JOURNAL OF ECONOMIC DEVELOPMENT 31
Volume 41, Number 3, September 2016

'DAVIDS' ARE NOT SMALL 'GOLIATHS': R&D AND TECHNOLOGY LICENSING IN BRAZILIAN PRODUCTION

DANIEL K.N. JOHNSON*

Colorado College, U.S.

Small firms are qualitatively different than large firms with respect to technology acquisition. As such, liberalization of technology flows in newly industrialized nations may have two potential effects, possibly felt differentially by small firms and large firms. First, technology flows may replace domestic research with cheaper imported foreign research. Second, they may combine with domestic research to improve local economic growth. This paper uses a unique firm-level dataset, modelling the choice between R&D expenditures and technology licensing behaviour in Brazil, explicitly considering corner solutions. Extending the results found elsewhere in the literature, econometric estimation of simultaneous input demand for capital, labor and both types of technology acquisition reveals that while very small firms see technology licensing and R&D as contemporaneous substitutes, firms of moderate to large size treat them as complements. Each firm's licensing experience also plays a key role in the decision.

Keywords: Brazil, Patent, Licensing, Technology Acquisition, Kuhn-Tucker
JEL Classification: O3, O1, L2

1. INTRODUCTION

The primary question that this paper addresses 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 technological dependence (more licensing in the future, i.e. inter-temporal complementarity between R&D and licensing) or independence (less future licensing or even R&D instead, i.e., inter-temporal

* Thanks to anonymous reviewers of this journal, to R.E. Evenson, T.N. Srinivasan, J.O. Lanjouw, to faculty and students at Yale University, Wellesley College, Universidade de Sao Paulo, and the Instituto Getulio Vargas in Rio de Janeiro for comments on earlier drafts. Financial support was provided by the Sasakawa World Leaders Fellowship, the John Enders Research Fellowship, and the Coca-Cola World Fund. The author is naturally responsible for any remaining errors.

substitutability). Since the answer to that question clearly depends upon the size of the firm, this analysis uses a firm-level dataset to clarify and extend the existing literature.

The question of R&D/licensing complementarity is critical for all firms deciding on a method for technology acquisition, and is commonly referred to as the "insourcing versus outsourcing" debate and is an important public policy issue for less developed nations in particular, who express concern about technological dependence and capital outflows. 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.

Beginning in 1962, any contract in Brazil concerning a piece of intellectual property, whether of foreign or domestic origin, was required to have a government license (Johnson, 2002). Concerns in the 1970's about excessive payments abroad led to stricter legislation about technology licensing, including laws dictating remuneration in accordance with instructions by the Central Bank and Instituto Nacional da Propriedade Industrial (INPI). By 1975, a maze of contract guidelines existed, including rules for ceilings on both upfront and royalty payments. Contracts could not require the purchase of raw materials or components from the licensor, could not limit or hinder the research and technological development policy or activities of the licensee, and passed the rights to all improvements introduced by the user to the licensee. All of these requirements were aimed at fostering technological independence and domestic R&D capability (or to discourage cheating on the dictated payment ceilings).

Starting in 1983, the policy stance changed, and the Brazilian government began to see for itself a role as facilitator of technology flows, with INPI promoting domestic transfers of technology, and other legislation promoting domestic innovation and R&D. By 1988, revitalized movements were also focused on the liberalization of international technology flows, with initial efforts aimed mainly at streamlining the application process required for a contract's approval. By 1990, tax concessions were granted for payments for foreign technology, and forty PDTI's (Programas de Desenvolvimento Tecnologico Industrial, agencies designed to foster technology flows between industries and between regions) had been instituted. In 1993, legislation restricted INPI to the formal examination of contracts with no power to refuse licenses, stating 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. In fact, INPI has a new mandate to render support services to Brazilian firms interested in the acquisition of new technology, foreign or domestic.

It is obviously important to evaluate the potential reactions of domestic R&D to these policy changes, and empirical evidence on the issue indicates that R&D and technology licensing can be used as complements. Industry-level studies for India (Katrak 1985; Siddharthan, 1988; and Deolalikar and Evenson, 1989 for example), Canada (Mohnen and Lepine, 1991), and foreign branches of American firms

(Blomstrom et al., 1994) show that industries which perform more of their own R&D also license more technology. However, it is unclear that this evidence points to much more than a distinction between those sectors active in technology acquisition and other less active sectors.

Firm-level data reveal an important set of issues for consideration during technology flow liberalization. Braga and Willmore (1991) confirmed that Brazilian firms which license technology were more likely to also have an R&D unit, but Dahab's survey (1992) found that small Brazilian firms tended not only to perform less R&D but also to use it differently than large firms. Small firms in her sample used licensed technology for imitation and production rather than as inspiration for future innovations. There is also evidence of a “lock-in” effect to foreign technology, a result one can infer from the Brazilian survey data of Christensen and Rocha (1988), where the fixed costs of initial adoption are high enough to preclude switching to technologies with lower marginal costs later. Executives of chemical firms ranked the attributes of available foreign and domestic technology, showing a substantial preference for domestic sources which are more suited to the needs of the firm, but also revealed that most firms used foreign technology in spite of their current preferences, due to purchase choices made long ago.

To incorporate the issues of firm size and history with licensed technology, this work builds upon Fikkert (1994), who estimated simultaneous demand functions for R&D and technology purchases (licensing) using Indian firm-level data from the 1970’s. 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. Interestingly, his results partially contradict the industry-level consensus, declaring R&D and technology licensing to be substitutes, but with increases in licensing exercising very small dampening effects on domestic R&D. In fact, the spillover effects of foreign R&D 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 greater access to (i.e., lower costs of) foreign technology, perhaps due to better access to financing or experience still present in the firm.

The following section describes the unique new dataset gathered for this research, and the third section outlines a microeconomic model created to explain the data, a model which extends Fikkert's work through the use of Kuhn-Tucker conditions for corner solutions and four simultaneous input choice variables. The fourth section presents results of the model's estimation and interpretation before the conclusions are summarized in the final section.

2. DATA

2.1. Sample Construction

With the co-operation of the Instituto Nacional da Propriedade Industrial (INPI) and the Ministério da Fazenda (MF), a unique dataset for the study of Brazilian firm-level activity in R&D and technology licensing was compiled for this research. While tax records are confidential, INPI agreed to match their records of technology (the DIRTEC dataset) contracts with firm-level tax records from MF (the CADEC dataset). Unfortunately, access was granted to only a small corner of CADEC, and retrieval of variables was done by hand. Therefore, a sampling strategy ensures representation of a) firms with a history of technology licensing and b) firms of different sizes, although the vast majority of firms in the general population do not have a history of licensing.

First, a random sample of firms from the DIRTEC list was constructed (roughly every sixth firm listed from the initial list of over 5,900 firms) and all 1988-90 CADEC documents were scanned for their data. Since many licensee firms have not survived the interval since their license, only 443 firms with license histories were uncovered by this sample in the 1988-90 period. It is assumed that no bias in firm size was introduced into the sample by this selection process, and that the firms from the DIRTEC list located in CADEC reflect the underlying distribution of CADEC firms in every way (except for their known licensing history), particularly in size. While survivor bias would jeopardize the results, we know of no way to test whether it is a problem here.

