R&D REACTIONS TO HIGH-TECHNOLOGY IMPORT COMPETITION*

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Abstract

For a seventeen-year panel covering 308 U.S. manufacturing corporations, we analyze firms' R&D spending reactions to changes in high-technology imports. On average, companies reduced their R&D/sales ratios in the short run as imports rose. Individual company reactions were heterogeneous, especially for multinational firms. Short-run reactions were more aggressive (i.e., tending toward R&D/sales ratio increases), the more concentrated the markets were in which the companies operated, the larger the company was, and the more diversified the firm's sales mix was. Reactions were less aggressive when special trade barriers had been erected or patent protection was strong in the impacted industries. Companies with a top executive officer educated in science or engineering were more likely to increase R&D/sales ratios in response to an import shock, all else equal. Over the full 17-year sample period, reactions may have shifted toward greater average aggressiveness.

Keywords: International Trade, Research and Development, International Competitiveness

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I. Introduction

Once so dominant in high-technology fields that Servan-Schreiber (1968, p. 63) called their lead "overwhelming," U.S. manufacturers have experienced rapidly growing competition from innovative foreign firms. When challenged by imports, domestic R&D teams can react in a variety of ways. They might in effect lie down and die, as occurred in several branches of consumer electronics; or they may redouble their efforts to meet and perhaps repel the threat, as Boeing did with respect to Airbus and Kodak with respect to Fuji's new 35 mm. color films. This paper taps 1971-87 data for 308 corporations to ask, how did U.S. companies' R&D spending respond to generally rising imports of merchandise embodying new technology? And what industry and company characteristics affected the reaction pattern?

II. Theory

There is a vast theoretical literature on how intensification of rivalry affects incumbent firms' R&D timing and spending decisions. For surveys, see Baldwin and Scott (1987), Reinganum (1989), and Scherer and Ross (1990, Chapter 17). Predicted outcomes are sensitive to the assumptions made about the nature of first-mover advantages and other relevant variables. However, several generalizations emerge.[1]

(1) When market structure is endogenously determined by the equation with quasi-rents and R&D costs, an increase in the

number of rivals can lead to either increased or decreased R&D spending by individual firms, depending upon the exact structure.

(2) When market structure is exogenous, an increase in the number of symmetrically positioned rivals induces higher individual firm R&D outlays (an "aggressive" reaction) up to a point, but if rivalry becomes too intense, R&D spending will be cut back or discontinued (a "submissive" reaction).[2]

(3) Reactions are less likely to be submissive with large numbers of rivals, the more rapidly R&D costs fall with advancing knowledge.

(4) Firms dominating their home markets tend to be slow innovators, but react aggressively and perhaps preemptively when their positions are threatened by smaller innovators or new entrants.

(5) When, because of recognition lags or other asymmetries, one firm gains an overwhelming lead in a new product rivalry, the other firms are likely to react submissively, i.e., cutting back or discontinuing competing R&D efforts.

III. Measuring the Variables

Asymmetries like those emphasized in theoretical proposition (5) may have been especially prominent when U.S. companies were confronted with new high-technology competition from abroad during the 1970s and 1980s. Data permitting a direct test of how U.S. firms' R&D spending reacted to changes in the outlays of overseas rivals are not available. However, the vigor of foreign firms' competition can be proxied by their success in importing to the United States technology-based products. Concretely, our sample is limited to companies whose sales are principally in Standard Industrial Classification groups 26, 28, 30, and 32-39, in which product and/or process innovation has been prominent.[3] The magnitude of the foreign challenge is measured by the ratio of imports to domestic output and, to recognize that in industries such as automobiles and computers, multinational firms simultaneously export and import similar products, by net exports, i.e., the ratio of exports minus imports to domestic output.[4]

A limitation of the import indices comes from the possibility that, after penetrating the U.S. market with high-technology imports, foreign firms may invest in production facilities within the United States. If foreign direct investment (FDI) is positively correlated with import penetration, estimates of domestic firms' R&D reactions to foreign competition will be exaggerated. If FDI replaces imports so much that the two are negatively correlated, reactions estimated using import data alone will be biased toward zero. Data on foreign firms' manufacturing activities in the United States are available only at higher levels of industry aggregation, and for less complete time series, than the import data used in most of this paper. For 64 (mostly) three-digit aggregations spanning the same SIC codes as our main sample, the correlation between the 1981 payrolls of foreign-owned plants as a percentage of total industry payrolls and U.S. industry imports as a fraction of output ranged from 0.16 to 0.19, depending upon the lag.[5] None of the correlations is statistically significant, suggesting that the positive bias imparted by taking import penetration as a proxy for foreign competition generally is at worst modest.

