A Test for R&D Complementarities in Bio-Pharmaceutical and Software Industries Using R&D Tax Price Changes

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Abstract
Firms fund R&D to generate commercializable innovations and to increase learning, i.e. the firm's ability to understand and absorb knowledge from elsewhere. This dual role and opposed incentive structure of internal R&D creates a significant question for both theory and R&D policy: Is internal R&D a complement or substitute for external R&D? In theory, ignoring the learning aspects, the ability of firms to learn from external sources implies that relying on external R&D is an alternative to doing R&D in-house—a substitute. Yet without in-house learning, the firm might not be able to understand and exploit that external information—a complement. Despite the large volume of literature related to R&D incentives and to absorptive capacity, we are unaware of any research that empirically tests for the complementarity or substitutability of the two types of R&D expenditures.

We first develop a model and novel technique for empirically estimating R&D substitution elasticities. We then implement the model empirically, focusing on the bio-pharmaceutical and software industries, which in recent years have been particularly dynamic and technically complex and also particularly commercially dependent on basic science—where the positive absorptive capacity incentives, R&D complementarity, might be expected to be particularly strong. These industries are concentrated in California and Massachusetts, and we focus on firms in these two states. In California, the tax credit rates changed differently over time for the two types of R&D, changing the effective prices of R&D differently and creating a natural experiment.

Combined with firm-level qualification thresholds, the effective tax prices for the two different R&D types differ from type to type, firm to firm, state to state, and year to year. This allows us to examine whether firms increased total research expenditure in response to state-level R&D tax credit rate increases, as well as to consider changes in the composition of firms' R&D budgets between in-house R&D and external basic research when the relative tax prices of each category of research changes. We find evidence of a substitute relationship.

JEL Classification: O31, O38, L65, L86
Keywords: R&D; Absorptive capacity; Tax credit; R&D substitution; Technology policy

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1. Introduction.

Firms fund R&D to generate commercializable innovations and also to increase learning, i.e. the firm's ability to understand and absorb knowledge from elsewhere. The recognition of these second, learning-enhancing aspects of R&D has spawned a vast literature on the competitive, strategic, organizational, inter-organizational, industry structure, and national-innovation-systemic implications of absorptive capacity (e.g. Cohen & Levinthal, 1990, Rosenberg, 1990, Teece & Pisano, 1994, Mowery & Oxley, 1995, Cockburn & Henderson, 1998, van den Bosch, van Vijk and Volberda, 2003). One implication is that the disincentives for R&D investment stemming from the spillover characteristics of information (Nelson, 1959, Arrow, 1962, Griliches, 1979, Romer, 1990) may be overcome by the positive incentives for creating absorptive capacity.

This dual role and opposed incentive structure of internal R&D creates a significant question for both theory and R&D policy: Is internal R&D a complement or substitute for external R&D? (See David, Hall & Toole, 2000, for a summary of the conflicting evidence and a critique of research methodology in this area). Addressing the theoretical context and policy issues in turn, first in theory, ignoring the learning aspects, the ability of firms to learn from external sources implies that relying on external R&D is an alternative to doing R&D in-house—a substitute. Yet without in-house learning, the firm might not be able to understand, absorb and exploit that external information—a complement. This theoretic duality is a central feature, for example, in the rapidly expanding literature on inter-organizational learning (Lane and Lubatkin, 1998). The learning incentive may be particularly important in fast-moving, technically complex, multi-disciplinary sectors. This complementary relationship between in-house R&D and the effectiveness of learning through connections with external sources has, in fact, been suggested, specifically for bio-pharmaceutical industries by Nicholls-Nixon (1993), Lane and Lubatkin (1998) and Cockburn and Henderson (1998).

Moving, second, to the policy relevance of the question, the role of basic R&D in firm productivity and economic growth is well understood (Solow, 1957, Scherer, 1982, Griliches 1986, Mansfield 1980, 1981) and the spillover R&D disincentive problem drives much R&D policymaking (see Watkins 1991, Jaffe, 1996, and Tassey, 1997 for overviews of this literature). Clarifying the direction of the relationship is important for designing R&D policies such as R&D grants, subsidies and tax incentives because such policies often treat different types of R&D differently. For example, the federal and many U.S. state governments offer corporate income tax credits on qualified research expenditure (QRE) and external "basic research" payments exceeding certain threshold levels. Qualified research expenditure primarily consists of in-house research expenditures for new product and process development, excluding items such as market research or existing product modifications. For tax purposes, external "basic research" is comprised of firms' payments to colleges, universities and other qualified, not-for-profit research organizations under a written contract. Both credits are incremental; they are designed to reward firms for increasing marginal investments in R&D. Consistent with the spillover R&D disincentive theory, the policy goal is to induce firms to spend more on R&D than they would in the absence of the credit.

Although the federal research and experimentation incentive provides the same rate of credit (20%) for both forms of research, several states provide a significantly higher credit rate for investments in basic research. For example, in 2002 California's basic research credit was 24% with a QRE rate of 15%; in Massachusetts the basic research and QRE rates were 15% and 10%, respectively (CCH, 2003). Offering a higher credit rate for basic research suggests state-level policymakers want to lower firms' tax-price of industry-sponsored university research to encourage firms to increase investment in basic science. However, it may not have been their intention for firms to increase industry-sponsored university research by decreasing in-house R&D or reducing inter-firm collaboration—substitution of external for internal R&D in response to relative tax prices.

Another line of research in this area focuses on the composition of firms' R&D investment. For example, Mansfield (1981) noted that consideration of the composition of R&D, and not just attention to the size of research expenditure, is an important aspect of research policy evaluation. However, many of these works utilize different definitions of basic research. For example, Cassiman et al. (2001) define basic research as the activities and investments of firms that allow them to absorb external information and knowledge. Similarly, Cassiman and Veugelers (1998) consider the complementarity of internal and external R&D across a variety of firm and industry dimensions. However, the basis for defining research type rests on firms' intentions, not on the NSF or IRS guidelines.

The literature's focus on inter-organizational learning and research expenditure composition in recent years most likely stems from a change in firms' observed research investment strategies and relationships. Firms no longer rely exclusively on in-house capability for applied or basic research investment (Hamel and Prahalad, 1994). Some reasons behind this trend are the rapid pace of technological change (Teece, 1986, Bettis and Hitt, 1995), employment contracts, market conditions and regulatory constraints (Hamel and Prahalad, 1994). External R&D occurs through collaboration with competing firms, research organizations, government laboratories, industry research organizations and universities (Watkins, 1991, Santoro and Chakrabarti, 2002). The fraction of R&D devoted to external activities and the partner chosen is related to firm size. Small firms are focused on survival (Steele, 1989); therefore, the external financing of university research tends to be targeted toward their core business areas (Santoro and Chakrabarti, 2002). In the case of large firms, a new form of relationship has developed, whereby university spin-off ventures act as intermediaries with large firms seeking to contract research (Pavitt, 2001).

Despite this large volume of literature related to R&D incentives, absorptive capacity and inter-organizational learning, we are unaware of any research that empirically tests for the complementarity or substitutability of internal and external R&D. Specifically absent is consideration of the complementarity and substitutability of firms' support of basic research performed by universities and their in-house research investment. We first develop a model and novel technique for empirically estimating R&D substitution elasticities. Empirically, we focus on the bio-pharmaceutical and software industries, which in recent years have been particularly dynamic and technically complex and also particularly commercially dependent on basic science—where the positive absorptive capacity incentives, R&D complementarity, might be expected to be particularly strong. These industries are concentrated in California and Massachusetts, and we focus on firms in these two states.

The R&D tax credit tax credit rates changed differently over time for the two types of R&D, creating a natural experiment. Effective in 1997, California doubled the tax credit rate available to basic research (12% to 24%) and increased the rate on QRE nearly 50% (8% to 11% and 12 % in 1999). In contrast, Massachusetts' tax credit rates were constant during this period. The differences between the credit rates across the categories of R&D, the variation in credit rates pre- and post-1997 and across states allow us to examine whether firms increase total research expenditure in response to state-level R&D tax credit rate increases. We also consider how the composition of firms' R&D budgets may be affected when the relative prices of each category of research changes. We find a substitute relationship between in-house and external basic research expenditures.