In addition, a random sample from the 1990 CADEC database stratified by liquid receipts as an indicator of size was added. Thirty-four firms were randomly selected from each of eight ranges, but since most small firms in 1990 were not in the CADEC set in 1988, additional groups of 34 firms for the two smallest categories in 1988 were chosen and traced forward to 1990 wherever possible. The goal was to ensure representation of small firms in all years, and since small firms with three years of data in the CADEC database were rare, selection included other small firms to augment the sample. This random sample stratified by size was then properly weighted to reflect the true underlying distribution of the CADEC database firms which, as a tax database, consists of larger firms in the economy.

The sample database therefore has 1,877 observations, incorporating data for 783 firms (including 340 with no history of technology licensing) in one or more years. As Table 1 indicates, even the combined sample has a sparse collection of firms from firms performing R&D or licensing. Without the subsample based on licensing history, all further analysis would be crippled. The combined weighted sample represents the size distribution of firms in the CADEC database, but has proportionately many more firms with a licensing history. By construction, all sizes of firm have an equally inflated probability of licensing history in the sample, so estimation results are driven by the relationships between size, history and input choices, and not by sample selection.

The sample spans a wide variety of firms covering fifteen broad industries (primary, electrical, chemical, drugs/health, transport, metals, instruments/office equipment, other machinery, food, textiles, rubber/plastics, stone/glass, wood/paper, other manufactures and miscellaneous/services), but disaggregation is limited by the information provided by CADEC. Thus, definitions are determined by primary activity of the firm, as determined by Brazil’s MF, with one-quarter drawn from unknown, miscellaneous,

Table 1. Probabilities of a Sample Firm Licensing and R&D

	Licensing	R&D	Both
Small firm	0.009	0.018	0.000
Medium firm	0.029	0.011	0.000
Large firm	0.071	0.063	0.012
Sample average	0.043	0.035	0.005

service, or multiple-industry classifications. Estimations below are presented for the full sample and for the three-quarters of the sample for which manufacturing sectors can be identified.

If there is measurement error in the technology payment and R&D expenditure variables, technology payments can be expected to understate actual transaction value, while R&D expenditures will be 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 closely by the Central Bank, leaving no room for overstatement for tax purposes. They may even be understated if side payments were required between firms to procure technology which could not be purchased at state-regulated prices. R&D expenditures faced no such limit, and so can be expected (if anything) to overstate rather than understate.

Technology spillovers, or the knowledge one firm receives from research performed by another firm, have become an accepted part of the literature on technology (see Evenson and Johnson, 1997; Bernstein 1995; Eaton and Kortum, 1994; Fikkert 1994; Mohnen and Lepine, 1991; Griliches, 1990). Measurement of disembodied spillovers (pure knowledge or research, where no financial transaction occurs) raises several difficult issues, including the degree of relevance which foreign R&D has for Brazilian production. However, this paper leaves the exploration of that issue to Johnson (2002), and simply considers the total possible spillover pool as the sum of R&D performed in the industry in France, Germany, Japan, the United Kingdom and the United States. Averages of R&D over the three years preceding the observation year were used to avoid reporting problems in the published series and to allow time for technological spillovers to be felt in Brazil. Longer lags may be appropriate, but these data are adequate proxies due to the relatively small annual changes in R&D series.

2.2. Summary Statistics for Key Variables

Descriptive statistics for the main variables are presented in Table 2. All variables have been converted to constant September 1986 currency units (using the 'Indice de precos ao consumidor' for September of each year to approximate the middle of the fiscal year). Interest rates are from the International Financial Statistics Yearbook and wage data by industry are from annual household surveys (Pesquisas Nacional de Amostra de Domicilias).

Technology purchases (T) and R&D expenditures (R) are directly from CADEC tax forms. Labor (L) is the implicit hours of work hired, found as labor expenditures divided by the average monthly salary in the industry. Capital (K) is a residual measure, found as all non-labor, non-R&D, non-license expenditures divided by the annual interest rate (the price or opportunity cost of those expenditures). It broadly represents the physical quantity of inputs other than labor and technology obtained by the firm. Firm size (Z) is capital stock from tax forms. Licensing history (M) is the number of technology licenses signed by the firm between 1962 and 1987. The technology pool (P) is the number of technology licenses issued in the industry during the preceding five years, excluding those signed with the observation firm. The R&D spillover pool (S) is measured as R&D expenditures (reported by the Organisation for Economic Cooperation and Development in millions of constant 1990 US dollars), as performed by France, Germany, Japan, UK, and US. Since not all research performed elsewhere is relevant to the Brazilian industry, we followed Johnson and Evenson (2000) in measuring the share of patents from those source nations protected in Brazil, by industry, and attributed that protection share to research expenditures during the preceding five years. Training (N) is the share of total labor expenditures spent on training, as recorded by CADEC tax forms.

Table 2. Summary Statistics for Variables

Variable	Mean	Std. Dev.	Minimum	Maximum	Freq of zeroes
T (Tech purchases)	667	1.12×10^3	0.00	4.23×105	1,729
R (R&D spending)	1.90×10^3	4.42×10^4	0.00	1.81×10^6	1,781
L (Labor hours)	8.22×10^4	3.43×10^5	0.31	7.84×10^6	0
K (Physical capital and other inputs purchased)	167	4.93×10^3	3.06×10^{-4}	2.13×10^5	0
Z (Size, capital stock)	4.45×10^6	4.71×10^7	1.82	1.73×10^9	0
M (History, previous licenses)	6.53	22.9	0.00	428	705
P (Licensing pool)	502	805	0.00	2.35×10^3	344
S (Foreign R&D pool)	9.49×10^3	1.88×10^4	1.15×10^2	5.99×10^4	0
N (Training, share of labor expenditures)	7.15×10^{-3}	1.81×10^{-2}	0.00	2.53×10^{-1}	1,044
Total obs			1,877		

3. MICROECONOMIC MODEL

There are at least three explanations for the preponderance of zeroes in the technology purchase and R&D variables. First, the one-year tax 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, but firms this small probably do not spend much on product improvement or research so the omission is slight. Therefore R&D observations might be expected 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 an inability 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. The only bias would occur if small firms shifted purchases more or less than large firms do (Kleinknecht, 1987).

The third and mostly likely explanation is that the choices of zero R&D and/or zero technology license payments are the result of a rational and unconstrained choice by the firm, a corner solution in the typical production input-choice problem. In decisions regarding the purchase of technological inputs (R&D or licensing), other input choices are made concurrently, so the model allows the demand for R&D, technology licensing, labor and capital to be simultaneously determined. In addition, firm size is permitted to affect how much a firm pays for capital or labor, and how quickly the firm can adjust to changes in technology. The degree of training in the labor force may alter the speed of adjustment to new technology, but also impacts upon labor costs and the productivity of labor. A firm's history of previous licensing experience may affect how much it learns from new R&D or licensing, as well as how easily it can find new licenses. Disembodied spillovers augmenting the intellectual capital stock of the firm in combination with new technological acquisitions, and so may impact upon a firm's choices.