Time series data needed to estimate short-run R&D reaction coefficients were drawn from annual Census Bureau surveys of R&D expenditures by corporations operating in the United States. A relatively long panel was deemed essential to span the period of R&D spending stagnation during the early 1970s, the resurgence in the late 1970s and early 1980s, the sharp increase in imports between 1983 and 1986, and the renewed stagnation of industrial R&D growth from 1986 on. See National Science Board (1989, p. 351). The maximum period for which usable data were available was from 1971 through 1987. Because only companies with sizable threshold levels of R&D are surveyed with unit probability, because not all "certainty" survey members responded in every year, because many companies disappeared through merger, and because of other data-linking problems, the sample was winnowed to 308 companies with acceptably complete and accurate time series.[6] The sample companies, mostly but not all large, accounted for 62 percent of all U.S. company-financed R&D in

1972, 61 percent in 1980, and 51 percent in 1985. Their declining aggregate share suggests an omission from our sample: rapidly growing high-technology companies too small to qualify for sample inclusion between 1971 and 1975, the first of four Census sampling frames.

Mergers, sell-offs, and other corporate restructurings pose another analytic challenge. With one short-lived exception, reliable industrial R&D data are available only at the whole-company level. But consider what happens when a company such as ITT, originally specialized in the high-technology telecommunications equipment field, acquires a sizable low-technology company, e.g., Continental Baking. The R&D/sales ratio drops abruptly from one year to the next for no reason plausibly connected with import competition. The opposite happens when, as in 1984, ITT sold off Continental Baking. To deal with such structural changes, which were widespread due to a major sell-off wave during the 1970s and a merger wave in the 1980s, we adopt a novel technique. We define a variable:

$$(1) \quad RDINDEX_{it} = \sum_{j=1}^{449} w_{ijt}(RD/S)_{j,77},$$

where $(RD/S)_{j,77}$ is the average 1976-77 ratio of R&D to sales in the j^{th} industry occupied by company i and w_{ijt} is the share of company i's total domestic manufacturing industry sales in four-digit industry j during year t.[7] Thus, RDINDEX is an industry-weighted average telling what company i's R&D/sales ratio would be if the company pursued R&D exactly as intensively in each of its domestic lines as all surveyed companies in those lines did during 1976 and 1977. Changes in company structure, e.g., through mergers and sell-offs, lead to changes in the weighting variable w_{ijt} and hence in RDINDEX. We use as our dependent variable in the time series analyses that follow the first differences over time in an adjusted R&D variable:

$$(2) \quad ADJRD_{it} = (RD/S)_{it} - RDINDEX_{it},$$

where $(RD/S)_{it}$ is the ratio of company i's self-financed R&D conducted in the United States to its domestic sales. The R&D variables are henceforth scaled uniformly in percentage terms, i.e., as the ratios x 100.

RDINDEX in effect controls for structural differences in what students of R&D have called "technological opportunity." See Baldwin and Scott (1987, pp. 105-109) and Cohen and Levin (1987). Table 1 tests its effectiveness in doing so. In regression 1.1, annual R&D/sales ratios (in the levels, not time differences) for the 308 sample companies are regressed on RDINDEX alone. The r^2 is 0.492, surpassing the explanatory power achieved in earlier studies using fixed industry effects or survey-based variables to measure technological opportunity.

Regression 1.2 adds dummy variables for each year 1972-87 and a price-cost margin variable PCM_{it}.[8] The dummy variable coefficients exhibit a cyclical pattern, with R&D outlays, which tend to be relatively sticky from one year to the next, falling less than sales in recession years 1975 and 1982. A rising trend in the late 1970s and mid-1980s is also evident. The coefficient of 1.247 on RDINDEX after correcting for time effects shows that our sample companies were over-achievers relative to averages for the industries in which they operated. This selection bias occurred because companies had to exceed certain R&D spending thresholds consistently to remain in the Census Bureau's "certainty" sample. The PCM coefficient is significantly positive, confirming either the operation of the Dorfman-Steiner theorem in short-run R&D spending decision-making or the necessity, in the long run, for quasi-rents to be elevated enough to cover R&D expenditures.[9]

The other main variables in our time series analysis seek to measure the intensity of import competition. Import data are necessarily collected at the industry or product line level. They are linked to sample companies by computing weighted averages, i.e., of import/output ratios $(IMP/VS)_{jt}$ in industry j multiplied by w_{ijt}, the share of company i's sales recorded in industry j during year t. Like R&D/sales ratios, the weighted average import competition values can vary, sometimes wildly, with changes in company structure over time. We control for structural changes by defining an import index variable, which is the sales share-weighted average of imports (or net exports) as a percentage of domestic value of shipments, averaged over the base years 1978-80. Our adjusted measures of import competition for company i are therefore:

$$(3)\quad ADJIMP_{it} = \sum_{j=1}^{449} w_{ijt}(IMP/VS)_{jt} - \sum_{j=1}^{449} w_{ijt}(IMP/VS)_{j,78\text{-}80};$$

$$(4)\quad ADJNX_{it} = \sum_{j=1}^{449} w_{ijt}(NX/VS)_{jt} - \sum_{j=1}^{449} w_{ijt}(NX/VS)_{j,78\text{-}80};$$

for imports and net exports respectively. The scaling, again, is in percentage form.