The paper is organized as follows. Section 2 develops the model and econometric specification. The third section describes the data and variable estimation methodology. Section 4 provides the results and policy implications.

2. The Model

Our model combines and extends those used by Hines (1991, 1993) and Hall and Wosinka (1999). We investigate not only the relationship between R&D tax credits and R&D expenditures, as they did, but also include two different types of R&D expenditures: in-house R&D and externally contracted R&D. Tax policies treat these two types of R&D expenses differently, and in California the credit rates changed differently for each type. Moreover, whether a firm qualifies for credits depends on its individual situation. So, the effective tax prices for the two different R&D types differ from type to type, firm to firm, state to state, and year to year. We leverage that variation to investigate not only whether R&D tax credits are associated with higher R&D spending, but also to explore whether firms treat contact R&D as a substitute or a complement to in-house R&D. Section 2.1 develops the first-order profit maximization conditions for firms facing various forms or state and federal corporate taxes and tax credits. Then, Section 2.2 describes the econometric specification that enables us to empirically test for R&D input complementarity or substitutability.

2.1. Profit Model with Taxation and Input Tax Credits.

A firm with sales revenue (S), in house R&D spending (X_H), external contract R&D spending (X_C) and non-R&D expenditures (X_I) faces a before-tax profit function

$$\Pi = S - (X_H + X_C + X_I).$$

If the firm is located in a state with a corporate tax rate τ_{in}, and sells all its output in that single state, the profit function (before federal-tax) becomes

$$\Pi = [S - (X_H + X_C + X_I)](1 - \tau_{in}).$$

If the firm also has sales in other states, with an average tax rate of τ_{out}, and the fraction of its in-state sales for tax purposes is α, then the (before federal tax) profit is:

$$\Pi = \alpha[S - (X_H + X_C + X_I)](1 - \tau_{in}) + (1 - \alpha)[S - (X_H + X_C + X_I)](1 - \tau_{out}).$$

Because the model soon becomes somewhat visually unwieldy, it is helpful to combine the total input costs as

$$(X_H + X_C + X_I) = \Sigma_i X_i \qquad \text{for } i = H, C, I.$$

Suppose the state allows tax credits for the various inputs X_i. Tax credits are generally allowed only on incremental spending on Xi above some base level (B_i), and at the state level are generally only allowed on that fraction (ω_i) of that input's spending done in-state. If the state has a tax credit rate (γ_i) for each input, the firm's (before federal tax) profit is

$$\Pi = [\alpha(S - \Sigma_i X_i) + \Sigma_i \gamma_i (\omega_i X_i - B_i)](1 - \tau_{in}) + (1 - \alpha)(S - \Sigma_i X_i)(1 - \tau_{out}) \quad \text{for } i = H, C, I.$$

Including now the federal corporate tax rate (τ_{fed}), the after tax profits (before federal tax credits) are

$$\Pi = \left\{[\alpha(S - \Sigma_i X_i) + \Sigma_i \gamma_i(\omega_i X_i - B_i)](1 - \tau_{in}) + (1 - \alpha)(S - \Sigma_i X_i)(1 - \tau_{out})\right\}(1 - \tau_{fed}).$$

If there are a federal tax credit rates (ρ_i) on the U.S. fraction (υ_i) of incremental spending on inputs above some federal base (F_i), the firm faces after tax profits, including credits of

$$\text{(1)} \qquad \Pi = \left\{[\alpha(S - \Sigma_i X_i) + \Sigma_i(\gamma_i(\omega_i X_i - B_i))](1 - \tau_{in}) + (1 - \alpha)(S - \Sigma_i X_i)(1 - \tau_{out}) + \Sigma_i(\rho_i(\upsilon_i X_i - F_i))\right\}(1 - \tau_{fed}).$$

Rewriting (1),

$$\Pi = \left\{S[\alpha(1 - \tau_{in}) + (1 - \alpha)(1 - \tau_{out})] - \Sigma_i X_i[\alpha(1 - \tau_{in}) + (1 - \alpha)(1 - \tau_{out})] + \Sigma_i[\gamma_i(\omega_i X_i - B_i)(1 - \tau_{in})] + \Sigma_i(\rho_i(\upsilon_i X_i - F_i))\right\}(1 - \tau_{fed}).$$

Further rearranging,

$$\Pi = S[\alpha(1 - \tau_{in}) + (1 - \alpha)(1 - \tau_{out})](1 - \tau_{fed})$$
$$- \acute{O}_i X_i[\alpha(1 - \tau_{in}) + (1 - \alpha)(1 - \tau_{out})](1 - \tau_{fed})$$
$$+ [\acute{O}_i(\tilde{a}_i\omega_i X_i) - \acute{O}_i(\tilde{a}_i B_i)](1 - \tau_{in})(1 - \tau_{fed})$$
$$+ [\acute{O}_i(\rho_i \upsilon_i X_i) - \acute{O}_i(\rho_i F_i)](1 - \tau_{fed}).$$

Which, collecting the X_i terms, yields,

(2)
$$\Pi = S[\alpha(1 - \tau_{in}) + (1 - \alpha)(1 - \tau_{out})](1 - \tau_{fed})$$
$$- \acute{O}_i[\tilde{a}_i B_i(1 - \tau_{in}) + (\rho_i F_i)](1 - \tau_{fed})$$
$$- \acute{O}_i X_i\Big\{[\alpha\,(1 - \tau_{in}) + (1 - \alpha)(1 - \tau_{out}) - \tilde{a}_i\omega_i(1 - \tau_{in}) - \rho_i\upsilon_i](1 - \tau_{fed})\Big\}.$$

The first line of (2) represents the revenues adjusted for taxes. The second line shows the after-tax profit-reducing effect of limiting input tax credits to only that input spending above statutory base levels. Note that in tax statutes, these base levels (F_i and B_i) generally do not depend on current spending, and so behave like fixed costs. The third line accounts for input costs with adjustments for taxes and input tax credits.

Written this way, it becomes apparent that the effective tax-adjusted prices (P^t_i) that the firm faces on inputs (X_i) are

(3)
$$P^t_i = [\alpha\,(1 - \tau_{in}) + (1 - \alpha)(1 - \tau_{out}) - \tilde{a}_i\omega_i(1 - \tau_{in}) - \rho_i\upsilon_i](1 - \tau_{fed})$$

So, total effective input costs are given by $\theta = \acute{O}_i(X_i P^t_i)$ for i = H, C, I. We can estimate the prices given by (3) for C, H and I, using data gathered from a detailed perusal of each firm's 10K filings.

If we assume that exogenous market forces drive pre-tax input and output prices, sales (S) and the in-state fraction of sales (α)--which seems reasonable in this case for econometric modeling purposes because we have very disaggregated (i.e. firm-level) data—and treating the F_i and B_i terms (as well as the tax and credit rates) as fixed by regulation so not dependent on current choices by the firms, then the profit maximizing problem faced by the firm can be modeled as the cost-minimizing dual: choosing the X_i to minimize effective costs.

Assuming constant returns to scale, we can approximate any general unknown complex cost relationship with a second-order Taylor series, Diewart's (1971) generalized Leontief cost function:

(4)
$$\theta = S\,[\acute{O}_i \acute{O}_j\, d_{ij}\,(P^t_i P^t_j)^{½}] \qquad \text{for } i, j = C, H, I \text{ and where } d_{ij}=d_{ji}$$

Because we are primarily interested in the substitutability or complementarity of the R&D inpits, the generalized Leontief is nice here because it makes no assumptions about the substitution elasticities among inputs, and its additive form turns out to enable (compared to the alternative translog specification) in estimating the appropriate coefficients given constraints discussed below in the empirical data.