This model builds directly on the excellent work of Fikkert (1994), but endogenizes the factor choices of capital and labor, allowing for a flexible form of production function, and extends the analysis by explicitly including firm size and employee training variables. Firm size proves to be a particularly important addition, both on its own and in interaction terms with other variables. In fact, if Fikkert's model is used on the dataset here, his result holds (i.e., R&D and licensing are substitutes), while the extensions offer further insight. Our results are consistent with industry-level analyses as well, but clarify some important points.

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

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

is the knowledge stock at any given time t, where today's stock depends only on increments I for previous periods. The increment is really a set of new innovations (new applicable productive knowledge), and so will be represented as an "innovation production function" in expectation as

$$\begin{aligned} I_t = {} & a_R\bar{R}_t + a_T\bar{T}_t + a_M M_t + a_S S_t + a_{RM}\bar{R}_t M_t + a_{TM}\bar{T}_t M_t \\ & + a_{RS}\bar{R}_t S_t + a_{TS}\bar{T}_t S_t + a_{RT}\bar{R}_t T_t, \end{aligned} \tag{2}$$

where $\bar{R}$ is real R&D by the firm ("quantity of R&D", in a 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 previous experience 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. The experience variable M is included to capture effects associated with previous exposure to technology as well as benefits or costs which repeat licensees face. Spillovers have been widely acknowledged to play a role in the creation of new knowledge and are included here to test that fact and their specific interactions with other technology acquisition variables.

Technology increases expected output multiplicatively, so is either Hicks-neutral or can be approximated as such over a brief time period (i.e. three years of data). Assuming a CES production function with constant returns to scale, expected output can be written as

$$Y_t = W_t F_t = W_t(a_K \bar{K}_t^{\ \rho} + a_L[(1 + a_N N_t)\bar{L}_t]^{\rho})^{1/\rho}, \tag{3}$$

where F is the production function omitting technology, $W\bar{K}$ is the real capital input used in production ($K = p_K\bar{K}$), N is the proportion of labor costs devoted to training, and $\bar{L}$ is the real labor input used ($L = p_L\bar{L}$).

In the work which follows, the capital input is a residual category, including all inputs which do not qualify as labor, R&D or technology purchases. Therefore, the factors of production are now skill-adjusted labor and "capital". Training is expressed as a proportion of labor costs, and so acts as a proxy for the human capital stock of the employees, over and above pure labor inputs. Total sales are represented by Y_t, meaning that output prices are proxied by the technology level inherent in the product and therefore are subsumed into the W term during estimation.

Three new variables are introduced in the next equation (Z, N, and P), all to capture differences between firms and between industries. Firm size Z, measured as capital stock (alternatively sales, with no appreciable change in results), is included to permit large and small firms to react differently to input choices. Expenditures on training N distinguish firms with well-trained workforces. They may also be associated with more technical industries, but industry dummies will account for those differences. For example, some industries have a tradition of more licensing than others, by nature of their products and processes or for legal reasons. The technology pool variable P indicates the number of licenses signed in the industry in the five years prior to the observation year by other firms, as an indicator of the prevalence of licensing in the industry.

Assuming that firms maximize the expected present discounted value of future profit streams (or the present value of the firm) by choosing $\{\bar{R}_t, \bar{T}_t, \bar{K}_t, \bar{L}_t\}$ combinations, the choice problem is:

$$\max \pi_t = \mathrm{E}\left\{\sum_{t=0}^{\infty} \beta^t W_t \left(a_K \bar{K}_t{}^{\rho} + a_L[(1 + a_N N_t)\bar{L}_t]^{\rho}\right)^{\frac{1}{\rho}} - (p_R + u^R{}_t)\bar{R}_t - (p_T + g_t)\bar{T}_t - (p_K + \alpha_{KZ}(1/Z_t) + u^K{}_t)\bar{K}_t - (p_L + \alpha_{LN} N_t + \alpha_{LZ}(1/Z_t) + u^L{}_t)\bar{L}_t - f(X_t)]\right\}, \tag{4}$$

where

$$g_t = \alpha_M M_t + \alpha_P P_t + D_j + u_t{}^T, \tag{5}$$

$$f(X_t) = \varphi_1 X_t + \varphi_2 X_t{}^2, \tag{6}$$

$$X_t = \gamma_R \bar{R}_t + \gamma_T \bar{T}_t + \gamma_Z Z_t + \gamma_N N_t, \tag{7}$$

Z_t is an indicator of firm size so $(1/Z_t)$ is an indicator of firm “smallness”, N_t is training expenditures on labor force, P_t is the technology license pool, and D_j is the industry dummy.

Equation (4) uses E as the expectations operator, and as the discount factor, both of which apply to total revenues and costs in every period of the future. It is simply output (with the price of output standardized to unity) followed by five cost components.

The costs of R&D are the direct costs of searching for a technology, which the firm recognizes at the time of the decision. Included is a random term which the econometrician cannot observe, and which depends directly on the nature of the technology (i.e. how difficult it is to research this particular technology) but which is observed by the firm before input choices are made.

The search and transactions costs of obtaining a technology contract follow, and are captured by equation (5), where costs are dependent upon the licensing history of the firm (M_t), the pool of technology contracts available in the industry (P_t), an industry indicator (D_j), and a random error term u^T. Once again, the error term is observed by the firm when the decision is made, but not by the econometrician, since it depends on the specific nature of the technology (i.e. how difficult it is to license this technology). The error term is assumed independent of u^R.

The costs of capital (or the opportunity cost of “other inputs”) include the economy-wide p_K with some recognition of the smallness of the firm $(1/Z_t)$ and α_{kz} should be positive, since the indicator is the inverse of firm size and larger firms in general face lower interest rates or better credit terms. Also included is the random term u_K which is uncorrelated with other variables in the model, and is seen by the firm before input decisions are made.

Similarly, the direct cost of labor incorporates the industry's wage rate and a random component u_L, as well as the effects of training N_t, and firm smallness $(1/Z_t)$. The coefficient $\alpha_L N$ should be positive, and the hypothesis that smaller firms pay more for labor will be informally tested through the estimated sign of $\alpha_L Z$.

Adjustment to new technology is the last term in equation (4) and is modeled by equations (6) and (7), with quadratic adjustment costs dependent on the choice variables of R&D and technology purchases (or magnitude of the change in technology), as well as on the size of the firm and training of the labor force (or ability to cope with technological change).

Assume that the random terms are independent and identically distributed as

$$u_t^R \sim N(0, \sigma_R^2), \tag{8}$$

$$u_t^T \sim N(0, \sigma_T^2), \tag{9}$$

$$u_t^K \sim N(0, \sigma_K^2), \tag{10}$$

$$u_t^L \sim N(0, \sigma_L^2), \tag{11}$$

and are observed by the firm but not by the econometrician at the time input decisions are made. It is also important to assume that the error terms are uncorrelated and that they are bounded by $p_R + u_t^R > 0$ and $p_T + u_t^T > 0$ to ensure a well-defined maximization problem in (4).[1] Also assume that observational errors (and all other shocks unobserved by the econometrician but seen by the firms) are independent and identically normally distributed.