Along with year dummies, three additional time series variables will be used. For one, Lichtenberg (1988) has shown that some company-financed R&D is devoted to winning future government R&D and procurement contracts. We test this hypothesis by including a forward-lagged variable FEDRD/S, measuring a company's federal contract R&D outlays as a percentage of sales. Second, special import quotas, tariffs, and other trade barriers were emplaced by the United States government with increasing frequency during the 1970s and 1980s to protect domestic producers from import competition. If competition spurs innovation, such barriers could lead companies to relax their R&D efforts, but if competition undermines appropriability so severely that R&D becomes unprofitable, barriers could facilitate intensified R&D. Our measure of trade barriers began with a tabulation of affirmed trade restraint actions by four-digit industry, with a dummy variable for each year during which Section 201 "escape clause" barriers were in effect and another dummy for the first three years of restraint under other sections of the currently applicable U.S. Trade Act. These industry dummies were linked to the company level using the sales share weights w_{ijt}, and the two weighted average variables computed in this manner were then summed to form the composite company index $TRADEBAR_{it}$. Finally, we introduce a dummy variable $TECHED_{it}$, whose value is 1 if at least one of a company's top two executives in year t had a university scientific or engineering educational background and zero otherwise. The expectation was that companies led by technically educated individuals would react more aggressively to high-technology import competition.

IV. The Time Series Model

Our basic hypothesis is that U.S. firms alter their R&D/sales ratios in response to changes in technology-based import competition, shown by falling or (mostly) rising import/output ratios. This implies a differences regression of the general form:

(5) $\text{ª}ADJRD_{it} = a + b_1 L(\text{ª}ADJIMP)_{it} + b_2 X_{it} + e_{it}$,

where X is a matrix of business conditions, profitability, government contract opportunity, trade protection, and other relevant variables and L(.) is a lag operator. Because of imperfect links between industry-level trade flows and weighted company-level aggregates, ªADJIMP is measured with error. This, as Griliches and Hausman (1986) have shown, is likely to cause the b_1 reaction coefficients to be biased toward zero, especially in a first differences time series specification.[10]

In addition, unusually large changes in both the R&D and import first differences sometimes materialized, especially when multi-line plants experienced sales mix changes, causing their industry classification to jump from one SIC category to another. A plot revealed the first differences of ADJRD, ADJIMP, and ADJNX to have a non-normal distribution, peaked near the mean values but with long, thin tails on both sides. The extreme ªADJRD and ªADJIMP values were nearly orthogonal, and because of the disproportionate weight they received in OLS regressions, they forced estimated response coefficients to be statistically insignificant. To deal with this outlier problem, common in detailed micro-data sets, we deleted 77 to 104 observations on which either ªADJRD or an adjusted import competition variable lay more than four standard deviations from its mean.[11] Sensitivity tests revealed sign patterns to be essentially unaltered over alternative truncation thresholds, but the statistical significance of estimated coefficients declined as the thresholds were moved well above and well below four standard deviations.

Table 2 presents the basic results, with regressions using ªADJIMP as the import impact variable in the left-hand columns and those using ªADJNX in the right-hand columns.

Perhaps the most striking result is the regressions' weak explanatory power, shown by low R^2 values. Tests for autocorrelation revealed that the considerable amount of residual noise was essentially "white," at least in the time series dimension. There was no evidence of systematic heteroskedastity.

Despite the high noise levels, systematic signals were detected. The import reaction coefficients reveal that on average, U.S. companies' R&D spending was cut back in response to import shocks, traceable largely to the contemporaneous year and (for net exports) the preceding year. (For imports, reactions with negative signs are "submissive," those with positive signs "aggressive." For net exports, whose value falls with rising imports, ceteris paribus, a positive sign implies a submissive response.) Had rising imports merely eroded companies' domestic sales without inducing R&D spending changes, the denominator effect should have led to rising R&D/sales ratios, so coefficients showing a submissive response to imports imply a distinct behavioral change. The reactions were small and (for imports) of marginal statistical significance. Thus, the ADJIMP(T) coefficient in regression 2.1 implies that a ten percentage point increase in imports reduced the average company's R&D as a percentage of sales from 3.25 (the all-company average) to 3.16, all else equal. From regressions 2.2 and 2.7, which add a forward import lag, there is no indication that firms anticipated the shocks in their R&D behavior.

Regressions 2.3 and 2.8, which compress the import variables into a triangular lag structure with weights of 0.6 for year T, 0.25 for T-1, 0.1 for T-2, and 0.05 for T-3, have either superior or insignificantly inferior explanatory power compared to their unconstrained four-lag counterparts. Because of its parsimoniousness and lower susceptibility to multicollinearity problems, we emphasize the triangular lag specification in subsequent regressions.

In all regressions, changes in company price-cost margins ªPCM have signs contrary to original expectations. Further investigation clarified this surprise. According to U.S. Census Bureau enterprise statistics (1986, pp. 4, 11), more than half of all industrial R&D employees work outside free-standing laboratories or other central offices; that is, they are employed within plants that also produce goods for sale. An increase in R&D outlays thus raises in-plant materials and payroll costs, reducing price-cost margins in the short run. Rewards in the form of increased PCMs follow only with a lag.