Applying Shepard's Lemma and differentiating the cost dual (4) with respect to input prices (here effective tax-adjusted prices), yields the first order cost minimization conditions:

$$X_i^* = \delta\theta/\delta P^t_i = S[\Sigma_j d_{ij} (P^t_i/P^t_j)^{1/2}] \quad \text{for i, j = C, H, I and where } d_{ij}=d_{ji}$$

Or in optimal input-output ratio form:

$$X_i^*/S = [\Sigma_j d_{ij} (P^t_i/P^t_j)^{1/2}] \quad \text{for i, j = C, H, I and where } d_{ij}=d_{ji}$$

So for our three inputs, the three equation system for cost minimization is

(5) $$r_C = C/S = d_{CC} + d_{CH} (P^t_H/P^t_C)^{1/2} + d_{CI} (P^t_I/P^t_C)^{1/2}$$

(6) $$r_H = H/S = d_{HH} + d_{CH} (P^t_C/P^t_H)^{1/2} + d_{HI} (P^t_I/P^t_H)^{1/2}$$

(7) $$r_I = I/S = d_{II} + d_{CI} (P^t_C/P^t_I)^{1/2} + d_{HI} (P^t_H/P^t_I)^{1/2}$$

For the generalized Leontief form, after Uzawa (1964) and Berndt (1991), we can estimate the Hicks-Allen partial elasticities of substitution between inputs i and j as:

(8) $$\sigma_{ij} = ½[\theta d_{ij}(P^t_i P^t_j)^{-1/2}]/S r_i r_j \quad \text{for i, j = C, H, I but } i \neq j$$

Ideally, we could estimate these elasticities from estimates of the d_{ij} in this system of equations using data on firms' choices of C, H and I and the effective tax-adjusted prices they face for the various inputs. Unfortunately, firms do not ordinarily publicly disclose expenditures contract R&D (C) separately from in-house R&D. Rather they report a combined research expenditure (R=C + H).

So, we combine (5) and (6) to get:

(9) $$r_R = (C+H)/S = (d_{CC} + d_{HH}) + d_{CH} [(P^t_H/P^t_C)^{1/2} + (P^t_C/P^t_H)^{1/2}] + d_{CI} (P^t_I/P^t_C)^{1/2} + d_{HI} (P^t_I/P^t_H)^{1/2}$$

We use the two equation system of (7) and (9) to get estimates of d_{CH} , d_{CI} and d_{HI}. However, because of the empirical data constraint, this approach cannot separately identify d_{CC} and d_{HH} but only their sum, $d_{RR} = d_{CC} + d_{HH}$.

Nonetheless, all the parameters in (8) except d_{ij}, must be positive. So, the *sign* of the substitution elasticity, e.g. whether the in house R&D and contract R&D behave as production complements ($\sigma_{CH} < 0$) or substitutes ($\sigma_{CH} > 0$) or are independent ($\sigma_{CH} = 0$), depends entirely on the sign of d_{CH}, which we can estimate. Had we used the translog approximation, this would not have been separable.

2.2. Econometric Specification

To estimate the coefficients in (4), we append time, industry, firm-effect and stochastic-error terms to equations (7) & (9). For firm f, in time period t and industry k:

$$r_{Ift} = d_{II} + d_{CI}\,(P^t_{Cft}/P^t_{Ift})^{½} + d_{HI}\,(P^t_{Hft}/P^t_{Ift})^{½} + (w^c_t + u^c_k + v^c_f + e^c_{ft}) \tag{10}$$

$$r_{Rft} = d_{RR} + d_{CH}\,[(P^t_{Hft}/P^t_{Cft})^{½} + (P^t_{Cft}/P^t_{Hft})^{½}] + d_{CI}\,(P^t_{Ift}/P^t_{Cft})^{½} + d_{HI}\,(P^t_{Ift}/P^t_{Hft})^{½} + (w^R_t + u^R_k + v^R_f + e^R_{ft}) \tag{11}$$

where w^c_t and w^R_t are terms common to all firms in period t, u^c_k and u^R_k are industry-specific fixed effects for industry k, v^c_f and v^R_f are fixed firm effects for firm f, and e^c_{ft} and e^R_{ft} are normally distributed random terms. To investigate the robustness of the findings to including these various terms, we show results below both with and without year dummies, industry effect variables (either industry SIC dummies or industry average R&D ratio) and firm effects variables (ln[sales], firm's age in 1994, recent IPO dummy, loss dummy).

Rather than obtaining separate estimates from (10) and (11), we employ a systems estimator. This is because d_{CI} and d_{HI} are in both equations (10) and (11), each contains different regressors, and the error terms e^c_{ft} and e^R_{ft} may be correlated, which would be associated with a non-diagonal error covariance matrix. As suggested by Humphrey and Moroney (1975) and by Berndt (1991) (both following Kmenta (1967)), we use the iterative Zellner (1962) efficient estimation procedure, imposing cross-equation coefficient equality constraints. This is more efficient than separate OLS estimation and yields estimates equivalent to the maximum likelihood estimator. The iterative computations follow Green's (2000) asymptotically efficient, feasible generalized least-squares algorithm.

3. The Data

We constructed an original data set from detailed reading of firms' individual 10K and/or S-1 filings. Section 3.1 describes how we identified and selected the firms in the sample. Section 3.2 explains the data sources, and section 3.3.1 – 3.3.5 describe the procedures for estimating various variables for each firm.

3.1. Sample Selection

We used Compustat, a database of North American businesses from Standard & Poor's Research Insight 7.6, to identify our sample (though as explained below, we went directly to the 10K forms for the data). The "CS Active" subset of the database was screened for the following four criteria:

- SIC Codes: 2834, 2835, 2836, 7372, 7373
- R&D Expense > 0 and Sales > sum of other (non-R&D) expenses (CoGS + SGA).
- States: California or Massachusetts
- Firm in existence through entire study period, 1994-1999

We chose the first criterion because we are modeling unknown cost functions. To limit the inter-industry heterogeneity of possible production and cost functions, we focused on two industries: pharmaceuticals (SIC 2834, 2835 and 2836) and software development (SIC 7372 and 7373). During the study period, these industries are two of the top three among 3-digit SIC industries in R&D intensity as measured by the ratio of R&D employees to total employees, according to the National Science Foundation (NSF, 2000). As discussed below, we empirically model these two industries both together and separately.

Second, this study considers the relationship between basic and in-house research as the tax price of R&D changes. So, all firms in the sample reported positive research and development expense during the study period. Moreover, because we rely on R&D tax price variation in our estimating procedures, we limited the sample only to firms who might qualify for R&D tax credits. Since we do not have access to the actual tax records of firms, we preferred to minimize the potentially large measurement and discounting problem from differing choices made my firms in their actual tax treatment of R&D spending, particularly in using loss carry-forward provisions and in the wide variation in the tax treatment from state to state for firms. Instead, we limited our sample only to those firms and years in which they might immediately qualify for the R&D tax credits, i.e. where revenues exceeds the sum of cost of goods sold plus sales and administrative expenses. In other words, all have positive operating margins, excluding R&D, so that at least some R&D expenses should immediately qualify for the R&D credits.

Third, to facilitate analysis of the effect of state-level R&D credits, yet at the same time to control for unknown exogenous differences among states, the sample was limited to firms with headquarters in either California or Massachusetts. Both states have a large number of firms in the two industries studied. Both states have tax credits for both in-house and contract research, but treat the two types of R&D differently. Moreover, rates for each type differ between the two states. In addition, California's research tax credit rates were increased during the period under analysis, while the Massachusetts research credit rate remained constant. This gives us significant variation in the tax prices across firms, industries, years and states, which in turn allows us to estimate and test firms' treatment of contract and in-house research as complements or substitutes.

Fourth, to avoid likely heterogeneity in R&D choices unrelated to price effects among firms that are failing, acquired or newly started, we excluded those firms not in operation for the entire study period, 1994 –1999. In some cases, firms that were operational in 1994 may have ceased operations before 1999. Conversely, firms in operation in 1999 may not have been in existence in 1994.

With these criteria, Compustat generated a preliminary sample of 307 firms. From this initial group, through an examination of 10K and/or S-1 filings, we excluded 128 firms that undertook research in multiple states because the breakdown of research expenditure by location is not publicly available information. If a firm has R&D in more than one state there is no way to determine how much of the research expenditure is subject to a particular state's research tax credit. Since states require qualified research expenditure pertain exclusively to activity within the state in order to qualify for the credit, we included only single-state R&D performers in the analysis (though included firms often had non-R&D activities in multiple locations). An additional 49 firms we excluded because one or more forms of incomplete data. Some firms did not have publicly reported financial information available in the earlier years of the study because they were privately held. Privately owned firms are not required to make public their financial statements. In other instances, firms were acquired and, so, not independently reported as stand-alone entities for the entire study period.

