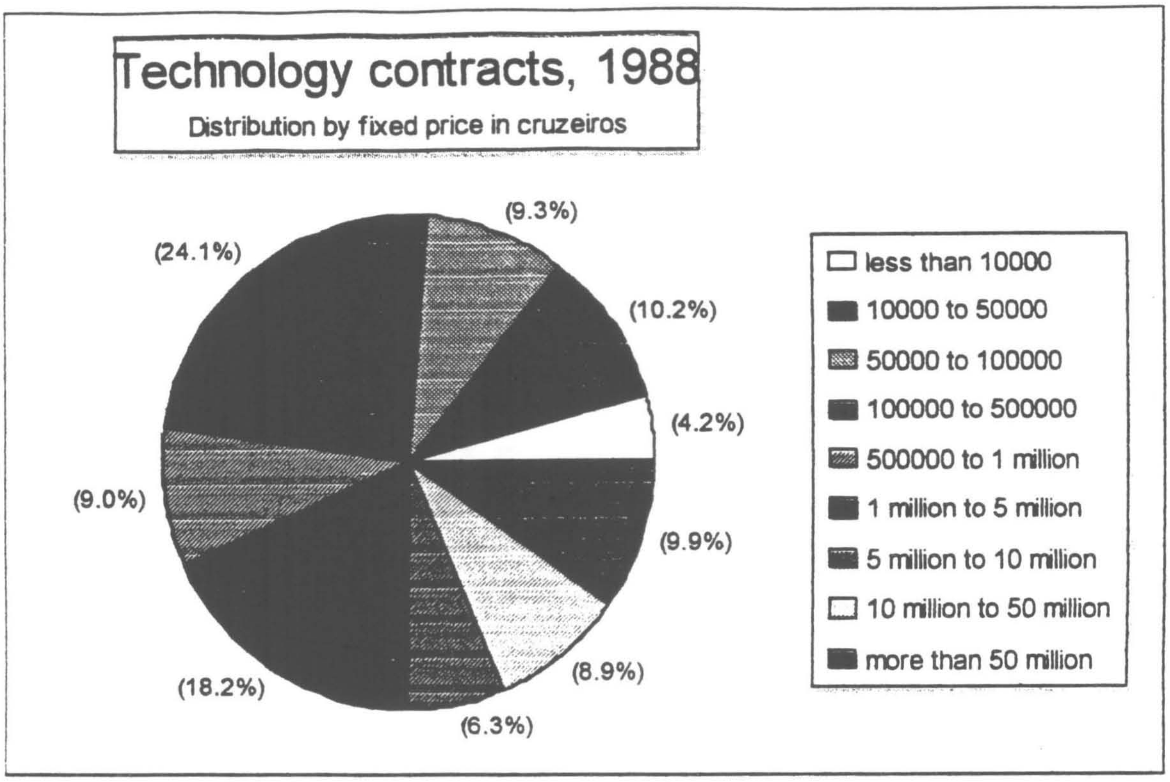


Almost all (89% or 32548) listed an imported technology, while another 9% (or 3546) listed a transfer internal to the firm. 5914 distinct licensee firm codes occurred in the database, indicating repeat licensing at an average of over 6 licenses per firm represented.

Only 8 licenses have no information on financial transactions, but over one-third (12608) have a complicated mix of fixed price and shares of returns. A sample distribution of fixed prices for 1988 is shown in the table on the following page.

CADEC: Firm-level data on Revenues and Expenditures

The full CADEC database includes data from the tax returns of almost 40000 enterprises in Brazil. I was admitted to only a small corner of that dataset (amounting to fiscal years 1988 and 1990), and was only able to retrieve permitted variables, handcopying those from files. Therefore, I developed a sampling strategy to ensure some representation of a) firms with a history of technology licensing and b) firms of different sizes.



I first took a random sample of firms from the DIRTEC list above (roughly every sixth firm listed, for a total of 910 firms) and scanned all 1988 and 1990 CADEC documents for their data. Since many licensee firms have not survived the interval since their license, only 229 firms with license histories were uncovered by this sample in 1988, and 270 in 1990.[1]

In addition, I took a random sample from the 1990 CADEC database, stratified by liquid receipts as an indicator of size. Unfortunately the retrieval process limited me to 34 records from any one category, so I selected 34 from each of 8 ranges. My random sample therefore overrepresents the small and large firm at the expense of the medium-sized firm. A bias in my sample favouring small firms is perhaps desirable to offset the innate bias of the CADEC dataset which consists of larger firms in the economy. However, overrepresentation of large firms could