The use of forward-lagged federal contract R&D/sales ratios to test the Lichtenberg hypothesis was uniformly unsuccessful, perhaps because the lag from company-financed R&D to the receipt of government R&D contracts exceeded one year (the maximum forward lag allowed by the data), and/or because production as well as R&D contracts and subcontracts were sought.

The negative and marginally significant coefficients on TRADEBARS suggests that companies whose industries enjoyed special import protection had slightly lower R&D/sales ratio growth, all else (including import changes) held equal. Regressions 2.4 and 2.9 explore whether protection from imports affected the strength of companies' reactions to rising imports. The evidence is mixed. For imports directly, but not net exports, the interaction effect is statistically significant, but it erodes the non-interacting reaction coefficient because of multicollinearity. For a company protected continuously from import competition (TRADEBARS = 1)[12], a ten percentage point increase in imports led to an annual R&D decline of 0.52 percentage points. Thus, strong import protection made companies' reactions more submissive on average.

Regressions 2.5 and 2.10 introduce an interaction between the triangularly lagged import variables and the dummy variable indicating whether a company had a leader educated in science or engineering. For both imports and net exports, there is a significant increase in R^2 values. Despite a multicollinearity impact on the non-interactive import coefficient, it is clear that having a technically educated top executive made companies' reactions more aggressive on average.

In sum, our time series analysis reveals much unsystematic variation in company R&D/sales ratio changes from one year to the next and a weak average tendency toward submissive short-run reactions to rising import competition. Having protection from imports appears to have rendered the reactions slightly more submissive. The presence of a top executive with a scientific or engineering educational background contributed to aggressive responses.

V. Why Reactions Differ: Cross-Section Analysis

One reason why the regressions in Table 2 have little explanatory power might be that firms' reactions to import shocks were heterogeneous. In this section we develop support for that hypothesis and explore why reactions differed from one company to another.

For each of the 308 sample members, we computed individual time series regressions of the form:

$$(6)\ {}^{a}ADJRD_{it} = a + b_1{}^{a}ADJIMP(TD)_{it} + b_2YEAR + b_3BUSCON_{it} + e_{it},$$

where ADJRD(TD) is a triangularly distributed import lag similar to those tested in regression 2.3 (replaced by ªADJNX(TD) in other company regressions), YEAR a time variable, and BUSCON a business cycle index. Specifically, BUSCON measures year-to-year percentage changes in real manufacturing GNP, subdivided between durable and nondurable goods industries, with the components weighted to the company level by the shares of company sales each year comprising durables and nondurables. BUSCON and YEAR together control for trend and business cycle effects more parsimoniously than the 16 annual dummy variables used in the Table 2 regressions, but were found in parallel full-sample regressions to leave the import coefficient values essentially unaffected.

In the individual company regressions for both imports and net exports, the hypothesis of heterogeneous time and business cycle effects is rejected. However, adding 308 separately estimated import reaction coefficients to the regressions of R&D/sales first differences on BUSCON and YEAR revealed significant heterogeneity, with F(308,3558) = 1.37 for the triangularly distributed import regressions and F(308,3531) = 1.46 for the net export regressions.[13] (The F-test one percent significance point is 1.24.) The mean import reaction coefficient value was -0.088 -- nine times the value estimated in pooled regression 2.3. The average value of five coefficients nearest the median was -0.032. Fifty-nine percent of the 308 import reaction coefficients were negative. The mean net export reaction coefficient value was +0.021, 1.16 times the value estimated in regression 2.8. Positive coefficients emerged for 55.5 percent of the 308 companies. Thus, the disaggregated regressions continue to exhibit submissive reactions on average, but with marked heterogeneity.

Companies might react heterogeneously to intensified import competition because of differing sales and market structures, technological opportunities advancing at unequal rates, diverse means of appropriating the benefits from technological innovation, and more or less rich links to science bases. The role of these differences is investigated in two stages.

Some of the companies in our sample operated mainly in the United States, while others had extensive multinational activities. We test the role of multinationality by identifying the subset of companies reporting R&D expenditures outside the United States in any Census Bureau survey year. The average reaction coefficients b_1 (from equation (6) above) for the two distinct groups were as follows:

	Imports	Net Exports
191 firms with overseas R&D	-0.097	-0.003
117 firms without overseas R&D	-0.074	+0.061

For companies without overseas R&D, the mean reactions were consistently submissive and of similar magnitude. Companies <u>with</u> overseas R&D differed insignificantly from those without in their reaction to changing imports; F(1,306) = 0.16. However, the two groups exhibit quite different mean reactions to changes in net exports; F(1,306) = 3.98, exceeding the 5% point of 3.88. The near-zero net export reactions of R&D multinationals may reflect a tendency for increases in imports from offshore branches to be offset by increasing exports from their U.S. plants. The <u>import</u> reactions of R&D multinationals were also much more heterogeneous than those of domestic specialists. The null hypothesis of homogeneous import reaction coefficient variances is rejected at the 1% level, with F(191,117) = 2.39.[14] The widely varying reactions of R&D multinationals may imply more diverse threats (e.g., with rising imports coming in some cases from rivals and in others from captive overseas branches) and the ability to increase defensive R&D overseas as well as, or instead of, in the United States.