Table 1 provides a breakdown by state and industry of the preliminary and final sample. The table shows the existence of multiple-site research and development activity is the most significant factor affecting a firm's acceptance or rejection from the study. This criterion tended disproportionately to eliminate the largest firms.

Table 1. Firm Acceptance / Rejection Statistics- Sorted by State & SIC Code

	Selected by Compustat	*In Study*	*Multi-Location R&D*	*Incomplete Data*
CA Pharmaceutical 283X				
Number of Firms	78	42	28	8
% of Row		53.8%	35.9%	10.3%
CA Software 737X				
Number of Firms	135	41	65	29
% of Row		30.4%	48.1%	21.5%
MA Pharmaceutical 283X				
Number of Firms	49	30	16	3
% of Row		61.2%	32.7%	6.1%
MA Software 737X				
Number of Firms	45	17	19	9
% of Row		37.8%	42.2%	20.0%
Total	307	130	128	49
% of Total		42.3%	41.7%	16.0%

In terms of state location, the preliminary and net samples are not materially different. Of the preliminary list of firms generated by Compustat, approximately 69% were from California. In the net sample, California firms comprise approximately 64% of the firms studied. This suggests that a firm's headquarters location did not materially affect a firm's chance of being included in the net sample. In contrast, the ratio of pharmaceuticals to software firms was different between the preliminary and final groups. Pharmaceuticals comprised approximately 41% of the preliminary sample; they represent approximately 55% of the net sample. This suggests software firms had a slightly higher chance of being excluded from the study than the pharmaceuticals. This reflects largely the fairly turbulent investment environment in information technology industries in general during the dot-com boom of the second half of the 1990s. This might bias our results towards pharmaceuticals when we model the two industries together, but we also treat them separately.

A more complete picture of the nature of firms in the study comes from descriptive statistics. Table 2 shows the (industry price deflated) sales, R&D expenses and R&D intensity ratios over the study period between 1994 and 1999 for the firms and years included in the study.

Table 2 Annual Sales and R&D Spending, Sample Firms & Years

Variable	Mean	Std. Dev.	Min	Max
All Firms & Years in Sample				
Annual sales (millions of 1994 dollars)	135	758	0.236	9560
Annual R&D expenses (millions of 1994 dollars)	27.1	85.4	0.036	953
R&D/sales ratio	0.743	0.868	0.014	4.37
Pharmaceutical Firms (SIC 283X)				
Annual sales (millions of 1994 dollars)	50.3	161	0.236	1090
Annual R&D expenses (millions of 1994 dollars)	30.3	64.5	0.146	454
R&D/sales ratio	1.39	0.922	0.014	4.37
Software Firms (SIC 737X)				
Annual sales (millions of 1994 dollars)	204	1010	0.457	9560
Annual R&D expenses (millions of 1994 dollars)	24.4	99.4	0.036	953
R&D/sales ratio	0.208	0.201	0.020	1.293

The size of the pharmaceutical firms' research intensity highlights a significant difference between the firms that are included in the study and those with multiple site research activity. Pharmaceutical firms in the study, because of their generally limited size, reveal a disproportionate amount of annual investment in R&D as a ratio of sales, when compared to industry norms: the NSF (2000) reports overall pharmaceutical industry-level R&D/sales ratios of 0.101 to 0.106 in the study period. However, without detailed information regarding the spending by location of multi-site R&D performers we had no way of estimating R&D tax prices firms face.

In summary, then, our results pertain to the R&D investment behavior of publicly held, surviving pharmaceutical and software firms, existing from at least 1994 to 1999, generally small to medium sized, that undertake research solely in either California or Massachusetts.

3.2. Data Sources

Publicly owned corporations owned by more than 500 investors and more than $10 million in assets are required to file annual reports with the SEC. These filings are generally referred to as the 10-K; they include the firm's annual report and additional detailed information on a variety of operational and managerial items. During the years 1994-1996, the SEC phased in an electronic filing system called EDGAR: the Electronic Gathering Analysis and Retrieval system. Generally, 10-K filings prior to 1996 are not available in the EDGAR system. However, since firms are required to report prior periods' statements and information for comparative purposes, the available filings used to generate the data and estimate research tax prices typically extended back to 1992 for the firms in operation at that time.

In some cases, firms that were operational during the study period and prior years may not have been publicly owned or may have made their initial public offering (IPO) of stock during the study period. In these cases, 10-K filings may not be available, but an equally informative alternate source of data is filed and available within EDGAR. Section 11 of an S-1 registration, the "Information with Respect to the Registrant," includes the same sections of financial and operational data as the 10-K. Therefore, in cases a 10-K was not available, we used the S-1 registration as the data source.

We used the online version of EDGAR to create our dataset. To verify the accuracy of the filings as provided by EDGAR-online, one income statement for every tenth firm in the sample was tested. The year of the income statement was rotated in reverse chronological order to avoid bias. Without exception, there were no discrepancies between the information in EDGAR and the text version. Moreover, there were no cases where EDGAR-online supplied fewer filings than what is publicly available from the SEC.

3.3.1. State Corporate Income Apportionment Fraction (α) *Estimates*

R&D tax credit calculations, by law, require attributing a fraction of income to the home state. In our model above, this is the α term. The procedures in both states are the same. Both states' tax laws use a three-factor apportionment formula based on property, payroll and sales, applying double weight to the sales factor (See: California Schedule R: Apportionment and Allocation of Income, 1999; Massachusetts Schedule F: Income Apportionment, 1999). In addition, both are throwback states. This means that if no other state has jurisdiction to tax a portion of the firm's income, it is taxed in the home state. Estimates for the three factors, as discussed in turn below, were gleaned from information provided in the firms' 10-K filings.

<u>Property Fraction</u>. The property fraction is, by law, the ratio of in-state property to total property used by the firm. If the real property is owned, the ratio of state cost to total cost is used. In the case of leased real property, eight times the rental cost is used to proxy for cost, in the fraction of in-state to total ratio. Although details of a firm's real property and leasehold costs are available in the notes to the financial statements, the information is given only on an aggregate basis. Thus, there is no way to determine how much of the holdings are in a particular state. Therefore, a proxy for the property fraction is needed.

Item 2 of the 10-K, the Description of Properties section, provides information on facilities used. At a minimum, it includes the location of principal facilities. Generally, firms provide the square footage by location. Firms with the most complete disclosure included square footage, relevant cost information and a description of activities by site. Firms with only one location, the headquarter state, were assigned a property ratio of 1.0. For firms with multiple sites, the ratio of the square footage in the headquarter state to the total square footage was calculated and serves as the proxy for the property percentage for the income apportionment computation. In the cases where incomplete square footage information was provided, (typically this occurred for small sales office locations domestically and internationally) an estimate of 3,000 square feet per location was used to estimate the property fraction. The 3,000 square feet estimate is representative of the "typical" sales office based on a review of the firms that provided specific square feet amounts for all facilities.

There were several instances where sales office locations were not disclosed in the Description of Properties section, but were made reference to in the Sales and Marketing Analysis section of Item 1. In the cases where no reference was made to sales offices, domestic or international in the Description of Properties, the Sales and Marketing segment was reviewed for location information. For each state or country listed, 3,000 square feet was assigned to estimate the property fraction. In the few cases where neither square footage nor sales office specifics were available, the ratio of domestic to total long-lived assets was used if available. Long-lived assets include property, plant, and equipment owned or leased by the firm. The reasoning behind this approach is based on the idea that greater amounts of long-lived assets will be housed in larger facilities, with higher cost or rental values.

<u>Payroll Fraction</u>. The payroll factor is, by law, based on the total wages, salaries, commission and other compensation paid to employees. To be part of the home state's portion of payroll only one of any of the following need apply:

- The service is performed within the state;
- The service is performed in and out of the state, but the out of state portion is secondary/incidental;
- Part of the service in performed in state, and the service is controlled/operations are based in state.