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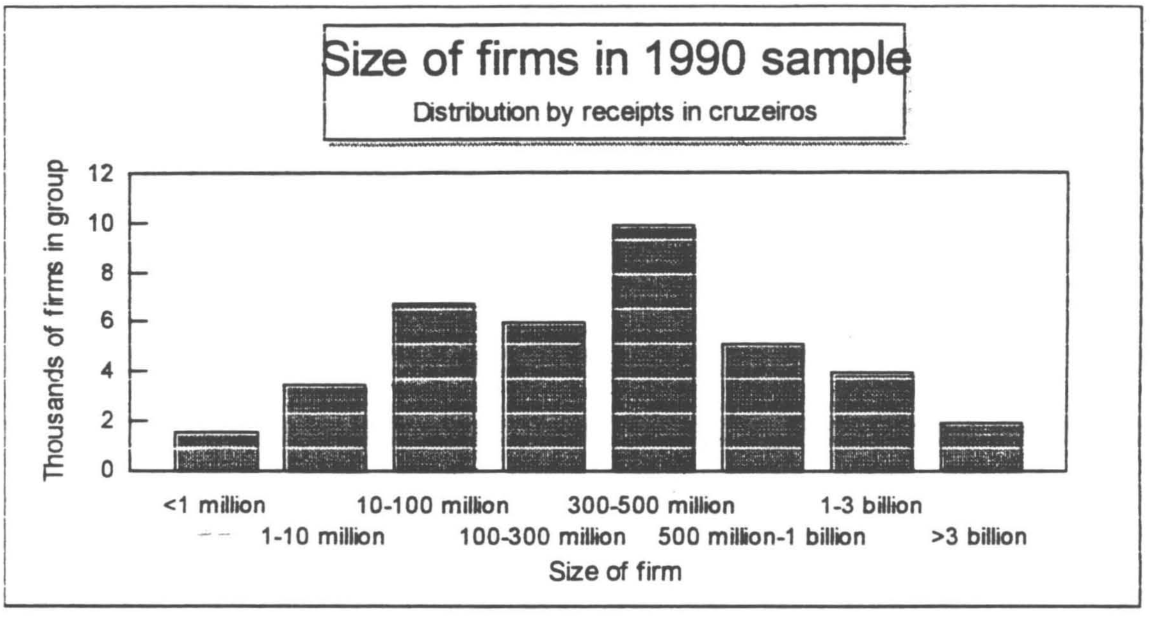
1 While it would be interesting to study the effects of licensing on the probability of a firm's survival over time, presently we have no similar information for firms with no licensing history.

potentially bias my results since larger firms typically conduct more R&D and technology licensing than do small firms. A weighting of the sample could address this issue but has not yet been performed. The graph below gives some idea of the actual weights to be assigned to each of the eight sampling groups used.



To build a dataset across time if possible, I consulted the 1988 records to find all of the above 272 random CGCs appearing in that year as well. Most small firms in 1990 were not in the CADEC set in 1988, so I sampled additional groups of 34 for the two smallest categories in 1988 and traced those CGC codes forward to 1990 wherever possible. The result was therefore a set of 340 random firms, each of which occurred in at least one of the two sample years.

The result is some information for one year or more concerning 619 firms (including complete data in at least two years for 320 firms, and complete data for at least one year for another 266). Roughly half of the sample are from the DIRTEC list and thus have a history of technology licensing.

The CADEC data present detailed expenditure records as well as more general financial and locational information. The variables of relevance include:

fiscal year of report	advertising expenditures
principal economic activity of firm	royalty payments to domestic firms
legal nature of firm	royalty payments to foreign firms
location of firm	expenditures on R&D
exports	total operational expenditures
domestic sales	profit post-tax, post-subsidies
total wages and salaries	profit pre-tax, pre-subsidies
payments to administrative personnel	capital stock

Despite the fact that my access was limited to 1988 and 1990 files, filing procedures often made other years' data available to me as well, so the distribution of data is as follows:

1986	4 firms	1989	18 firms
1987	9 firms	1990	505 firms
1988	413 firms	1991	11 firms

Naturally, some of those have missing values (as some are "advance" reports).

The data span a wide variety of firms, covering the spectrum of industries, more than 100 geographical areas, and several distinct legal structures including sole proprietorships, partnerships, and corporations.

We might expect that technology payments recorded during this period understated the actual transaction value, while R&D expenditures were overstated. Since both can be deducted for tax purposes, firms would presumably report as high a value as was credible or legal. However, technology payments were regulated by the Central Bank leaving no room for overstatement, and they may even understate if side payments were required between firms to procure technology which could not be purchased at prices fixed by the state. R&D expenditures faced no such limit, and so can be expected to overstate rather than understate.

Preliminary analysis shows that there is little correlation between a history of licensing and royalty payments in the current period. Well over 200 firms have a licensing history, and yet

only 30 report royalty payments in either 1988 or 1990. This points to a long-term ability of firms to use licenses for a period and to avoid lock-in.