The impact of other environmental variables on company reactions is tested by estimating cross-sectional regression equations of the form:

$$(7) \quad b_{i,\Delta ADJIMP(TD)} = a + kZ_i + e_i,$$

where b(.) is the import or net exports reaction coefficient estimated from individual company regressions (6) above and Z is a matrix of explanatory variables.[15] Because the b(.) coefficients are estimated with varying precision, we compute (7) using weighted least squares, with the inverse of the b(.) coefficient standard errors serving as weights.

A given percentage increase in import penetration reduces producers' domestic sales proportionately, all else equal, but it causes larger absolute sales (and presumably, quasi-rent) losses for firms with large market shares than for smaller sellers. One therefore expects firms with larger market shares to react more aggressively, all else equal.[16] We measure this structural influence through three variables: CR4, the average four-seller 1977 domestic concentration ratio for the industries occupied by a company, weighted as in other industry - company linkages by the firm's sales shares w_{ijt}; LOGSALES, the logarithm (to base 10) of average company sales over the 17 year sample period; and DIVERS, a Herfindahl-type diversification index obtained by summing the squared values of w_{ijt} and averaging those values over the sample period. The more specialized a company's industry focus, the more nearly DIVERS approaches unity from its lower bound of zero.

The perceived importance of diverse means of appropriating the quasi-rents from innovation and the strength of company links to the science base have been measured through a survey of 650 industrial R&D managers by a Yale University group. See Levin et al. (1987). The survey responses are available for 130 three- and four-digit industry categories, including most of the industries in which our sample companies concentrated their efforts. Potentially relevant variables from the Yale survey data set were linked to our sample companies using the weighting factor w_{ijt}, with t = 1979.[17] Table 3 provides mnemonics and descriptions. Because some Yale survey variables were derived from only one or a very few respondents, creating a sampling error problem, because aggregation to the firm level compresses the variables' variance and lessens their explanatory power, and because many of the variables are mildly collinear, coefficient values proved to be unstable when several collinear variables were introduced simultaneously, so we proceed in clusters.

Table 4 reports the principal results, with import reaction coefficient regressions on the left-hand side and net export coefficient regressions on the right-hand side.

The structural hypotheses are strongly supported, although the exact chain of causation is left in doubt because of collinearity among the LOGSALES, DIVERS, and CR4 variables. (The simple correlation between DIVERS, whose value <u>falls</u> with greater diversification, and LOGSALES is -0.517; the correlation between CR4 and LOGSALES is 0.096.) LOGSALES has higher t-ratios than DIVERS, but undermines the significance of CR4, which, without LOGSALES, is consistently significant.[18] DIVERS shares a significant explanatory role with CR4, with which it is uncorrelated, in both sets of regressions. Evidently, some combination of large firm size, high seller market shares, and extensive diversification made firms' R&D reactions to import shocks more aggressive. Whether diversification had its effect because it implies larger size, even though smaller market shares for a given sales volume, or whether more diversified companies had greater shock absorption capacity, remains unclear.

For the appropriation and science base variables, the results are more equivocal. Submissive reactions are associated with strong patent protection, although for net exports, the coefficients are not statistically significant. An emphasis on customer service was consistently but even more weakly linked to submission. When market positions were captured by moving rapidly down the learning curve, aggressive reactions were somewhat more likely. (In unreported regressions lacking the SCIENCE variable, LEARNING was statistically significant.) SCIENCE itself has coefficients significant for imports, but not for net exports, whose signs contradict the originally maintained hypothesis that firms for which the science base was highly relevant would react more aggressively. A possible rationalization is that Japanese companies, who have sustained the most broad-ranging high-technology import challenge to American industry, have been more aggressive than their American counterparts in exploiting the possibilities opened up by academic science.[19] An alternative technological opportunity measure characterizing the rate at which new and improved products were introduced during the 1970s was consistently insignificant. Companies occupying industries in which product niche-filling was an important strategy exhibited weakly submissive reactions. For imports but not net exports, regression 4.4 reveals, reactions were significantly more aggressive in industries where process R&D, on which Japanese firms spend a higher fraction of their R&D budgets than American industry, was emphasized.[20]

We found earlier that reactions to changing imports and especially net exports differed between companies with and without overseas R&D operations. To explore this difference further, the company sample was again divided into two groups, and the homogeneity of the regression coefficients for regressions 4.1, 4.2, 4.5, and 4.6 was tested. In every case, a heterogeneity hypothesis is rejected, with F-ratios ranging between 0.41 and 0.61. Although R&D multinationals reacted differently to import shocks,[21] their reactions were influenced in similar ways by the domestic structure, appropriability, and science base variables.