Unfortunately, payroll expense by location is not available in the 10-K. Accordingly, we used a proxy to estimate the payroll fraction.

If the property percentage was 100% because all operations occur within the headquarters state, then the applicable payroll fraction is also 100%. For firms with multiple-state facilities, an estimate of the payroll fraction came from head counts as a proxy for payroll expense. In the few cases where only a total headcount was provided, with no supporting details, then we used the property percentage as a proxy for payroll. Firms that provided staff by job category facilitated an estimate of in-state payroll using the information from the Description of Properties to allocate staff to the relevant locations. For example, if a firm is headquartered in California, but has three sales offices in three states, then all the non-sales staff was charged to California and the sales staff then divided evenly.

Sales Fraction. In the tax codes, this is the ratio of state revenue from operations to total revenue from operations, not including investment income such as interest and dividends. In the case of merchandise, it does not include shipments to buyers in foreign countries. In the case of service revenue, a sale is attributed to the home state if the service is wholly performed in the state or if the majority of the service activity's cost occurs in the home state.

In Item 2 of the 10-K filing, the Description of Properties, firms generally list the locations of significant manufacturing facilities and/or sales offices by state and country. As with the other ratios, if a company's operations are entirely within the home state, then all sales were attributed to that state. Similarly, for firms that sell services and not merchandise, all sales were assigned to the home state. In the cases of multi-state operations, sales from products or services attributable to other states were backed out to determine the level attributable to the home state. If a firm operated internationally, none of the foreign sales are attributable to the home state so the ratio of domestic to total sales was used. In the event that no breakdown of revenue by product and service was available, or if products by state were not disclosed, yet the firm had multi-state sales offices, all the sales were attributed to the home state. The reasoning for this is as follows. If the majority of operations, production, development, etc., occur in the headquarter state, and only sales administration takes place out of state, then the revenue should be attributable to the location with the majority of the income producing activity, the home state. This is consistent with both states' tax codes regarding the taxation of the sale of services, applied in this case to sales of goods.

3.3.2. Estimated Out-of-Home-State Tax Rate (τ_{out})

Tax statutes make allowances for taxes paid to other jurisdictions. Based on out-of-headquarters state locations disclosed for each firm, we identified the corporate income tax rate for each location in each period of the study. We then averaged these rates for each firm each year to estimate the out-of-home state corporate tax rate (τ_{out} in our model above). The available data does not facilitate a more precise sales weighted estimate of the out-of-home state tax rate faced be each firm. There were two sources of corporate tax rate data used. For individual U.S. states, Commerce Clearing House (CCH, 2000) summarizes the corporate tax rates in effect by state. For international locations, the source of corporate tax rate information was the annual KPMG Corporate Tax Rate Survey. Because of the significant changes in corporate tax rates across countries during this period, we obtained the tax rate survey for each year of the study.

3.3.3. State-level R&D Tax Credits ($\tilde{a}_i$)

The credit rates we used as the ($\tilde{a}_i$) terms in the model come directly from state tax statutes. The California credit is patterned after the federal legislation, with the purpose of rewarding only the R&D activity undertaken with the state. Unlike the federal credit, the California credit is permanent. For in-house R&D in excess of a threshold amount (B_H), the tax credit rates ($ã_H$) are:

- For tax years beginning prior to 1/1/97: 8%
- For tax years beginning prior to 1/1/99 11%
- For tax years beginning prior to 1/1/00 12%
- For tax years beginning on or after 1/1/00 15%

For basic research payments, "contract research," above threshold levels (B_C), the tax credit rates ($ã_C$) are:

- For tax years beginning prior to 1/1/97 12%
- For tax years beginning on or after 1/1/97 24%

As Hall and Wosinska (1999) discuss,

> "The California law uses the federal definition of the base levels [here B_H and B_C] but with the important feature that although the R&D intensity used to determine the "Base Amount" is the same number used in the federal calculation, the sales figure by which it is multiplied is the California share of total sales. This has the strange, but possibly intended, effect that a firm with sales throughout the United States but which does all of its R&D in California can have a rather low base level of R&D spending relative to its current level, year after year, even though it is not increasing its R&D… The effect of the provision is to give firms a strong inventive to locate their R&D laboratories in California, even if the rest of the firm is nationwide. It is likely that this is one of the goals of the legislation."

Like California, Massachusetts uses the federal R&E credit legislation as the foundation for its research tax credit. The credit is granted for qualified research expenditure within the state of Massachusetts. Since its inception on January 1, 1991, it has been a permanent part of Massachusetts' corporate tax law. Unlike the federal and California statutes, very little of the Massachusetts R&E tax code has been changed since that time. The rate of credit is 10% on excess QRE and 15% for basic research expenditure, as these terms are defined by the federal code. These rates have been constant since the credit became available to Massachusetts firms.

Since the state's credit law inception, the only significant change has been to offer an alternate means of computing the base amount of QRE by offering a choice of two means of computing the four-year sales averages. From the credit's inception in 1991 through December 31, 1996, firms applying for the Massachusetts R&E credit used national sales in determining the four-year average sales for computation of the Base Amount. Effective for tax years beginning on or after January 1, 1997, Massachusetts gave firms the option of using Massachusetts' sales or national sales in the computation. If a firm chooses to use Massachusetts' sales, they must continue with this method for a minimum of three tax years. The provision is not retroactive; firms may not amend prior years' returns to recalculate the credit for previous years.

As with the California provision, on the surface it appears to be a valuable option. If the base QRE is lower, because sales are limited to Massachusetts' sales, more of a firm's research expense will qualify as "excess" thereby increasing the amount of credit granted in a given year. However, given the limitations placed on the maximum Massachusetts R&E credit that may be applied in a given tax year, the impact of the alternate computation may not be very significant. The Massachusetts R&E credit:

1. May not exceed the excise tax for a given tax year
2. Cannot exceed 100% of the corporation's first $25,000 of excise tax, PLUS
3. Cannot exceed 75% of the excise tax over the first $25,000 (before any credits are allowed)

Where the California credit may be carried over indefinitely to future periods until the credit is exhausted, the Massachusetts credit is also subject to some carryover limitations. If the credit was not fully used because of limitation (2) above, the excess credit may be carried over indefinitely. If the credit was not fully used because of limitation (1) or (3) above, these amounts may only be carried forward for a maximum of fifteen subsequent tax periods (CCH, 2001).

These restrictions serve to limit the benefit of the credit. It is interesting to note that Massachusetts gives firms a choice between national and state-level sales, where California does not. The amount of Massachusetts' state sales is the same as the value used in the income apportionment computation. Thus, for some firms with nexus in other states, the use of state-level sales may be beneficial, subject to the previously noted restrictions. The use of the same value for both Massachusetts computations lowers the record keeping costs, unlike the California requirements.

In other aspects, the California and Massachusetts R&E credits are quite similar. Massachusetts follows the federal code's definition and rates applicable to start-up firms. Start-up firms use a 3% fixed base percentage. The maximum fixed base percentage is 16%; this is also the rate applied by Massachusetts to firms with inadequate records. The computation of basic research credit is the same for both states. One significant difference between the California and Massachusetts credits is California's offering of the alternate credit computation. Under Massachusetts corporate tax law, this method is not available. For purposes of this paper, it is assumed all firms employ the standard credit computation. This is consistent with the literature on the federal credit. This assumption is also supported by the high research intensities of the firms in the study. The alternate method was instituted to allow firms with dramatic sales growth or historically high research intensities to receive credit for their R&D investments. Firms with high research intensities in current periods receive a larger credit under the standard method. Therefore, our assumption of their use of this method is reasonable.

3.3.4. Other Parameters.

Several other parameters are also necessary for estimating the tax prices in (3). First, note that because by design all firms in our sample do all their research activities in their home state, we set the in-state R&D fraction ω_i=1.0 as well as the U.S. R&D fraction υ_i=1.0 for all firms. Moreover, we assume no tax credits for inputs other than R&D, so both the state rate $\tilde{a}_I$=0 and federal rate ρ_I=0.