Arora (1996) reports the interesting statistic that in his sample of 144 technology licenses for Indian industry over the 1949-1984 period, seventeen percent of the licensees had a history of licensing, while 22 percent had previous contact of some kind between licensor and licensee. Similar analysis of our sample data indicate much more frequent historical links. *Every* current domestic licensee has a history of licensing, as do over three-quarters of current licensees of foreign technology, and over seventy percent of current performers of R&D. In contrast, less than twenty percent of those performing R&D currently hold technology licenses, indicating an ability to use licenses and then to move on to independent research.

Sbragia and Kruglianskas (1995), in a random sample of 400 surveyed firms in 1993, found an average R&D/Sales ratio of less than one percent compared to an American survey average of 3.5 percent. They found fewer R&D personnel than their American counterpart firms, and less funding per researcher. Our sample gives an average R&D/Sales ratio of 0.03 percent for all firms, but if we restrict analysis to those firms reporting R&D (which the above surveys attempted to do), we find an average of 0.4 percent.

IV. Analysis and Estimation

Heuristic studies

My earliest attempts at input demand equations for technology purchases and R&D recognized that estimation required some acknowledgment of simultaneity. Therefore I used a simple log-linear form for the demand equations, estimating a multivariate model with FIML and

the supposition that I could directly estimate the structural form of log-linear input demand functions. The key variables were defined as the logarithms of:[2]

Royalty	payments to domestic or foreign sources for technology
R&D	expenditures on R&D
Capital	all expenditures not classified as labour, royalty or R&D
Labour	all expenditures associated with labour, including wages and salaries, training, and meal costs for employees
Export share	percentage of total sales attributed to exports
Size	capital stock
Tech pool	number of technology contracts signed in the same industry
History	number of technology contracts previously signed by firm
R&D pool	total constant dollar amount of R&D in the industry in the previous five years by Japan, Germany, France, UK, and US
Trained L	percentage of labour costs attributed to training of personnel
Admin L	percentage of labour costs attributed to administrative personnel

First, I considered capital and labour to be exogenous variables and left them out of the system, as some previous work has done. Note that the R^2 values are incredibly low, and that according to both the numeric (BHHH) and analytic (Gaussian) estimates of variance, the variables are largely not significant.

FIML on two-equation simultaneous system (full dataset)

Royalty equation				**R&D equation**			
Variable	**Coefficient**	**T-statistic**		**Variable**	**Coefficient**	**T-statistic**	
		BHHH	**Gauss**			**BHHH**	**Gauss**
Constant	223.1	0.46	2.42	**Constant**	-126.74	0.02	0.41
R&D	0.02	0.03	1.84	**Royalty**	2.28	0.08	24.2
Export share	330.13	0.19	0.54	**Export share**	-470.13	0.06	0.21
Size	-0.02	0.94E-03	0.01	**Size**	29.1	0.92	4.86
Tech pool	-0.26	0.33	0.86	**R&D pool**	0.02	0.44	1.13
History	-1.9	0.02	0.92	**Trained L**	0.50E-05	0.57	4.23
$\mathbf{R^2}$		0.79E-04		$\mathbf{R^2}$		0.161E-02	

[2] All variables involving Brazilian currency units have been converted to constant September 1986 currency units using the "Indice de precos ao consumidor" (IPC) for September of each year from Conjuntura Economica.

The sizable differences between the two measures of variance are the result of the many "zero" observations, which make the gradients of several variables zero while they are stillnot at their maximum likelihood values. Endogenizing capital and labour and repeating the exercise with four simultaneous equations gives similarly distressing results for the same reason.

I also estimated the two-equation system and then the four-equation system using only those firms displaying some R&D or technology purchases, where they of course display much greater explanatory power (with R^2 in the 0.1 to 0.3 range). However, these estimates are obviously biased towards a conclusion of complementarity of R&D and technology purchases.

The arbitrary model structure and imposed functional form of the demand equations persuade one not to regard these results as anything but preliminary. So I emulated the procedure used by previous literature for industry-level data, proposing a translog cost function and estimating share equations for the factors of R&D, technology purchases, labour, and other inputs (referred to loosely as capital). While this methodology allows flexibility of functional forms for the demand equations, it still does not address the issue of the zeroes in the dependent variables, and introduces a new problem of calculating factor prices for the inputs. While interest rates and industry-level wage rates are available[3], prices for R&D and technology purchases had to be constructed with some heroics. Using a license contract as a unit of measurement, I set prices for technology purchases as the average price paid for a contract in the industry that year (unless the firm actually purchased a contract, in which case I used the actual, not the average, price). For R&D, lacking any other data, I assumed that each firm conducting R&D performed only one project, thus making value the price of R&D. Average R&D (among

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[3] I used the 1995 International Financial Statistics Yearbook for interest rates, and data from annual household surveys (Pesquisas Nacional de Amostra de Domicilias) for wages by industry.

non-zero R&D performers) in an industry was used as a price for those firms not conducting R&D in that year.