VI. Long-Run Growth Relationships

Our focus thus far has been the short-run reaction of companies to import shocks. It is conceivable that longer-run reactions could be more aggressive on average, e.g., as companies defeated in one round of a new product competition strain to catch up when the next generation is developed. For a longer-run view, we analyze a variable RDGROWTH, which is the average percentage rate per year at which a company's R&D/sales ratios grew over the 1971-87 time frame. It was estimated by regressing the logarithms of RD/S linearly on a calendar year variable. Its average value for the 308 companies was 1.87 percent, with a standard deviation of 4.72 percent.

We expect the growth of R&D intensity to be influenced not only by the intensity of import competition, but also by a host of company structure and technological opportunity variables. In addition to the variables SCIENCE and TECHCHANGE, both of which were considered highly relevant, but proved weak statistically in RDGROWTH regressions and are therefore omitted, we define the following variables:

IMPGROWTH: The log-linear growth trend of imports as a percentage of domestic output, 1971-86.

NXGROWTH: The log-linear growth trend of net exports as a percentage of domestic output, 1971-86.

FUTADV: A Yale survey variable recording whether product development opportunities were expected to be greater in the 1980s than in the 1970s.

FEDRD/S: Federally-supported R&D as a percentage of sales; 1971-87 average.

OVERSEAS: R&D conducted in company laboratories outside the United States as a percentage of domestic sales.

FOREIGN: A dummy variable with unit value for companies owned by a foreign parent throughout 1971-87.

AVEPCM: Average price-cost margin in the company's domestic manufacturing operations, 1971-1986.

TRADEBARS: Seventeen-year average of the trade barriers variable used in the Table 2 analysis.

TARGETDIFF: The arithmetic difference between the actual company-financed R&D/sales ratio, averaged over 17 years, and the similarly averaged TARGET ratio.

Most of the variables have transparent rationales. TARGETDIFF is less obvious. It accounts for the possibility of Galtonian regression. This is, firms which are R&D over-achievers relative to the norms of industries they occupy might be expected to have relatively low R&D growth rates, all else equal.

Table 5 reports the results of weighted least squares regressions for all of the variables defined above. Each observation is weighted by the inverse of the standard error from the regression estimating that company's R&D/sales growth rate. The import and net export growth variables, which are highly correlated ($r = -0.90$), are introduced separately.[22]

The import competition variables show a long-run tendency toward aggressive reactions to import competition, although neither coefficient reaches conventionally accepted statistical significance thresholds. The erection of trade barriers is associated with slower R&D growth, all else equal. Whether this reflects the lulling effect of protection or the possibility that, despite protection, import growth undermined the profitability of R&D, cannot be inferred confidently. That both import growth and profitability are taken into account by other variables lends credence to the "lulling" interpretation.

Higher price-cost margins are associated with more rapid R&D growth rates as well as (see Table 1) the level of R&D. Since much of the growth in R&D/sales ratios occurred during the 1980s, the relatively strong performance of the FUTADV variable, predicting the rate of technical change during that period, is not surprising. A Yale survey variable evaluating the pace of product technology change during the 1970s had no explanatory power. Consistent with Lichtenberg's findings, an active position in federal R&D contracting was weakly conducive to the growth of company-financed R&D during our sample period, characterized by generally rising military R&D and procurement. The establishment of R&D laboratories overseas does not appear to have impaired the growth of R&D spending at home. U.S. R&D operations owned by foreign corporations experienced lower domestic growth rates,although the effect falls short of statistical significance. There is only weak evidence of Galtonian regression in R&D growth rates.

VI. Conclusion

We have analyzed the R&D spending reactions of U.S. companies to high-technology import competition, which intensified between 1971 and 1987. Most changes in company R&D/sales ratios were unsystematic, related neither to import competition changes nor to other plausible explanatory variables. But import competition does appear to have made a difference. The short-run reaction to increased imports was on average submissive, that is, R&D/sales ratios fell. However, reactions varied widely from company to company. Large, diversified firms occupying concentrated markets reacted more aggressively than their smaller, less diversified counterparts. Multinationals reacted more heterogeneously to imports and less submissively to net export reductions. Insulation from import competition through trade barriers or strong patent protection blunted firms' short-run reactions. Over the longer run, there appears to have been a reversal of the average reaction pattern from submissive to aggressive, although the evidence on this point remains weak.

During the past half century, American industry has enjoyed comparative advantage across a broad range of high-technology products. How U.S. firms react to growing high-technology import competition is likely to influence future patterns of comparative advantage. Although we have provided some first insights into the dynamics of these reactions and the factors that influence them, much remains to be learned from further empirical research.

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Table 1

REGRESSION ANALYSIS OF ANNUAL R&D/SALES LEVELS*

308 Companies, 1971-87 (N = 5,210)

Explanatory Variables	Equation 1.1		Equation 1.2	
RDINDEX	1.323	(71.01)	1.247	(65.91)
PCM			2.931	(12.95)
DUM72			-0.13	(0.76)
DUM73			-0.24	(1.37)
DUM74			-0.29	(1.67)
DUM75			-0.10	(0.55)
DUM76			-0.15	(0.84)
DUM77			-0.08	(0.47)
DUM78			-0.17	(0.97)
DUM79			-0.13	(0.76)
DUM80			0.08	(0.49)
DUM81			0.20	(1.17)
DUM82			0.63	(3.59)
DUM83			0.63	(3.63)
DUM84			0.53	(3.04)
DUM85			0.66	(3.80)
DUM86			0.78	(4.44)
DUM87			0.69	(3.88)
Intercept	0.091	(1.68)	-0.70	(5.01)
R^2	0.492		0.520	

*OLS estimates. T-ratios are presented in parentheses. The intercept in equation 1.2 is the deviation from the mean for 1971.