Another parameter is the marginal federal corporate tax rate, τ_{fed}. This varies by firm and by year according to the somewhat complex statutory levels and the 10K or S-1 reports by the firm on their level of before-tax profits, as follows:

- 15% if the year's profit before taxes > 0 & < $50,000;
- 25% if profit before taxes $\geq$ $50,000 & < $75,000;
- 34% if profit before taxes $\geq$ $75,000 & < $100,000;
- 39% if profit before taxes $\geq$ $100,000 & < $335,000;
- 34% if profit before taxes $\geq$ $335,000 & < $10 million;
- 35% if profit before taxes $\geq$ $10 million & < $15 million;
- 38% if profit before taxes $\geq$ $15 million & < $18.333333 million;
- 35% otherwise.

Finally, the federal R&D credit rates (ρ_C and ρ_H) were by statute 0.20 for all study periods, except 1995 and 1996. Congress let the credit lapse for the one year period between July 1995 - June 1996. Effectively, the credit was zero for half of each year. But our data is annual. So, although not ideal because firms could have front or back loaded R&D expenditures, we used an average 0.10 federal credit rate for each of those full years.

3.3.5. Resulting Effective R&D Tax Prices

Combining the data above and using equation (3) gives us estimates of the effective tax prices faced by each firm for R&D. For a typical example, one California software firm in our sample faced the following characteristics relative to contract research in 1999:

State R&D credit rate for contract research: $\tilde{a}_C = 0.24$
Federal R&D credit rate for contract research: $\rho_C = 0.20$
Federal corporate tax bracket: $\tau_{fed} = 0.35$
State corporate tax: $\tau_{in} = 0.0884$
In-state sales apportionment fraction: $\alpha = 0.9575$
In-state R&D fraction: ω_C =1.0 [True for all firms in sample]
US R&D fraction: υ_I =1.0
Average out of state tax: $\tau_{out} = 0.075$

So the effective tax price for contract research for this firm in 1999 is:
$P^t_C = [\alpha\,(1 - \tau_{in}) + (1 - \alpha)(1 - \tau_{out}) – \tilde{a}_C\omega_C(1 - \tau_{in}) - \rho_C\upsilon_C](1 - \tau_{fed})$

$P^t_C = [0.9575(1 - 0.0884) + (1 - 0.9575)(1 - 0.075) – 0.24(1)(1 - 0.0884) – 0.20(1)](1 – 0.35) =$
$P^t_C = \$0.3207$

In other words, the added cost to the firm of one more dollar of R&D spending for this firm, after tax credits is only 32 cents. This reflects the combined 24 percent contract R&D credit in California, 20 percent Federal credit, the reductive effect of both the firm's 35 percent federal corporate tax bracket and the 8.84 percent CA corporate tax rate, and accounts for a bit of out of state sales apportionment.

Note the effect of the change in California tax laws. In 1996 and prior years, the California credit rate for contract research was only 12 percent, while the corporate tax rate was 9.3 percent. If the rates had not changed, a firm with otherwise similar characteristics would have faced an effective price $P^t_C = \$0.3893$, roughly 20 percent higher.

Overall, there is wide variation across firms and across years, with effective tax prices usually between 30 and 50 cents. Table 3 summarizes the tax prices, by state, industry and year. Note that before 1997 California firms faced prices a few cents higher on average than in Massachusetts, but lower thereafter. Prices for in-house R&D are higher than for contract research because of the more generous state credit rates in both states for contract research. The jump in both prices in both states in 1995 and 1996 is due to the lapse of the Federal R&D credit during that period.

Table 3. Summary of Effective R&D Tax Prices by State and Year

	Contract R&D				In-House R&D			
	Tax Price	St. Dev.	Min	Max	Tax Price	St. Dev.	Min	Max
All Firms, All Years	$0.373	$0.059	$0.198	$0.597	$0.415	$0.044	$0.275	$0.628
California								
All Years	$0.366	$0.066	$0.198	$0.597	$0.416	$0.045	$0.275	$0.628
1994	$0.382	$0.026	$0.318	$0.508	$0.406	$0.027	$0.342	$0.539
1995	$0.446	$0.024	$0.385	$0.597	$0.469	$0.025	$0.408	$0.628
1996	$0.444	$0.020	$0.332	$0.465	$0.468	$0.020	$0.356	$0.489
1997	$0.309	$0.023	$0.198	$0.327	$0.386	$0.023	$0.275	$0.404
1998	$0.308	$0.024	$0.201	$0.333	$0.385	$0.024	$0.278	$0.412
1999	$0.307	$0.023	$0.213	$0.330	$0.378	$0.023	$0.284	$0.402
Massachusetts								
All Years	$0.385	$0.040	$0.279	$0.533	$0.414	$0.041	$0.308	$0.571
1994	$0.366	$0.029	$0.300	$0.487	$0.396	$0.030	$0.330	$0.526
1995	$0.429	$0.024	$0.366	$0.533	$0.459	$0.025	$0.395	$0.571
1996	$0.427	$0.024	$0.370	$0.523	$0.457	$0.025	$0.400	$0.562
1997	$0.363	$0.025	$0.291	$0.459	$0.392	$0.026	$0.320	$0.498
1998	$0.361	$0.027	$0.279	$0.466	$0.391	$0.028	$0.308	$0.505
1999	$0.361	$0.026	$0.286	$0.463	$0.391	$0.027	$0.316	$0.502

4. Results & Conclusions

Tables 4 and 5 show our results. Both tables include various combinations of included time, industry and firm effect variables. The top half of each table represents various estimates the R&D/output equation (11) and the bottom is equation (10). Table 4 combines all the sample firms, thus assuming equal coefficients for pharmaceutical and software firms, while Table 5 shows separate regressions for the two industries.

The key coefficient, d_{CH}, for addressing the principal question of the complementarity or substitutability of in-house and contract R&D is the second line of each table, in bold. As we see in Table 4, except for Column 1 which has only the price variables, the coefficient d_{CH} is uniformly positive and significant. From (8), this implies that the partial elasticitiy of subsitution (σ_{CH}) between in-house and contract research is positive, and so the two forms of R&D behave as production substitutes.

This basic finding is robust to the variations in effects variables, except in Table 4 column 1 and Table 5 column 9P when no effects variables are included at all. Because the level of R&D/output is significantly higher in pharmaceuticals than in software, including with the tax-price ratios any variable that captures differences between industries or firms eliminates a downward bias in the Column 1 estimate of d_{CH} and significantly improves the overall statistical fit. As Table 5 shows, the finding is also robust to modeling the industry sectors separately. Contract research and in-house research appear to be substitutes in both industries.

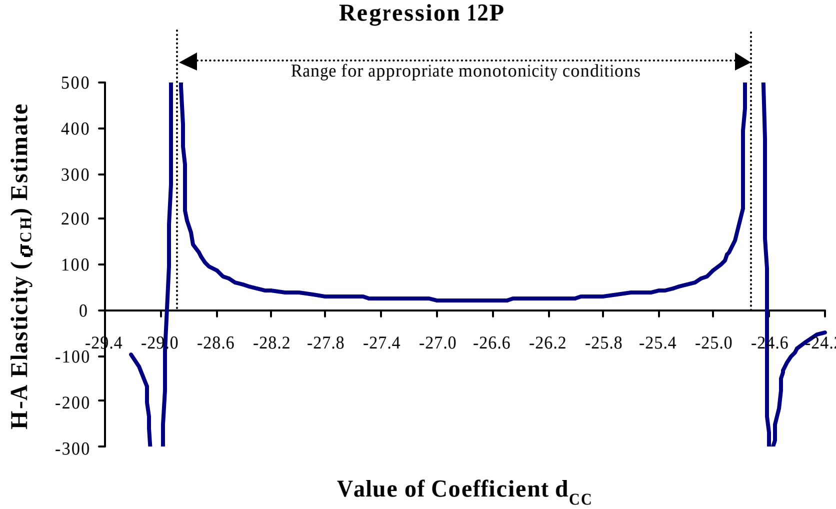
On the other hand, we find inconsistent evidence whether R&D of either type is interdependent with other inputs. In the combined industries models in Table 4 neither d_{CI} nor d_{HI} is significant in any of the specifications, and the sign on d_{HI} is unstable. In the pharmaceutical-only models in Table 5, in columns 10P-12P, contract research does appear complementary to other inputs.