However, SUR estimation of the input demand equations (dropping the capital equation, normalizing by interest rates and restricting the coefficients to ensure homogeneity of degree one in prices) gave hopelessly insignificant estimates[4]:

SUR estimation of share equations normalized by price of capital

	Royalty equation		R&D equation		Labour equation	
Variable	**Coefficient**	**T-statistic**	**Coefficient**	**T-statistic**	**Coefficient**	**T-statistic**
Constant	0.17E-02	1.97	0.25E-02	1.75	0.42	27.69
Royalty price	-0.22E-13	0.19				
R&D price	-0.25E-14	0.18	-0.88E-14	1.68		
Labour price	-0.23E-11	0.78	0.30E-12	0.78	-0.12E-06	0.84
Export share	-0.11E-02	0.62	0.02	0.84	-0.07	1.62
Size	0.36E-05	0.05	0.70E-04	0.44	0.29E-02	1.19
Tech pool	0.19E-06	0.06				
R&D pool			-0.21E-04	0.08		
Trained L			0.23E-03	2.13	0.68E-03	0.83
Admin L					0.27E-02	0.11
History	-0.63E-05	1.84				
R^2		0.27E-03		0.96E-02		0.88E-02

With sample data means for the shares of capital (0.61142), labour (0.38445), R&D (0.0026377) and technology contracts (0.0014901), estimated own-price elasticities (if one accepts the estimates as significantly different from zero) are -1.67 for capital, -5.76 for labour, -378.12 for R&D, and -670.09 for technology licenses. The estimated coefficients are so small that elasticities of substitution cannot be distinguished from one. Variations of this regression using

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4 All t-statistics here are from BHHH calculations, since Gaussian versions were not computable for this model owing to the number of "zero" observations.

only observations with royalty payments or R&D, or only observations with a history of licensing, or only those with no licensing history, proved only marginally more effective.

These dismal results were expected considering the lack of model design underlying the structural equations. The primary issue of concern and the problem driving all of these insignificance results, is the predominance of "zero" choice observations, which will be modelled in the next section.

V. Microeconomic modelling

There are at least three explanations for the preponderance of zeroes in the technology purchase and R&D variables. First, the one-year observation period may simply be too short for firms to have performed enough R&D to be worthwhile reporting for tax purposes. Small firms might not consider their efforts to improve products and processes as R&D at all. We might therefore expect our R&D observations to have a few more zeroes than would be correct, but little can be done about this traditional omission in R&D data.

Second, the zero observations may be involuntary, due to lack of ability to perform R&D in the current period (acquisition of research personnel requires a time-consuming search process) or lack of suitable technology contracts offered on the market (again a lengthy search process may be involved). This does not really cause more zeroes to occur in the sample than is appropriate, but rather shifts non-zero observations from the period when demand is recognized to the end of the search period. There is no *a priori* reason to believe that our sample therefore is biased with too many or too few zero observations.

The third and mostly likely explanation is that the choices of zero R&D and/or zero technology licenses are the result of rational choice by the firm, a corner solution in the typical

consumption problem. The decision may be made for non-economic reasons (e.g. vegetarians abstain from meat regardless of its relative price) or for economic reasons. While we could model non-economic reasons for the zero observations using a "double-hurdle" model (Pudney, 1989), I could not imagine a non-economic reason worthy of modelling. So for this work I have adopted an approach using only economic reasons for the corner solutions, making use of the Kuhn-Tucker conditions to a profit-maximization problem.[5]

For analytical ease, let us assume that increases to technology are time-separable, so that

$$W_t = \sum_{n=1}^{\infty} (1-\delta)^{n-1} I_{t-n} \qquad (1)$$

is the knowledge stock at any given time t, where today's stock depends only on increments I for previous periods. The increment is defined by

$$I_t = a_R\bar{R}_t + a_T\bar{T}_t + a_{RM}\bar{R}_tM_t + a_{TM}\bar{T}_tM_t + a_SS_t + a_{RS}\bar{R}_tS_t + a_{TS}\bar{T}_tS_t + a_{RT}\bar{R}_t\bar{T}_t \qquad (2)$$

where $\bar{R}$ is real R&D by the firm ("quantity of R&D", in some sense, since $R = p_R\bar{R}$),
$\bar{T}$ is real technology purchases by the firm (again, where $T = p_T\bar{T}$),
M is an indicator of the previous experience of the firm with technology licensing, and
S is a spillover pool of knowledge in the industry, from R&D performed by other nations.

This formalization allows for interactions between each technology variable of interest and the technology meta-variables for history and spillovers.

Now I propose that technology increases output multiplicatively, in the form of

$$Y_t = A(W_t)F_t \qquad (3)$$

Assuming a CES production function, we can rewrite output as

$$F_t = (a_K\bar{K}_t^{\rho} + a_L\bar{L}_t^{\rho})^{1/\rho} \qquad (4)$$

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[5] This model builds directly on the work of Fikkert (1994a) but his model treated capital and labour as exogenous variables determined by the capacity licensing law in India at the time. I have endogenized those factors.

where $\bar{K}$ is the real capital input used in production ($K = p_K\bar{K}$), and
$\bar{L}$ is the real labour input used ($L = p_L\bar{L}$).