The full mathematical derivation of first-order conditions, along with the estimation technique, are described in the appendix and result in estimation of parameters for the production function (equation 3), input demand for R&D:

[1] Since technology prices are unobservable, it is impossible to test whether the boundary conditions are binding, even using estimated errors. If the variance of the error terms is small relative to technology prices, which will be assumed here, the boundary conditions will be irrelevant for all but extremely negative (and highly infrequent) errors. For readers uncomfortable with these assumptions, the same estimation results could be obtained with a completely non-stochastic model using estimation equations which treat the random terms as pure measurement error, uncorrelated between licensing and R&D and normally distributed with no boundary conditions on the error terms.

$$\bar{R} = b^R + b_T^R T + b_{TF}^R TF + b_Z^R Z + b_N^R N + b_{MF}^R MF + b_{SF}^R SF + b_F^R F + \varepsilon^R \tag{12}$$

and input demand for technology licensing:

$$\begin{aligned}\bar{T} = b^T + b_R^T R + b_{RF}^T RF + b_Z^T Z + b_N^T N + b_{MF}^T MF + b_{SF}^T SF + b_F^T F \\ + b_M^T M + b_P^T P + D_j^T + \varepsilon^T.\end{aligned} \tag{13}$$

4. RESULTS

Estimation was performed in two stages, first obtaining coefficients for the K and L equations, and then using those coefficients to estimate F in the subsequent estimation of the T and R equations. Thus, the results will be reported in two distinct blocks. While actual sales data could be used here, rather than relying on estimated sales, that alternative would use data unavailable to firms at the time of input choice.

Integrals were approximated using Gaussian quadrature of order 12, and FIML estimations used a combination of random search and gradient check routines. Standard tolerances determined convergence.

4.1. The Production Function: K and L Equations

Only selected results of estimation for the K and L first-order conditions (A.3) and (A.4) are presented in Table 3. Elasticities of substitution show capital and labor to be substitutes in all industries. The approximate skill-adjusted labor shares of total product implied by the estimates are also presented, varying between 60 and 90 percent in all industries with the exceptions of the primary, metals and service sectors. Metals is unexpectedly high, and services are unexpectedly low, but the primary sector result may be explained more by definition of the sectors than by innate differences. Labor-intensity may have been a criterion in assigning firms to the primary, food or wood sectors. Although not reported here, values of anwere consistently positive, indicating that trained labor does indeed add to the output value of a firms, and were especially productive in the services, drugs/health, food and plastics sectors.

Remembering that $1/Z$ is a measure of smallness of the firm, $\alpha_{KZ} > 0$ shows that capital costs are higher for small firms (as expected, if larger firms face better credit terms, for example) in almost every industry. Only two sectors, Stone/Glass and Miscellaneous Manufactures, show lower capital costs for small firms. Note that in Drugs/Health and Services, the effect of firm size is insignificantly different than zero.

More training of employees is associated with slightly lower costs ($\alpha_{LN} < 0$) in all sectors except primary industries, indicating that one highly-skilled worker can replace low-skill workers who would cost more to hire. The effects are significant particularly in the Chemicals, Metals, Machinery, Food, and Plastics sectors, but even there the size of the total effects is very small.

Small firms experience lower labor costs in all industries ($\alpha_{LZ} < 0$) but one, affecting labor costs very slightly in all cases. So there is support for the hypothesis that large firms consistently face higher labor costs, albeit with a small difference.

Table 3. Parameter estimates (and t-statistics) for K and L equations (equations A.3 and A.4)

	Implied Elasticity of Substitution	Implied Share of Labor in Output	Cost Effects of Small size (1/Z) and Training (N): Capital Costs	Labor Costs		R-squared by equation
			α_{KZ}	α_{LN}	α_{LZ}	
Primary	4.88	0.91	1.34	0.01	-0.01	K=0.39
			(0.4)	(0.8)	(2.5)	L=0.36
Electrical	1.71	0.69	0.37	-0.18	0.15	K=0.88
			(0.1)	(0.9)	(4.9)	L=0.94
Chemical	1.76	0.67	0.67	-0.01	-9.2e-4	K=0.52
			(0.3)	(2.6)	(0.7)	L=0.70
Drugs and	7.63	0.87	-0.01	-0.01	-7.8e-6	K=0.50
Health			(0.2)	(1.6)	(0.0)	L=0.68
Transportation	2.07	0.82	0.92	-6.7e-3	-2.1e-4	K=0.70
			(0.4)	(1.6)	(0.1)	L=0.82
Metals	1.74	0.91	0.86	-4.6e-3	-2.4e-3	K=0.95
			(0.5)	(1.8)	(2.7)	L=0.94
Instruments	1.99	0.67	0.05	-1.9e-3	-3.6e-4	K=0.70
			(0.2)	(0.3)	(0.2)	L=0.77
Machinery	1.97	0.72	0.83	-7.3e-3	-1.2e-3	K=0.48
			(0.5)	(2.7)	(1.3)	L=0.84
Food	4.57	0.77	0.87	-8.8e-3	-1.5e-3	K=0.54
			(0.5)	(9.0)	(1.3)	L=0.74
Textiles	4.76	0.66	1.15	-3.1e-3	-8.6e-4	K=0.55
			(0.6)	(1.2)	(0.8)	L=0.57
Plastic and	3.24	0.81	0.35	-0.01	-1.9e-3	K=0.66
Rubber			(0.1)	(2.1)	(1.3)	L=0.80
Stone and	4.09	0.69	-0.37	-7.2e-3	-3.8e-5	K=0.47
Glass			(0.1)	(1.0)	(0.2)	L=0.78
Wood and	1.65	0.73	0.03	-5.6e-3	-1.2e-5	K=0.41
Paper			(0.1)	(0.6)	(0.1)	L=0.82
Misc.	2.34	0.74	-0.36	-6.1e-3	-1.2e-4	K=0.69
Manufactures			(0.2)	(1.1)	(0.1)	L=0.94
Services	3.61	0.49	-1.7e-3	-6.4e-3	-9.5e-7	K=0.03
Unknown			(0.1)	(7.7)	(0.1)	L=0.11

Notes: t-statistics are in parentheses. "Pseudo" R-squared values are calculated as in the linear case, as the share of variation in K and L explained by the independent variables.

4.2. Technology Acquisition: The T and R Equations

Using the parameter estimates from the K and L equations, all of the variables necessary for estimation of the T and R equations can be constructed. For readability of the coefficients, size variables (F and Z) are in tens of thousands of units, while training (N), as above, is expressed as a percentage of labor costs. Table 4 gives results for the regression including all sectors but results are similar if only manufacturing industries (sectors 2 through 14) are considered. The three coefficients constrained in value by our cross-equation knowledge are indicated.