Table 2

OLS REGRESSION ANALYSIS OF ANNUAL R&D/SALES FIRST DIFFERENCES

308 Companies, 1971-78

Independent Variable:	Regression Number 2.1	2.2	2.3	2.4	2.5
[a]ADJIMP(T)	-.0085 (1.60)	-.0091 (1.69)			
[a]ADJIMP(T-1)	.0059 (1.10)	.0099 (1.76)			
[a]ADJIMP(T-2)	-.0078 (1.40)	-.0024 (0.42)			
[a]ADJIMP(T-3)	-.0014 (0.25)	.0098 (1.60)			
[a]ADJIMP(T+1)		-.0015 (0.29)			
[a]ADJIMP(TD)			-.0099 (1.28)	.0041 (0.47)	-.0170 (1.50)
[a]PCM	-1.079 (6.69)	-.994 (6.31)	-1.074 (6.77)	-1.096 (6.91)	-1.311 (6.28)
[a]FEDRD(T+1)	.0027 (0.25)	-.0003 (0.03)	.0033 (0.31)	.0034 (0.32)	.0014 (0.13)
TRADEBARS	-.0654 (1.49)	-.0704 (1.61)	-.0660 (1.51)		
[a]ADJIMP(TD) x TRADEBARS				-.0557 (3.32)	
[a]ADJIMP(TD) x TECHED					.0156 (1.60)
17 Year Intercepts		(s u p p r e s s e d)			
R^2	.0447	.0462	.0439	.0457	.0519
N	4761	4761	4741	4741	3431

Table 2 (continued)

	2.6	2.7	2.8	2.9	2.10
[a]ADJNX(T)	.0099	.0088			
	(2.53)	(2.24)			
[a]ADJNX(T-1)	.0071	.0030			
	(1.83)	(0.73)			
[a]ADJNX(T-2)	.0004	-.0025			
	(0.09)	(0.59)			
[a]ADJNX(T-3)	-.0011	-.0059			
	(0.27)	(1.33)			
[a]ADJNX(T+1)		.0016			
		(0.41)			
[a]ADJNX(TD)			.0181	.0180	.0194
			(3.05)	(3.04)	(2.14)
[a]PCM	-1.021	-.888	-1.022	-1.021	-1.140
	(6.34)	(5.58)	(6.35)	(6.34)	(5.41)
[a]FEDRD(T+1)	.0086	.0054	.0087	.0083	.0080
	(0.79)	(0.46)	(0.81)	(0.77)	(0.72)
TRADEBARS	-.0545	-.0636	-.0544		
	(1.25)	(1.47)	(1.25)		
[a]ADJNX(TD) x TRADEBARS				-.0013	
				(0.09)	
[a]ADJNX(TD) x TECHED					-.0093
					(1.30)
Intercepts		(s u p p r e s s e d)			
R^2	.0446	.0460	.0447	.0444	.0512
N	4761	4761	4734	4734	3407

Table 3

VARIABLES FROM THE YALE SURVEY*

PRODPAT	How effective are patents as a means of capturing and protecting the advantages from new or improved products?
LEARNING	How important is moving quickly down the learning curve as a means of capturing and protecting the advantages from new or improved products?
SERVICE	How important are superior sales or service efforts as a means of capturing and protecting the advantages from new or improved products?
SCIENCE	How relevant were the basic sciences of biology, chemistry, and physics (average of three) to technological progress in this line of business over the past 10-15 years?
NICHES	To what extent have technological activities been oriented toward designing products for specific market segments?
PCTPROC	What percent of total R&D in the industry is directed toward new production processes, as distinguished from new and improved products? (Scaled from 0 to 100)

*Measured on a Likert scale of 1 to 7, with "7" implying "very effective" or "very important" or "very relevant" and 1 the opposite, unless otherwise stated.

Table 4

GLS REGRESSIONS OF COMPANY IMPORT REACTION COEFFICIENTS ON EXPLANATORY VARIABLES (N = 308)*

Explanatory Variable	Dependent Variable: $b_{aADJIMP(TD)}$ 4.1	4.2	4.3	4.4
LOGSALES	.058 (2.88)			
DIVERS		-.098 (2.01)	-.099 (2.11)	-.094 (2.03)
CR4	.0009 (1.49)	.0017 (2.65)	.0013 (2.08)	.0021 (3.17)
PRODPAT	-.047 (2.72)	-.043 (2.49)		-.052 (2.92)
SERVICE	-.023 (0.67)	-.035 (1.00)	-.030 (0.90)	-.044 (1.31)
LEARNING			.033 (0.96)	
SCIENCE	-.058 (2.17)	-.053 (1.98)	-.054 (2.01)	-.063 (2.36)
NICHES	-.023 (0.89)	-.0006 (0.02)		
PCTPROC				.0010 (2.00)
Intercept	0.28 (0.94)	0.54 (1.95)	0.18 (0.71)	0.62 (2.83)
R^2	.119	.131	.098	.131

*T-ratios are presented in subscripted parentheses. The R^2 values are for unweighted regressions with identical variables.