In the work which follows, we will use the capital input as a residual category, including all inputs which do not qualify as labour, R&D or technology purchases.

Assuming that the price charged is a function of the quality of the product, and therefore of the level of technology incorporated into the output, we now write total sales as

$$sales_t = p(W_t)A(W_t)F_t \qquad \textbf{(5)}$$

and to simplify the analysis we assume a functional form for

$$p(W_t)A(W_t) = mW_t \qquad \textbf{(6)}$$

so that we can use **(3)**-**(6)** to write

$$sales_t = mW_t(a_K\bar{K}_t^{\rho} + a_L\bar{L}_t^{\rho})^{1/\rho} \qquad \textbf{(7)}$$

Now we can set up the firm's choice problem, which is to maximize the present discounted value of future profit streams (or the present value of the firm):

$$\max \pi_t = E\{\sum_{t=0}^{\infty} \beta^t[mW_t(a_K\bar{K}_t^{\rho} + a_L\bar{L}_t^{\rho})^{1/\rho} - p_R\bar{R}_t - p_T\bar{T}_t - (p_K + j_{it})\bar{K}_t - (p_L + h_{it})\bar{L}_t$$
$$- g_{it}\bar{T}_t - f_{it}(X_t)]\} \qquad \textbf{(8)}$$

where $j_{it} = \alpha_{KZ}Z_t + \kappa_{it}$, **(9)**
$h_{it} = \alpha_N N_t + \alpha_{LZ}Z_t + \varsigma_{it}$, **(10)**
$g_{it} = \alpha_M M_t + \alpha_P P_t + D_j + \varepsilon_{it}$, **(11)**
$f_{it} = \lambda_{it}X_t + \lambda_2 X_t^2$ **(12)**
$X_t = \gamma_R\bar{R}_t + \gamma_T\bar{T}_t + \gamma_Z Z_t + \gamma_N N_t$. **(13)**
Z_t = indicator of firm size
N_t = training of labour force
P_t = technology license pool, and
D_j = industry dummy

Equation **(9)** recognizes that the direct cost of capital (or other inputs) is indeed the interest rate, but the rate offered to each firm may differ. Specifically, I assume that it is the

economy-wide p_K [from **(8)**] with some recognition of the size of the firm Z_t and a random component attributable to timing of loans, credit history with banks, etc. We would expect α_{KZ} to be negative, since larger firms in general face lower interest rates.

Equation **(10)** decomposes the direct cost of labour further than merely the industry-wide wage rate [which is in **(8)**], allowing for firm-specific differences in labour costs by average skill level of employees N_t and size of the firm Z_t. We expect α_N to be positive, and may test the hypothesis that larger firms pay higher wages, by testing the sign of α_{LZ}. Once again, there is a random component included, which depends on the timing of hirings during the year, and forces in the labour market.

The search and transactions costs of obtaining a technology contract are captured by equation **(11)**, where I suggest that costs are dependent upon the licensing history of the firm (M_t), the spillover pool of research in the industry (P_t), an industry indicator (D_j), and a random error term.

Adjustment to new technology is modelled by equations **(12)** and **(13)**, with quadratic costs dependent on the choice variables of R&D and technology purchases, as well as on the size of the firm and training of the labour force.

We now assume that the four error terms are independent and identically distributed as

$$\varepsilon_{it} \sim N(0, \sigma_\varepsilon^2) \qquad \textbf{(14)}$$
$$\lambda_{it} \sim N(\bar{\lambda}, \sigma_\lambda^2) \qquad \textbf{(15)}$$
$$\varsigma_{it} \sim N(0, \sigma_\varsigma^2) \qquad \textbf{(16)}$$
$$\kappa_{it} \sim N(0, \sigma_\kappa^2) \qquad \textbf{(17)}$$

The appropriate first-order conditions for maximization with respect to each choice variable, implying the subscript t unless otherwise stated, and remembering that the subscript $t+1$ indicates an expected future value at time t:

$$\begin{aligned}\pi_{\bar{R}} = &-p_R - \lambda_{it}\gamma_R - 2\lambda_2\gamma_R(\gamma_R\bar{R} + \gamma_T\bar{T} + \gamma_Z Z + \gamma_N N) \\ &+\beta(1-\delta)m(a_R + a_{RM}M + a_{RS}S + a_{RT}\bar{T})F_{t+1}\end{aligned} \qquad \textbf{(19)}$$

$$\pi_{\bar{T}} = -p_T - \lambda_{it}\gamma_T - 2\lambda_2\gamma_T(\gamma_R\bar{R} + \gamma_T\bar{T} + \gamma_Z Z + \gamma_N N) - \alpha_M M - \alpha_P P - D_j - \varepsilon_{it}$$
$$+\beta(1-\delta)m(a_T + a_{TM}M + a_{TS}S + a_{RT}\bar{R})F_{t+1} \qquad \textbf{(20)}$$

$$\pi_{\bar{K}} = m\bar{E}F^{1-\rho}a_K\bar{K}^{\rho-1} - p_K - \alpha_{KZ}Z - \kappa_{it} \qquad \textbf{(21)}$$

$$\pi_{\bar{L}} = m\bar{E}F^{1-\rho}a_L\bar{L}^{\rho-1} - p_L - \alpha_{LZ}Z - \alpha_N N - \varsigma_{it} \qquad \textbf{(22)}$$