Table 4. Parameter estimates (and t-statistics) for T and R equations (equations A.11 and A.12)

Parameter from equation (A.11)	Effect on R&D expenditures of	Coefficient	(t-statistic)
b^R	Constant	0.53	(0.4)
b_T^R	Technology purchases (T)	-3.95***	(3.8)
b_{TF}^R	Technology purchases (T) interacted with est. sales (F)	1.91***	(2.8)
b_Z^R	Firm size (Z)	1.62**	(2.2)
b_N^R	Training of employees (N)	0.09	(0.2)
b_{MF}^R	Licensing history (M) interacted with est. sales (F)	-0.75**	(1.9)
b_{SF}^R	Foreign R&D spillovers (S) interacted with est. sales (F)	0.13	(0.5)
b_F^R	Estimated sales (F)	1.43**	(1.9)
Parameter from equation (A.12)	**Effect on technology purchases of**	**Coefficient**	**(t-statistic)**
b^T	Constant	0.61	(0.8)
b_R^T	R&D expenditures (R)	-0.25	(constraint)
b_{RF}^T	R&D expenditures (R) interacted with est. sales (F)	0.12	(constraint)
b_Z^T	Firm size (Z)	1.62	(constraint)
b_N^T	Training of employees (N)	0.09	(0.1)
b_{MF}^T	Licensing history (M) interacted with est. sales (F)	1.32*	(1.7)
b_{SF}^T	Foreign R&D spillovers (S) interacted with est. sales (F)	-0.06	(0.3)
b_F^T	Estimated sales (F)	2.29***	(2.8)
b_M^T	Licensing history (M)	-2.11**	(1.9)
b_P^T	Technology license pool (P)	-0.76***	(2.1)

Notes: t-statistics are in parentheses. * for 10% confidence, ** for 5% confidence, *** for 1% confidence interval. “Pseudo” R-squared values, calculated as in linear models, as the proportion of variation in the dependent variable accounted for by the independent variables, are 0.73 and 0.11 for the R and T equations respectively, with 1,877 observations. 15 industry-level dummy variables were included as dictated by the model, but are not reported here.

Note that while FIML estimates are consistent, a bootstrapping procedure was required to correct for the effects of the estimated regressor F in both equations. Bootstrapping used a Monte Carlo approximation, repeating estimation until estimates and standard errors converged (see Shao and Tu, 1995).

Explanation of the coefficients is complicated by the presence of the unobservable "prices" of R&D and technology purchases in the coefficient definitions, since the estimated coefficients offer only a partial view at the model's parameters. Analysis will therefore interpret the intuition behind the estimated coefficients before outlining implications for the "deep" structural parameters of the model.

The relationship between R&D and technology licensing is delicate to interpret. While the coefficient of technology purchases in the R&D equation (b_T^R) is negative, there is an interaction effect with production represented by b_{TF}^Rwhich is positive. Thus, while the two forms of technology acquisition are contemporaneous substitutes, larger firms (measured by F or sales) use them as complements. This result makes intuitive sense, suggesting that without a certain critical size, the acquisition of technology through licensing only acts as a substitute for own R&D. However, for firms large enough to support their own R&D department or hire personnel devoted to product and process improvement, there is a mutually reinforcing or complementary relationship between R&D and licensing. For firms without a scale sufficient to support this fixed cost, the choice is made in favor of the cheapest alternative, either R&D or licensing.

In fact, in this sample less than five percent of all firms experienced a negative total effect of technology purchasing on R&D (the total coefficient on licensing T being $b_T^R + b_{TF}^R F$ in the R&D equation). So the critical size in Brazil is quite low relative to the size of firms in this sample, resulting in predominantly complementary effects of licensing on R&D. However, since the sample reflects the size distribution of firms in the tax database CADEC, which emphasizes medium- to large-sized firms, a higher percentage of firms in the general population are experiencing a "total substitute" effect.

As expected, size has a positive effect on R&D ($b_Z^R > 0$), and the incorporation of the effects of estimated sales ($b_F^R > 0$) into a total size effect does not change that fact. While the Z and F variables are of course correlated, subsequent estimation omitting either variable showed no significant change in any of the coefficients.

Training of the labor force is not strongly associated with high R&D and technology licensing expenditures ($b_N^R \cong 0, b_N^T \cong 0$), where it appears equally insignificant for both manufacturing and service industries. So firms with well-trained workforces do not on average spend more on acquisition than other firms do.

Prior licensing is associated with less current R&D expenditures and less current licensing expenditures. Coefficients actually indicate a dampening effect on current licensing which disappears for larger firms ($b_M^T < 0, b_{MF}^T > 0$ respectively). Prior licensing thus allows smaller firms to spend less on future licensing and R&D than they would otherwise. This is not the result of front-loaded payments on licenses (with large lump sum fees and few royalty payments), because the history variable is defined as the number of previous licenses, not prior license payments. So it truly is more exposure to the licensing process, and not more early expenditures on licenses, that enables future licensing costs to fall. They spend less on licensing because they form connections with licensing firms which permit cheaper future contacts, and spend less on R&D because they learn about the technology during the license period and can perform more effective R&D afterwards. Large firms may see a smaller decrease in their licensing expenditures, because despite the cost savings, they are interested in maintaining licensing activity as a complement to their ongoing R&D.

Knowledge spillovers, or the presence of recent foreign R&D in the industry, have a small positive effect on domestic R&D and a negative impact on technology licensing expenditures, as evidenced by b_{SF}^{R} and b_{SF}^{T}. One possible explanation for this weak result is that spillovers encourage Brazilian firms to perform more R&D, but the presence of those same spillovers permits each of them to generate effective results while spending less, keeping the effect on R&D spending roughly zero.

A cyclical pattern of licensing is captured by the technology license pool variable P, which shows that after a large number of licenses are signed, fewer firms want to license and licensing expenditures by each firm decline. There is an obvious incentive to avoid the peaks, waiting until after each successive wave of licenses is signed to benefit from lower prices. However, there is an implicit cost faced in allowing competitors to develop new technology before you, so the “bunching-up” of technology acquisition is not altogether surprising.

4.3. Model’s “Deep” Structural Parameters

Information about the model’s “deep” structural parameters is drawn from the estimated coefficients and their definition in equations (A.7) and (A.8).

The signs of the constant terms b^R and b^T are consistent with positive first-order and negative second-order coefficients of adjustment costs ($\varphi_1 > 0$ and $\varphi_2 < 0$), meaning that there are concave costs of adjustment, with larger changes costing less per unit. This makes intuitive sense, and is a reason for lumpy technological changes, or lumpy investments in technology acquisition.

The signs of b_T^R, b_R^T, b_Z^R, and b_Z^T together imply that $\gamma_R, \gamma_T < 0 < \gamma_Z$. In other words, from equation (7), adjustment costs are increasing functions in the amount of R&D and technology licensing performed (or technological change occurring in the firm), but are decreasing in firm size. Larger firms are thus better equipped to deal with adjustments to new technology. Training of the labor force (b_N^R and b_N^T, and therefore γ_N) make no difference in the adjustment to new technology.

For R&D’s effects on increments to each firm’s knowledge (equation (2)), the signs of $b_F^R, b_{TF}^R, b_{MF}^R$, and b_{SF}^R indicate that $a_R > 0, a_{RT} < 0, a_{RM} > 0$ and $a_{RS} \cong 0$. So it appears that R&D adds to knowledge in each period through a pure effect ($a_R > 0$), and gives an added boost if the firm has licensed in the past ($a_{RM} > 0$). However, simultaneous licensing detracts from R&D productivity ($a_{RT} < 0$). The lesson appears to be that it takes time to assimilate the knowledge gained through licensing, and to translate it into more productive R&D. This is a reason to continue R&D and licensing in the same period, even if the simultaneous interaction term is not adding to the productivity of either today. Each activity adds independently to the intellectual capital of the firm, and over time a history of licensing adds even further to the productivity of R&D. An alternative (but related) explanation is that only firms which succeed at licensing repeat the experience. The two explanations are observationally equivalent, since the difference relies on the unobservable ability of a firm to benefit from licensing.