Ideally, particularly for policy purposes, we would be able to estimate and report the value of these production- (and by extension price-) elasticities. However, these estimates would come from equation (8) above, which in turn requires r_C and r_H estimates using coefficients d_{CC} and d_{HH} in equations (5) and (6). Unfortunately, the data restrictions on reported research do not allow those equations to be estimated separately, but only a combined ($d_{RR} = d_{CC} + d_{HH}$).

As Figure 1 shows, using for example the pharmaceutical industry results from Table 5, column 12P, the in-house to contract research Hicks-Allen partial elasticity (σ_{CH}) estimates from (8) are highly sensitive to how d_{RR} is split between d_{CC} and d_{HH}. As is also shown, constraining the allocation only to those values that allow (5) and (6) to satisfy monotonicity conditions required (in this case that the fitted r_C and r_H estimates from (5) and (6) remain positive) does little to help identify σ_{CH} beyond eliminating negative values. This we know already from theoretical inspection of (8) and the sign on d_{CH} alone.

Figure 1

Sensitivity to d_{CC} of Estimates of Hicks-Allen Partial Elasticity of Substitution Between Contract & In-House Research (σ_{CH})
Regression 12P



If we include variation in the d_{ij} estimates from the standard error of the coefficients, possible estimates from model 12P (using the industry sample means of all variables in the model) range from slightly less than one (σ_{CH} =0.952 at the lowest bound estimate) to unreasonably high levels. Moreover, we are unaware of any well understood statistical interference tests which we could apply to point estimates of σ_{CH}, a problem driven by this same instability in the estimates based on generalized Leontief functional forms. So, we are left only being able to report the sign. Nevertheless, as we suggest in the introduction, we believe this is the first time even this directionality has been reported in the literature.

These results suggest the higher rates of credit for basic research result in increased basic science investment at the expense of in-house R&D expenditure. This R&D substitution suggests that, among relatively small firms in our sample at least, the absorptive capacity positive incentive for complementary internal R&D is outweighed, on average, by the negative incentive from the option of substituting external sources. Viewed in conjunction with the existing literature showing the importance of in-house research with respect to firms' ability to utilize the external knowledge acquisition (Rosenberg, 1990; Cohen & Levinthal, 1990, Cassiman and Veugelers, 1998), the results similarly suggest that the use of tax credits to increase external basic scientific research expenditures may, through reduction of in-house R&D, reduce these small firms' ability to benefit from these investments in the future.

For policymakers, the finding of R&D substitution also suggests limited net increases in overall R&D effort by these small firms in response to more favorable tax credits for funding external basic research. The firms, on average, shift away from in-house R&D when faced with lower relative prices of external research. Of related policy importance is whether the states offering these localized incentives reap any benefits from doing so. Mansfield (1995) suggests basic research funding is less tied to geographic proximity than more applied research contracting. However, this does not suggest out-of-state firms will increase basic research contracting in California in response to the credit rate increase in 1997. This is because a state-level incentive only has value to a firm when it reduces the firm's tax liability. If a firm is located in Colorado, but chooses to contract basic research with Stanford, the firm receives no benefit from California's higher basic research tax credit rate unless it has some California tax obligation that the credit can reduce or eliminate. Thus, with respect to inter-state competition for research investment among firms, state-level incentives are only effective if a firm chooses to move or setup a new facility in that state.

Similarly, Salter and Martin (2001) and Pavitt (2001) note there is little cross-state or cross-border free-riding with respect to basic research. More important than free-riding, they find is the establishment of a "critical mass" of basic and applied research activity from which to fully derive benefit from investments in university-developed, firm-sponsored basic research. Yet again, if firms are merely shifting dollars away from in-house endeavors and toward university inquiry, then the development of this necessary "critical mass" may be inhibited, rather than enhanced by the availability of state-level tax credits directed toward basic research.

As a final, theoretical and modeling issue, we note that using our novel approach, it is possible to empirically estimate the R&D substitution elasticities because of firm-to-firm variation in the effective prices they face for different forms of R&D expenditure. This is possible even when firms do not report the two types of R&D separately, by taking advantage of Diewart's generalized Leontief second-order Taylor series approximation rather than using the more traditional trans-log specifications. Unfortunately these estimates were unstable with respect to assumptions, enabling us to establish only the direction of the relationship. For the small firms in our study, in-house R&D and external research expenses are substitutes, but how strong? This question calls for further work on establishing the relative sizes of the d_{CC} and d_{HH} coefficients in systems models like equations 5-7 to enable better point estimates of R&D substitution elasticities.

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Table 4. IZEF Systems Estimator Regressions of Input / Ouput Ratios on Input Price Ratio Variables & Industry, Firm & Year Control Variables

All Sample Firms			Regression							
		Independent Var	1	2	3	4	5	6	7	8
R&D / Ouput Equation		d_{RR}	-13.37	-25.23 **	-21.99 *	-26.51 **	-32.14 ***	-28.67 *	-29.80 *	-28.43 *
			(13.65)	(12.25)	(12.11)	(11.37)	(10.89)	(15.68)	(15.59)	(15.56)
	Price Ratio Variables	$\mathbf{d_{CH}}$	**7.17**	**12.73** **	**11.11** *	**14.97** ***	**17.10** ***	**16.16** **	**16.37** **	**15.67** **
			(6.78)	**(6.09)**	**(6.02)**	**(5.68)**	**(5.44)**	**(7.82)**	**(7.77)**	**(7.76)**
		d_{CI}	-0.754	-0.631	-0.624	-0.737	-0.580	-0.325	-0.529	-0.636
			(0.506)	(0.405)	(0.406)	(0.514)	(0.414)	(0.516)	(0.513)	(0.504)
		d_{HI}	0.591	0.597	0.589	0.400	0.263	-1.336	-0.268	-0.099
			(0.810)	(0.633)	(0.633)	(0.823)	(0.653)	(1.310)	(1.316)	(1.284)
	Industry Controls	pharm dummy		1.188 ***					0.916 ***	
				(0.060)					(0.227)	
		sic2834 dummy			1.245 ***					0.979 ***
					(0.119)					(0.114)
		sic2835 dummy			0.758 ***					0.554 ***
					(0.145)					(0.140)
		sic2836 dummy			1.310 ***					1.019 ***
					(0.115)					(0.108)
		sic7372 dummy			0.013					-0.022
					(0.105)					(0.094)
		Industry R&D Ratio					1.241 ***	1.232 ***	0.043	
							(0.083)	(0.084)	(0.306)	
	Firm Contols	Loss dummy				0.608 ***	0.396 ***	0.398 ***	0.351 ***	0.310 ***
						(0.076)	(0.063)	(0.064)	(0.063)	(0.064)
		ln(sales)				-0.150 ***	-0.103 ***	-0.101 ***	-0.111 ***	-0.110 ***
						(0.026)	(0.021)	(0.022)	(0.022)	(0.021)
		IPO dummy				-0.031	0.027	0.024	0.038	0.062
						(0.164)	(0.133)	(0.134)	(0.131)	(0.129)
		Firm Age in 1994				-0.0158 ***	-0.0052	-0.0048	-0.0034	-0.0051
						(0.0054)	(0.0045)	(0.0045)	(0.0044)	(0.0044)
	Time	Year Dummies	No	No	No	No	No	Yes	Yes	Yes
Other Inputs / Ouput Equation		d_{II}	0.749 **	0.760 ***	0.732 ***	1.103 ***	1.497 ***	2.652 ***	1.847 **	1.756 **
			(0.333)	(0.255)	(0.256)	(0.373)	(0.295)	(0.875)	(0.884)	(0.859)
	Price Ratio Variables	d_{CI}	-0.754	-0.631	-0.624	-0.737	-0.580	-0.325	-0.529	-0.636
			(0.506)	(0.405)	(0.406)	(0.514)	(0.414)	(0.516)	(0.513)	(0.504)
		d_{HI}	0.591	0.597	0.589	0.400	0.263	-1.336	-0.268	-0.099
			(0.810)	(0.633)	(0.633)	(0.823)	(0.653)	(1.310)	(1.316)	(1.284)
	Industry Controls	pharm dummy		-0.253 ***					-0.209 ***	
				(0.017)					(0.071)	
		sic2834 dummy			-0.212 ***					-0.253 ***
					(0.035)					(0.036)
		sic2835 dummy			-0.215 ***					-0.143 ***
					(0.042)					(0.043)
		sic2836 dummy			-0.238 ***					-0.286 ***
					(0.034)					(0.034)
		sic7372 dummy			0.035					0.037
					(0.031)					(0.029)
		Industry R&D Ratio					-0.376 ***	-0.371 ***	-0.102	
							(0.025)	(0.026)	(0.095)	
	Firm Contols	Loss dummy				-0.038 *	0.026	0.023	0.034 *	0.044 **
						(0.023)	(0.019)	(0.019)	(0.020)	(0.020)
		ln(sales)				-0.013 *	-0.028 ***	-0.031 ***	-0.028 ***	-0.029 ***
						(0.008)	(0.007)	(0.007)	(0.007)	(0.007)
		IPO dummy				0.052	0.034	0.035	0.031	0.022
						(0.050)	(0.041)	(0.041)	(0.040)	(0.040)
		Firm Age in 1994				0.0055 ***	0.0023 *	0.0022	0.0019	0.0025 *
						(0.0017)	(0.0014)	(0.0014)	(0.0014)	(0.0014)
	Time	Year Dummies	No	No	No	No	No	Yes	Yes	Yes
	R&D / Outut Equation	R^2	0.0004	0.463	0.486	0.332	0.561	0.562	0.578	0.593
		chi2	6.9 *	398.4 ***	435.7 ***	223.3 ***	552.8 ***	548.5 ***	584.7 ***	620.0 ***
		RMSE	0.866	0.635	0.622	0.696	0.564	0.564	0.553	0.544
		n	457	457	457	424	424	424	424	424
	Other I / O Eqn	R^2	0.013	0.334	0.337	0.053	0.374	0.378	0.390	0.410
		chi2	6.2 **	229.1 ***	232.5 ***	23.5 ***	253.1 ***	258.1 ***	271.0 ***	294.6 ***
		RMSE	0.221	0.181	0.181	0.212	0.173	0.172	0.170	0.168