Since $\bar{K}$ and $\bar{L}$ are always chosen as interior solutions, equations **(21)** and **(22)** can be set equal to zero as first-order conditions to implicitly solve for them. Notice that the dependent variables $\bar{R}$ and $\bar{T}$ do not enter into **(21)** and **(22)** except as lagged values in W, so for any given period W can be treated as a firm-specific constant.

However, $\bar{R}$ and $\bar{T}$ are frequently chosen as zero values, so I take the Kuhn-Tucker conditions on the Euler equations for necessary first-order conditions. Considering **(19)** first, the Kuhn-Tucker conditions state that

$$\pi_{\bar{R}}\bar{R} = 0 \textit{ where } \pi_{\bar{R}} \le 0 \textit{ and } \bar{R} \ge 0 \qquad \textbf{(23)}$$

so we have two possible cases.

First, consider $\bar{R} > 0$ *so* $\pi_{\bar{R}} = 0$. Therefore, remembering that $R \equiv p_R\bar{R}$ and $T \equiv p_T\bar{T}$:

$$R^* = b^R + b^R_T T + b^R_{TF}TF_{t+1} + b^R_Z Z + b^R_N N + b^R_{MF}MF_{t+1} + b^R_{SF}SF_{t+1} + b^R_F F_{t+1} + \varepsilon^R_{it} \qquad \textbf{(24)}$$

where $b^R = p_R(\bar{\lambda} - p_R)/2\lambda_2\gamma_R^2$

$b^R_T = -\gamma_T p_R/\gamma_R p_T$

$b^R_{TF} = \beta(1-\delta)p_R m a_{RT}/2\lambda_2\gamma_R^2 p_T$

$b^R_Z = -p_R\gamma_Z/\gamma_R$

$b^R_N = -p_R\gamma_N/\gamma_R$

$b^R_{MF} = \beta(1-\delta)p_R m a_{RM}/2\lambda_2\gamma_R^2$

$b^R_{SF} = \beta(1-\delta)p_R m a_{RS}/2\lambda_2\gamma_R^2$

$b^R_F = \beta(1-\delta)p_R m a_R/2\lambda_2\gamma_R^2$

$\varepsilon^R_{it} = -p_R(\lambda_{it} - \bar{\lambda})/2\lambda_2\gamma_R^2$

Now, consider the case where $\bar{R} = 0$ *so* $\pi_{\bar{R}} \le 0$. Substituting $\bar{R} = 0$ into **(19)** and multiplying by $q = p_R/2\lambda_2\gamma_R^2$, which is necessarily positive, we find that $\pi_{\bar{R}}$ takes exactly the same form as R^*. So in this case $\pi_{\bar{R}} = qR^* \le 0$. Therefore, we can assert that the choice of R will satisfy

$$\begin{aligned} R &= R^* \quad \textit{iff} \quad R^* > 0 \\ &= 0 \quad \textit{iff} \quad R^* \le 0 \end{aligned} \qquad \textbf{(25)}$$

In other words, R^* is a standard indicator variable for R in the maximization problem.

Solving symmetrically for

$$T^* = b^T + b_R^T R + b_{RF}^T RF_{t+1} + b_Z^T Z + b_N^T N + b_{MF}^T MF_{t+1} + b_{SF}^T SF_{t+1} + b_F^T F_{t+1} + b_M^T M + b_P^T P + D_j^T + \varepsilon_{it}^T \quad \textbf{(26)}$$

where
$b^T = p_T(\bar{\lambda} - p_T)/2\lambda_2\gamma_T^2$
$b_R^T = -\gamma_{RP} p_T/\gamma_{TP} R$
$b_{RF}^T = \beta(1-\delta) p_T m a_{RT}/2\lambda_2\gamma_T^2 p_R$
$b_Z^T = -p_T \gamma_Z/\gamma_T$
$b_N^T = -p_T \gamma_N/\gamma_T$
$b_{MF}^T = \beta(1-\delta) p_T m a_{TM}/2\lambda_2\gamma_T^2$
$b_{SF}^T = \beta(1-\delta) p_T m a_{TS}/2\lambda_2\gamma_T^2$
$b_F^T = \beta(1-\delta) p_T m a_T/2\lambda_2\gamma_T^2$
$b_M^T = -\alpha_M p_T/2\lambda_2\gamma_T^2$
$b_P^T = -\alpha_P p_T/2\lambda_2\gamma_T^2$
$D_j^T = -p_T D_j/2\lambda_2\gamma_T^2$
$\varepsilon_{it}^T = -p_T[\varepsilon_{it} + (\lambda_{it} - \bar{\lambda})\gamma_T]/2\lambda_2\gamma_T^2$

we can similarly assert that the choice of T will satisfy

$$\begin{aligned} T &= T^* \quad \textit{iff} \quad T^* > 0 \\ &= 0 \quad \textit{iff} \quad T^* \le 0 \end{aligned} \quad \textbf{(27)}$$