Similarly, for technology licensing, b_F^T, b_{MF}^T and b_{SF}^T imply that $a_T > 0, a_{TM} > 0$ and $a_{TS} \cong 0$. That is, technology licensing itself adds to the knowledge stock today, although it adds less if the firm has a history of licensing. This implies that licensing in its own right (not in interaction with R&D) offers the greatest gains early. Later gains, following from a history of licensing, come through their interaction with R&D. Disembodied knowledge spillovers from foreign R&D have no direct impact through licensing activity.

Finally, $\alpha_M < 0$ and $\alpha_P < 0$ are tied to the signs of b_M^T and b_P^T and. Tracing these parameters back to equation (5) suggests that a history of licensing reduces the costs of a current license (due to familiarity with the system, contacts with licensor firms, etc.) as does the size of the license pool (perhaps a larger pool gives more market power to potential licensees).

5. CONCLUSIONS

Some policy considerations have already been identified, but are worth summarizing here. The results of this paper have shown that at first glance, R&D and technology licensing are substitute methods of obtaining technology, but only the smallest firms see them as such. Instead, most larger firms use them as complements. In our sample, the minimal estimated negative effects of licensing on R&D were greatly overwhelmed by a positive interaction with size, making a significant complementary relationship. This primary result is consistent with previous literature, agreeing fundamentally with both firm-level and industry-level analyses, but points to an important new dynamic.

Furthermore, a history of licensing is associated with less current R&D and less licensing expenditure. However, larger firms may actually see more licensing expenditure with a history of licensing behind them. Firms which license continue to do so, but become familiar with the system and spend less on licensing with experience. Their experience permits them to spend less on the R&D they perform, but that same experience does not discourage firms from creating or continuing an R&D program. Large firms, who see R&D and licensing as complements, tend to continue and even increase their expenditures on both activities with experience.

Entrepreneurs might be justifiably worried about this result. Large firms may lobby aggressively for open-door technology policy, while small firms are split in their allegiances. Small firms that perform creative R&D may very well be the lone camp arguing against technology liberalization.

What effects can be expected from recent changes in Brazilian legislation designed to liberalize technology transfers? Easier access to foreign technology licenses will act as a stimulus to R&D for most firms, but may discourage R&D by some small firms. Over the long run, as firms obtain exposure to technology via licensing, the history variable indicates that more firms will license technology from abroad, and thus will be able to spend less on R&D. However, there are at least two reasons for hope that liberalization will not act as a depressant on technological change and growth.

First, inasmuch as cheaper access to technology translates into lower costs via cheaper acquisition of new technology and greater growth potential, a liberalizing policy shift may be effective at fostering economic progress. Lower total expenditures on technology acquisition can be seen as a beneficial cost reduction provided to small firms, and we have presented no evidence yet on whether the speed of technological change and growth is faster or slower using licensing or innovation.

Second, there is no obvious need for concern even about a slowdown in Brazilian domestic innovative activity, or about the danger of becoming dependent upon foreign technology. While analysis indicates that firms with a history of licensing continue to do so, it also indicates that their expenditures on licensing tend to decrease with experience. Licensing may be permitting Brazilian firms to continue their R&D programs with lower expenditures for the same outcome.

Critics may still be justified in their fears about the potentially dire effects of technology liberalization on Brazilian innovative activity. However, if the goals of R&D and technology licensing are the same, to create new intellectual capital, then a decision to promote one and/or the other should be based on their relative costs and benefits. Future work should evaluate the ability of each activity to achieve the desired end--- the creation and improvement of output, particularly during an era of electronic communication when the definition of tacit knowledge may have changed.

APPENDIX

To simplify the solution, assume that the firm is on a steady-state path for both its capital and labor inputs, or that production next period net of any technological change will be today's production scaled by some constant economy-wide rate of growth γ_F. Therefore $E(F_{t+1}) = \gamma_F F_t$, where E represents an expected future value at time t. This assumption is made to simplify the time dimension of the estimation problem, and is necessary due to data constraints.

The first-order conditions for maximization with respect to each choice variable, assuming[2] that $|\beta\gamma_F(1-\delta)| < 1$ and defining $\beta^* = \beta\gamma_F(1-\delta)/(1-\beta\gamma_F(1-\delta))$,

[2] This assumption guarantees a finite solution to the infinite horizon problem. It is a realistic assumption, since only the expected growth rate will exceed unity, and then will probably be less than 1.1 (indicating

are:

$$\pi_{\bar{R}} = -p_R - \varphi_1\gamma_R - 2\varphi_2\gamma_R(\gamma_R\bar{R} + \gamma_T\bar{T} + \gamma_Z Z + \gamma_N N) - u^R + \beta^*(a_R + a_{RM}M + a_{RS}S + a_{RT}\bar{T})F, \quad \text{(A.1)}$$

$$\pi_{\bar{T}} = -p_T - \varphi_1\gamma_T - 2\varphi_2\gamma_T(\gamma_R\bar{R} + \gamma_T\bar{T} + \gamma_Z Z + \gamma_N N) - \alpha_M M - \alpha_P P - D_j - u^T + \beta^*(a_R + a_{RM}M + a_{RS}S + a_{RT}\bar{R})F, \quad \text{(A.2)}$$

$$\pi_{\bar{K}} = WF^{1-\rho}\alpha_K\bar{K}^{\rho-1} - p_K - \alpha_{KZ}(1/Z) - u^K, \quad \text{(A.3)}$$

$$\pi_{\bar{L}} = WF^{1-\rho}\alpha_L[(1 + a_N N)\bar{L}]^{\rho-1} - p_L - \alpha_{LZ}(1/Z) - -a_{LN}N - u^L, \quad \text{(A.4)}$$

where the subscript t is implied for all variables.

Since $\bar{K}$ and $\bar{L}$ are assumed always to be chosen as interior solutions, equations (A.3) and (A.4) can be set equal to zero as first-order conditions and estimated. Dependent variables $\bar{R}$ and $\bar{T}$ do not enter into (A.3) and (A.4) except as lagged values in W, so these two equations can be estimated independently of the other two equations, where for any given period W can be decomposed into a firm-specific element and a time trend common to all firms. Estimation uses industry-specific time trends for W, implying that the knowledge stock available to each firm in an industry is the same within a given year. Longer time series would be required to relax this assumption and allow W to vary on a firm level. Estimation by nonlinear least squares using the ratio of (A.3) and (A.4) eliminates the W term but gives insignificantly different results.

Unlike $\bar{K}$ and $\bar{L}$, $\bar{R}$ and $\bar{T}$ are frequently chosen as zero values, so the Kuhn-Tucker conditions

$$\pi_{\bar{R}}\bar{R} = 0, \quad \text{(A.5)}$$

$$\pi_{\bar{T}}\bar{T} = 0, \quad \text{(A.6)}$$

where $\pi_{\bar{R}} \le 0, \bar{R} \ge 0$, $\pi_{\bar{T}} \le 0$, and $\bar{T} \ge 0$ are necessary first-order conditions. They give four cases to consider:

(a) $\bar{R} > 0$ and $\bar{T} > 0$,

(b) $\bar{R} > 0$ and $\bar{T} = 0$,

(c) $\bar{R} = 0$ and $\bar{T} > 0$, or

expected growth of ten percent economy-wide!). Without this assumption, there is no defined maximum, since the discount factors would allow explosive solutions to the problem.