Notes: Standard errors in parentheses; *significant at 0.1 level; **significant at 0.05; ***significant at 0.01.

Table 5. IZEF Systems Estimator Regressions of Input / Ouput Ratios on Input Price Ratio Variables & Industry, Firm & Year Control Variables

Grouped by Industry			Regression							
			Software				Pharmaceuticals			
		Coefficient	9S	10S	11S	12S	9P	10P	11P	12P
R&D / Ouput Equation		d_{RR}	-16.93 **	-15.54 **	-15.78 ***	-14.75	-37.79	-56.94 ***	-56.18 **	-60.14 **
			(6.93)	(6.35)	(6.34)	(9.32)	(26.98)	(22.13)	(22.08)	(30.16)
	Price Ratio Variables	**d_{CH}**	**8.71** **	**8.24** ***	**8.37** ***	**8.00** *	**19.45**	**30.62** ***	**30.28** ***	**30.26** **
			(3.44)	**(3.16)**	**(3.16)**	**(4.63)**	**(13.43)**	**(11.07)**	**(11.04)**	**(15.02)**
		d_{CI}	-0.370	-0.222	-0.231	-0.134	-1.037	-1.581 **	-1.457 *	-2.419 **
			(0.350)	(0.328)	(0.327)	(0.424)	(0.783)	(0.773)	(0.766)	(0.961)
		d_{HI}	0.117	-0.046	-0.037	-0.408	1.254	1.618	1.365	5.755 **
			(0.512)	(0.488)	(0.488)	(0.886)	(1.225)	(1.221)	(1.214)	(2.756)
	Industry Controls	sic2834 dummy								-0.009
										(0.119)
		sic2835 dummy								-0.281
										(0.171)
		sic7372 dummy				0.013				
						(0.033)				
		Industry R&D Ratio			-0.188				0.033	
					(0.527)				(0.412)	
	Firm Contols	Loss dummy		0.0551 **	0.0537 **	0.0547 **		0.846 ***	0.8489 ***	0.769 ***
				(0.0263)	(0.0266)	(0.0267)		(0.147)	(0.1499)	(0.158)
		ln(sales)		-0.02576 ***	-0.02611 ***	-0.025131 ***		-0.218 ***	-0.217056 ***	-0.213 ***
				(0.009)	(0.009)	(0.009)		(0.053)	(0.055)	(0.055)
		IPO dummy		-0.05438	-0.0554	-0.062743		0.168	0.16603	0.195
				(0.057)	(0.058)	(0.058)		(0.273)	(0.273)	(0.278)
		Firm Age in 1994		-0.00138	-0.00134	-0.001308		-0.0099	-0.009998	-0.0192
				(0.0017)	(0.0017)	(0.0017)		(0.0144)	(0.0145)	(0.0151)
	Time	Year Dummies	No	No	No	Yes		No	No	Yes
Other Inputs / Ouput Equation		d_{II}	0.957 ***	1.086 ***	1.129 ***	1.340 **	0.276	1.842 ***	2.330 ***	-0.808
			(0.192)	(0.211)	(0.217)	(0.576)	(0.500)	(0.560)	(0.601)	(1.812)
	Price Ratio Variables	d_{CI}	-0.370	-0.222	-0.231	-0.134	-1.037	-1.581 **	-1.457 *	-2.419 **
			(0.350)	(0.328)	(0.327)	(0.424)	(0.783)	(0.773)	(0.766)	(0.961)
		d_{HI}	0.117	-0.046	-0.037	-0.408	1.254	1.618	1.365	5.755 **
			(0.512)	(0.488)	(0.488)	(0.886)	(1.225)	(1.221)	(1.214)	(2.756)
	Industry Controls	sic2834 dummy								0.064 *
										(0.035)
		sic2835 dummy								0.119 **
										(0.049)
		sic7372 dummy				0.018				
						(0.019)				
		Industry R&D Ratio			-0.250				-0.252 **	
					(0.301)				(0.120)	
	Firm Contols	Loss dummy		0.120 ***	0.118 ***	0.117 ***		-0.164 ***	-0.183 ***	-0.160 ***
				(0.015)	(0.015)	(0.015)		(0.043)	(0.044)	(0.045)
		ln(sales)		-0.00994 **	-0.01042 **	-0.012361 **		-0.083 ***	-0.092373 ***	-0.091 ***
				(0.005)	(0.005)	(0.005)		(0.016)	(0.016)	(0.016)
		IPO dummy		0.0059	0.004539	0.005023		0.085	0.091502	0.092
				(0.033)	(0.033)	(0.033)		(0.080)	(0.080)	(0.080)
		Firm Age in 1994		0.0012	0.0013	0.0013		0.0088 **	0.0099 **	0.0130 ***
				0.0010	0.0010	0.0009		(0.0042)	0.0042	(0.0043)
	Time	Year Dummies		No	No	Yes		No	No	Yes
R&D / Outut Equation		R^2	0.022	0.098	0.099	0.110	0.0055	0.400	0.400	0.414
		chi2	9.2 **	30.0 ***	30.3	33.5 ***	2.9	128.1 ***	128.3	134.5 ***
		RMSE	0.199	0.192	0.192	0.191	0.917	0.708	0.708	0.700
		n	250	243	243	243	207	181	181	181
Other I/O Eqn		R^2	0.015	0.260	0.262	0.282	0.0087	0.162	0.183	0.224
		chi2	6.6 **	87.1 ***	88.0	93.0 ***	2.1	35.4 ***	40.6	51.9 ***
		RMSE	0.126	0.110	0.110	0.108	0.231	0.208	0.206	0.200

Notes: Standard errors in parentheses; *significant at 0.1 level; **significant at 0.05; ***significant at 0.01.