Now to form a likelihood function, we recognize that

$$\Pr(R_{it}^*, T_{it}^*, \bar{K}_{it}, \bar{L}_{it}) = |J| \cdot \Pr(\varepsilon_{it}^R, \varepsilon_{it}^T, \kappa_{it}, \varsigma_{it}) \quad \textbf{(28)}$$

where
$$|J| = \begin{vmatrix} \partial\varepsilon_{it}^R/\partial R^* & \partial\varepsilon_{it}^R/\partial T^* & \partial\varepsilon_{it}^R/\partial \bar{K} & \partial\varepsilon_{it}^R/\partial \bar{L} \\ \partial\varepsilon_{it}^T/\partial R^* & \partial\varepsilon_{it}^T/\partial T^* & \partial\varepsilon_{it}^T/\partial \bar{K} & \partial\varepsilon_{it}^T/\partial \bar{L} \\ \partial\kappa_{it}/\partial R^* & \partial\kappa_{it}/\partial T^* & \partial\kappa_{it}/\partial \bar{K} & \partial\kappa_{it}/\partial \bar{L} \\ \partial\varsigma_{it}/\partial R^* & \partial\varsigma_{it}/\partial T^* & \partial\varsigma_{it}/\partial \bar{K} & \partial\varsigma_{it}/\partial \bar{L} \end{vmatrix} \quad \textit{or} \quad \begin{vmatrix} J_{11} & J_{12} & J_{13} & J_{14} \\ J_{21} & J_{22} & J_{23} & J_{24} \\ J_{31} & J_{32} & J_{33} & J_{34} \\ J_{41} & J_{42} & J_{43} & J_{44} \end{vmatrix}$$

and we must evaluate the determinant of the Jacobian for four possible cases: (a) R>0 and T>0, (b) R>0 and T=0, (c) R=0 and T>0, and (d) R=0 and T=0.

For case (a), using equations **(24)**, **(26)**, **(21)** set equal to zero, and **(22)** set equal to zero:

$$|J_A| = \begin{vmatrix} 1 & b_T^R + b_{TF}^R F_{t+1} & 0 & 0 \\ b_R^T + b_{RF}^T F_{t+1} & 1 & 0 & 0 \\ 0 & 0 & J_{33} & J_{34} \\ 0 & 0 & J_{43} & J_{44} \end{vmatrix} \quad \textbf{(29)}$$

where $J_{33} = mD_i(1-\rho)a_K\bar{K}^\rho F^{1-\rho}(a_K\bar{K}^{\rho-2}F^{-\rho} - 1)$,
$J_{34} = J_{43} = mD_i a_L a_K \bar{L}^{\rho-1}\bar{K}^{\rho-1}F^{1-2\rho}$, and
$J_{44} = mD_i(1-\rho)a_L\bar{L}^\rho F^{1-\rho}(a_L\bar{L}^{\rho-2}F^{-\rho} - 1)$.

Define $J^* \equiv J_{33}J_{44} - J_{34}J_{43}$
$$= a_L a_K \bar{K}^{\rho}\bar{L}^{\rho}F^{2-2\rho}[1 - mD_i(1-\rho)F^{-\rho}(a_L\bar{L}^{\rho-2} + a_K\bar{K}^{\rho-2})], \quad \textbf{(30)}$$

so that we may write
$$|J_A| = [1 - (b_R^T + b_{RF}^T F_{t+1})(b_T^R + b_{TF}^R F_{t+1})] \cdot J^* \quad \textbf{(31)}$$

For case (b), T=0 so T does not enter into any of the other three Euler equations. This means that $J_{12} = J_{32} = J_{42} = 0$, but otherwise the J_A matrix is unchanged. So, $|J_B| = J^*$. It can be verified that for cases (c) and (d), the determinant of the Jacobian is also $|J_C| = |J_D| = J^*$.

For now, I will specify the expectation of future production as
$$F_{t+1} = \gamma_F F_t \quad \textbf{(32)}$$
or an expectation that production without the added benefit of technological advances will grow at some common economy-wide rate γ_F.