(d) $\bar{R} = 0$ and $\bar{T} = 0$.

The equations which follow, distinguish between "real" inputs (and), and nominal inputs, so assume that prices are constant (an impossible assumption to test, but a realistic one considering the data are measured in constant terms.

Case (a) is the simplest, since $\bar{R} > 0 \; and \, \bar{T} > 0$ imply that $\pi_{\bar{R}} = 0$ and $\pi_{\bar{T}} = 0$, so input demand for R&D can be expressed in estimable form as

$$\bar{R} = b^R + b_T^R T + b_{TF}^R TF + b_Z^R Z + b_N^R N + b_{MF}^R MF + b_{SF}^R SF + b_F^R F + \varepsilon^R, \qquad \text{(A.7)}$$

where

$$\begin{aligned}
&b^R = -p_R(p_R + \varphi_1\gamma_R)/2\varphi_2\gamma_R^2 b_{MF}^R = \beta^* p_R a_{TS}\gamma_F/2\varphi_2\gamma_R^2,\\
&b_T^R = -\gamma_T p_R/\gamma_R p_T b_{SF}^R = \beta^* p_R a_{RS}\gamma_F/2\varphi_2\gamma_R^2,\\
&b_{TF}^R = \beta^* p_R a_{RT}\gamma_F/2\varphi_2\gamma_R^2 p_T b_F^R = \beta^* p_R a_R\gamma_F/2\varphi_2\gamma_R^2,\\
&b_Z^R = -p_R\gamma_Z/\gamma_R \varepsilon^R = -p_R u^R\gamma_F/2\varphi_2\gamma_R^2,\; b_N^R = -p_R\gamma_N/\gamma_R.
\end{aligned}$$

Input demand for licensing can be written similarly:

$$\begin{aligned}
\bar{T} = b^T + b_R^T R + b_{RF}^T RF + b_Z^T Z + b_N^T N + b_{MF}^T MF + b_{SF}^T SF + b_F^T F\\
+ b_M^T M + b_P^T P + D_j^T + \varepsilon^T,
\end{aligned} \qquad \text{(A.8)}$$

where

$$\begin{aligned}
&b^T = -p_T(p_T + \varphi_1\gamma_T)/2\varphi_2\gamma_T^2 b_{SF}^T = \beta^* p_R a_{RS}\gamma_F/2\varphi_2\gamma_T^2,\\
&b_R^T = -\gamma_R p_T/\gamma_T p_R b_F^T = \beta^* p_R a_R\gamma_F/2\varphi_2\gamma_T^2,\\
&b_{RF}^T = \beta^* p_T a_{RT}\gamma_F/2\varphi_2\gamma_T^2 p_R b_M^T = -\alpha_M p_T/2\varphi_2\gamma_T^2,\\
&b_Z^T = -p_T\gamma_Z/\gamma_T b_P^T = -\alpha_P p_T/2\varphi_2\gamma_T^2,\\
&b_N^T = -p_T\gamma_N/\gamma_T D_j^T = -p_T D_j/2\varphi_2\gamma_T^2,\\
&b_{MF}^T = \beta^* p_R a_{TS}\gamma_F/2\varphi_2\gamma_T^2 \varepsilon^T = -p_R u^T\gamma_F/2\varphi_2\gamma_T^2.
\end{aligned}$$

Estimation is simplified by duality conditions implying that $b_R^T = \frac{1}{b_T^R}, b_Z^T = \frac{b_Z^R b_N^T}{b_N^R}$, and $b_{RF}^T = (1/b_T^R)^2 b_{TF}^R$ must hold across both equations. Since they are implied by the model, these constraints on the coefficients are not tested during estimation.

For case (b), since $\bar{R} > 0$ so $\pi_{\bar{R}} = 0$, but $\bar{T} = 0$. Therefore the equations for input demand are

$$\bar{R} = b^R + b_Z^R Z + b_N^R N + b_{MF}^R MF + b_{SF}^R SF + b_F^R F + \varepsilon^R, \qquad \text{(A.9)}$$

$$\begin{aligned}
\bar{T} = 0 = b^T + b_R^T R + b_{RF}^T RF + b_Z^T Z + b_N^T N + b_{MF}^T MF + b_{SF}^T SF + b_F^T F\\
+ b_M^T M + b_P^T P + D_j^T + \varepsilon^T,
\end{aligned} \qquad \text{(A.10)}$$

with coefficients defined as above. Case (c) is symmetric, since it represents all observations with $\bar{R} = 0$ but $\bar{T} > 0$:

$$\bar{R} = 0 = b^R + b_T^R T + b_{TF}^R TF + b_Z^R Z + b_N^R N + b_{MF}^R MF + b_{SF}^R SF + b_F^R F + \varepsilon^R, \quad \text{(A.11)}$$

$$\bar{T} = b^T + b_Z^T Z + b_N^T N + b_{MF}^T MF + b_{SF}^T SF + b_F^T F + b_M^T M + b_P^T P + D_j^T + \varepsilon^T, \quad \text{(A.12)}$$

Case (d) has observations with two corner choices, and therefore uses:

$$\bar{R} = 0 = b^R + b_Z^R Z + b_N^R N + b_{MF}^R MF + b_{SF}^R SF + b_F^R F + \varepsilon^R, \quad \text{(A.13)}$$

$$\bar{T} = 0 = b^T + b_Z^T Z + b_N^T N + b_{MF}^T MF + b_{SF}^T SF + b_F^T F + b_M^T M + b_P^T P + D_j^T + \varepsilon^T. \quad \text{(A.14)}$$

Now to form a likelihood function for the R and T demand equations, recognize that

$$\Pr(R_{it}, T_{it}) = |J| \cdot \Pr(\varepsilon_{it}^R, \varepsilon_{it}^T), \quad \text{(A.15)}$$

where $|J| = \begin{vmatrix} \partial\varepsilon_{it}^R/\partial R & \partial\varepsilon_{it}^R/\partial T \\ \partial\varepsilon_{it}^T/\partial R & \partial\varepsilon_{it}^T/\partial T \end{vmatrix}$ or $\begin{vmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{vmatrix}$,

so the determinant of the Jacobian is required for all four possible cases. For case (a), using equations (A.7) and (A.8),

$$|J_A| = \begin{vmatrix} 1 & b_T^R + b_{TF}^R F_{t+1} \\ b_R^T + b_{RF}^T F_{t+1} & 1 \end{vmatrix} = 1 - (b_T^R + b_{TF}^R F_{t+1})(b_R^T + b_{RF}^T F_{t+1}). \quad \text{(A.16)}$$

For cases (b), (c) and (d), T does not enter into the R equation and R does not appear in the T equation. This means that $J_{12} = J_{21} = 0$ for these cases, but their diagonal elements are the same as those of the J_A matrix, meaning that $|J_B||J_C||J_D| = 1$. Therefore, to assure positive likelihood values (i.e. existence of a solution), the coefficients need only be constrained so that $|J_A| > 0$.

Finally, in forming the likelihood function, notice that the last three cases are integrated only over those ranges for which the Kuhn-Tucker conditions are met for maximization (namely where the first derivative of the objective function is non-positive). Thus the likelihood function for the T and R equations jointly is

$$L(R,T) = \prod_{i=1}^{nA} |J_A| f(\varepsilon^R, \varepsilon^T) \cdot \prod_{i=1}^{nD} \int_{-\infty}^{\hat{T}^B} f(\varepsilon^R, \varepsilon^T) d\varepsilon^T \cdot \prod_{i=1}^{nC} \int_{-\infty}^{\hat{R}^C} f(\varepsilon^R, \varepsilon^T) d\varepsilon^R \cdot \prod_{i=1}^{nD} \int_{-\infty}^{\hat{T}^D} \int_{-\infty}^{\hat{R}^D} f(\varepsilon^R, \varepsilon^T) d\varepsilon^R d\varepsilon^T, \quad \text{(A.17)}$$

where

$$\begin{aligned}
\hat{T}^B &= -(b^T + b_R^T R + b_{RF}^T RF + b_Z^T Z + b_N^T N + b_{MF}^T MF + b_{SF}^T SF + b_F^T F \\
&\quad + b_M^T M + b_P^T P + D_j^T), \\
\hat{R}^C &= -(b^R + b_T^R T + b_{TF}^R TF + b_Z^R Z + b_N^R N + b_{MF}^R MF + b_{SF}^R SF + b_F^R F), \\
\hat{T}^D &= -(b^T + b_Z^T Z + b_N^T N + b_{MF}^T MF + b_{SF}^T SF + b_F^T F + b_M^T M + b_P^T P + D_j^T), \\
\hat{R}^D &= -(b^R + b_Z^R Z + b_N^R N + b_{MF}^R MF + b_{SF}^R SF + b_F^R F),
\end{aligned}$$

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 (8), (9), and (A.7) through (A.14), the error terms are independent and distributed as

$$\varepsilon^R \sim N\left(0, \sigma_R^2 \left[\frac{p_R \gamma_F}{2\varphi_2 \gamma_R^2}\right]^2\right) = N(0, \sigma_{\varepsilon R}^2), \quad \text{(A.18)}$$

$$\varepsilon^T \sim N\left(0, \sigma_T^2 \left[\frac{p_T \gamma_F}{2\varphi_2 \gamma_T^2}\right]^2\right) = N(0, \sigma_{\varepsilon T}^2). \quad \text{(A.19)}$$

REFERENCES

Bernstein, J.I. (1995), "Interindustry R&D Spillovers, Electrical and Electronic Products: The Canadian Case," Unpublished working paper at Carleton University.

Blomstrom, M., A. Kokko, and M. Zejan (1994), "Host Country Competition, Labor Skills and Technology Transfer by Multinationals," *Weltwirtschaftliches Archiv*, 130(3), 521-533.

Braga, H. and L.Willmore (1991), "Technological Imports and Technological Effort: An Analysis of their Determinants in Brazilian Firms," *Journal of Industrial Economics*, 34(4), 421-432.

Christensen, C.H., and A. Rocha (1988), "Perceptions of Brazilian and Foreign Technology," *European Journal of Marketing,* 22(1), 5-16.

Dahab, S. (1992), "The Agricultural Machinery and Implement Industry in Brazil: Its Historical Development and Inventive Activity," Yale doctoral dissertation.

Deolalikar, A.B., and R.E. Evenson (1989), "Technology Production and Technology Purchase in Indian Industry: An Econometric Analysis," *Review of Economics and Statistics*, 687-692.

Eaton, J., and S. Kortum (1994), "International Patenting and Technology Diffusion," Unpublished working paper dated July.

Estache, A. (1990), "Brazil: Issues in the Design of Intellectual Property Rights," Internal Discussion Paper, Report #IDP-089, World Bank.

Evenson, R.E. and D. Johnson (1997), "Invention-Innovation Input-Output Measures," *Economic Systems Research*, 9(2), 149-160.

Fikkert, B. (1994), "An Open or Closed Technology Policy?: India's Regulation of Technology Licenses, Foreign Direct Investment and Intellectual Property," Yale doctoral dissertation.

Fundacao Getulio Vargas (1989, 1990, 1992), Conjuntura Economica. Instituto Brasileiro de Economia. Fundacao Instituto Brasileiro de Geografia e Estatistica. Anuario Estatistico do Brasil, 1987, 1991, 1993, 1995. Pesquisa Nacional por Amostra de Domicilios, 1988, 1989, 1990. Manual do Entrevistador and datasets prepared by the Diretoria de Informatica.

Griliches, Z. (1990), "Patent Statistics as Economic Indicators: A Survey Part I," NBER Working Paper 3301.

Instituto Nacional da Propriedade Industrial (1971, 1975, 1991, 1992, 1993, and 1996), Legislation including , Lei 5772/71, Ato Normativa 015/75, Presidencia Instrucao Normativa 001/91, Resolucao 022/91, Presidencia Resolucaos 034/92, 035/92, Presidencia Atos Normativos 115/93 and 116/93, and Lei No. 9279/96 Propriedade Industrial (14 May 1996), Rio de Janeiro.

Johnson, D.K.N. (2002), "Learning-by-Licensing: R&D and Technology Licensing in Brazilian Invention," *Economics of Innovation and New Technology*, 11(3), 163-177.

Johnson, D.K.N., and R.E. Evenons (2000), "How Far Away Is Africa? Technological Spillovers to Agriculture and Productivity," *American Journal of Agricultural Economics*, 82(3), 743-749.

Katrak, H. (1985), "Imported Technology, Enterprise Size and R&D in a Newly Industrializing Country: The Indian Experience," *Oxford Bulletin of Economics and Statistics*, 47(1), 213-229.

Kleinknecht, A. (1987). *Innovation patterns in crisis and prosperity: Schumpeter's long cycle reconsidered*, St. Martin's Press.

Ministerio da Fazenda, Secretaria da Receita Federal do Brasil (1988, 1989, 1990). Imposto de Renda Pessoa Juridica: Declaracao de Rendimentos. Formulario 1 and Anexo A for each year.

Mohnen, P.A., and N. Lepine (1991), "R&D, R&D Spillovers and Payments for Technology: Canadian Evidence," *Structural Change and Economic Dynamics*, 2(1), 213-228.

Organization for Economic Co-operation and Development (1995), *Basic Science and Technology Statistics*.

Programa de Apoio a Capacitacao Tecnologica da Industria [PACTI] (1996), Linhas de Financiamento para Capacitacao Tecnologica. Apoio a Capacitacao Technolgica Series, Financiadora de Estudos e Projetos (FINEP), Rio de Janeiro.

Shao, J. and D. Tu (1995), *The Jackknife and the Bootstrap*, Springer-Verlag Press, New York.

Siddarthan, N.S. (1988), "In-house R&D, Imported Technology and Firm Size: Lessons from Indian Experience," *Developing Economies*, 26, 212-221.

Mailing Address: Department of Economics and Business, 14 E Cache La Poudre, Colorado Springs, CO 80903, USA. Email: djohnson@ColoradoCollege.edu.

Received August 21, 2015, Revised March 16, 2016, Accepted July 25, 2016.