Finally, we express the likelihood function for all four equations jointly as

$$\mathscr{L}(R,T,\bar{K},\bar{L}) = \prod^{nA} |J_A| f(\varepsilon_{it}^R, \varepsilon_{it}^T, \kappa_{it}, \varsigma_{it}) \cdot \prod^{nB} \int_{-\infty}^{\hat{T}} J^* f(\varepsilon_{it}^R, \varepsilon_{it}^T, \kappa_{it}, \varsigma_{it}) d\varepsilon_{it}^T$$
$$\cdot \prod^{nC} \int_{-\infty}^{\hat{R}} J^* f(\varepsilon_{it}^R, \varepsilon_{it}^T, \kappa_{it}, \varsigma_{it}) d\varepsilon_{it}^R \cdot \prod^{nD} \int_{-\infty}^{\hat{T}} \int_{-\infty}^{\hat{R}} J^* f(\varepsilon_{it}^R, \varepsilon_{it}^T, \kappa_{it}, \varsigma_{it}) d\varepsilon_{it}^R d\varepsilon_{it}^T \quad \textbf{(33)}$$

where $\hat{T} = T^* - \varepsilon_{it}^T$ *and* $\hat{R} = R^* - \varepsilon_{it}^R$ using equations **(26)** and **(24)** respectively, and *nA* refers to all observations in case (a), *nB* to all in case (b), *nC* to all in case (c), and *nD* to all in case (d). Using **(14)-(17)**, **(21)**, **(22)**, **(24)** and **(26)** we can show that the four error terms are all independent and distributed as

$$\varepsilon_{it}^R \sim N(0, \sigma_\lambda^2[p_R/2\lambda_2\gamma_R^2]^2) = N(0, \sigma_{\varepsilon R}^2) \quad \textbf{(34)}$$
$$\varepsilon_{it}^T \sim N(0, [\sigma_\lambda^2\gamma_T^2 + \sigma_\varepsilon^2] \cdot [p_T/2\lambda_2\gamma_T^2]^2) = N(0, \sigma_{\varepsilon T}^2) \quad \textbf{(35)}$$
$$\kappa_{it} \sim N(0, \sigma_\kappa^2) = N(0, \sigma_{\varepsilon K}^2) \quad \textbf{(36)}$$
$$\varsigma_{it} \sim N(0, \sigma_\varsigma^2) = N(0, \sigma_{\varepsilon L}^2) \quad \textbf{(37)}$$

Variables

At present the sample (excluding all observations with missing or questionable data) has *nA*=3, *nB*=24, *nC*=37, and *nD*=781. In other words, all but three of the observations have some corner choice, and over ninety percent have *both* R&D and technology purchases as a corner choice. Descriptive statistics for the main variables (plus some other variables of interest added at the end) are presented in the table below.

Variable	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**	**Freq of zeroes**
Royalty	168.36	2,094.47	0	41,367.71	805
R&D	353.93	5,649.82	0	114,368.47	818
Capital (real)	7,971.16	161,002.29	3.2E-05	4.16E+06	0
Labour (real)	37,385.91	443,401.99	0.1	1.17E+07	0
Capital stock	6.59	62.32	0	1,368.6	
Export share	0.04	0.13	0	1	
Tech pool	137.88	193.05	0	526	
History	6.14	28.45	0	456	
R&D pool	6,294.45	13,428.58	0	79,150.34	
Trained L	0.01	0.02	0	0.25	
Admin L	0.14	0.27	0	1	
Domestic royalty	38.82	919.38	0	26,500.95	
Foreign royalty	129.54	1,884.46	0	41,367.71	
Total costs	7.66E+06	1.52E+08	0.51	3.98E+09	0
Current licensing	0.73	4.08	0	74.53	

where the variables are defined as:

Royalty expenditures- from tax forms, corrected to constant March 1986 currency units
R&D expenditures- from tax forms, corrected to constant March 1986 currency units
Capital- implicit real capital rented, found as all non-labour, non-R&D, non-license expenditures divided by the annual interest rate
Labour- implicit hours of work hired, found as labour expenditures divided by the average monthly salary in the industry
Capital stock- in millions of constant March 1986 currency units

Export share- exports as a proportion of total sales
Tech pool- number of technology licenses issued in industry during the year
History- number of technology licenses signed by the firm in the past
R&D pool- R&D expenditures in industry in previous five years by France, Germany, Japan, UK, and US, in millions of constant 1990 US dollars
Trained L- expenditures on training employees as a proportion of labour expenditures
Admin L- administrative and legal staff wages as a proportion of labour expenditures
Domestic royalty- royalty expenditures paid to domestic firms
Foreign royalty- royalty expenditures paid to foreign firms
Total costs- total expenditures reported in tax form
Current licensing- number of technology licenses held by the firm at some time during the year

Work in progress

I am in the process of programming the likelihood function in GAUSS, and will have FIML estimates by the end of May. In addition, a return trip to Brazil is scheduled for June and July, and I intend to use that opportunity to gather more data to augment my sample both cross-sectionally and across time. Those data should be fully incorporated into the analysis by the end of the summer.

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