Table 4 (continued)

Explanatory Variable	Dependent Variable: b. [a]ADJNX(TD)			
	4.5	4.6	4.7	4.8
LOGSALES	-.045 (3.07)			
DIVERS		.063 (1.92)	.062 (1.93)	.060 (1.89)
CR4	-.0005 (1.01)	-.0011 (2.24)	-.0011 (2.31)	-.0011 (2.34)
PRODPAT	.0043 (0.36)	.0035 (0.28)		.0047 (0.38)
SERVICE	.004 (0.18)	.012 (0.53)	.011 (0.47)	.013 (0.59)
LEARNING			.012 (0.51)	
SCIENCE	.019 (1.01)	.014 (0.76)	.016 (0.87)	.017 (0.92)
NICHES	.011 (0.64)	-.007 (0.04)		
PCTPROC				.0002 (0.70)
Intercept	0.12 (0.59)	-0.11 (0.59)	-0.16 (0.89)	-0.13 (0.87)
R^2	.105	.071	.073	.072

Table 5
GLS R&D GROWTH RATE REGRESSIONS (N = 308 COMPANIES)

Independent Variables	5.1	5.2
IMPGROWTH	.306 (1.25)	
NXGROWTH		-.165 (0.64)
TRADEBARS	-2.84 (1.81)	-2.84 (1.81)
AVEPCM	4.07 (2.25)	4.00 (2.21)
FUTADV	1.12 (2.07)	1.15 (2.12)
FEDRD/S	.075 (0.99)	.076 (0.99)
OVERSEAS	.415 (1.24)	.403 (1.20)
FOREIGN	-.466 (0.34)	-.464 (0.34)
TARGETDIFF	-.104 (0.90)	-.093 (0.81)
Intercept	-5.04 (1.80)	-5.04 (1.80)
R^2	.075	.070

*T-ratios are presented in subscripted parentheses. The R^2 values are for unweighted regressions with identical variables.

ENDNOTES

1. For a more complete statement of the relevant theory, see Scherer (forthcoming, Chapter 2).

2. The concept of "aggressive" and "submissive" reactions is drawn from Richardson's theory of arms race spending (1960, Chapter IV).

3. Petroleum refining (SIC 29) was excluded because import patterns were affected strongly by OPEC shocks. Some sectors such as paper products (SIC 26) and primary metals (SIC 33) had low rates of product innovation, but substantial process innovation affecting their competitiveness.

4. We are indebted to John Abowd and Larry Katz of the National Bureau of Economic Research and Bill Sullivan of the Industry Statistics Division, International Trade Administration, U. S. Department of Commerce, who provided the data from which our IMP and NX time series by four-digit SIC industry were developed.

5. The foreign-owned plant payroll data are from U. S. Bureau of the Census (1983). Publication of the series was discontinued after 1982.

6. In 18 cases, observations were available only for 1971-86, and in four cases, only for 1971-85. In several dozen cases where responses were missing for single years between 1972 and 1984, the missing R&D/sales values were interpolated linearly.

7. The R&D/sales ratios are averaged from the Federal Trade Commission Line of Business surveys for 1976 and 1977. The "LB" surveys, providing by far the most finely disaggregated statistics on industry R&D expenditures, ended after 1977, hence the termination of the index variable at that year.

8. PCM = (Value of shipments - materials costs - payroll costs - supplementary benefit costs) / (value of shipments) for company i's domestic manufacturing plants in year t. It is scaled in ratio form.

9. The coefficient value implies more support for the short-run view, since a ten percentage point increase in PCM is associated with a 0.29 percentage point increase in the R&D/sales variable, ceteris paribus.

10. Omission of on-shore manufacturing by offshore companies could, as we have been, impart a weak bias in the opposite direction.

11. Inspection revealed that most of the deleted observations were the result of classification or measurement errors rather than meaningful structural changes. After truncation, the mean year-to-year change in the R&D/sales ratio was 0.033 percentage points, with a standard deviation of .075 points. Before truncation, the mean was 0.039 points and the standard deviation 0.87 points. For ADJIMP, the mean year-to-year change before truncation was 0.77 percentage points and,

after truncation, 0.69 points. The standard deviations were 4.07 and 2.10 points respectively.

12. Values of TRADEBARS could exceed unit for companies whose industries had continuing protection under both Section 201 and other Trade Act provisions. The average value was 0.135.

13. The individual company effect controls raise implied R^2 values to 0.293 and 0.305 in the analogues of regressions 2.3 and 2.8 respectively.

14. For the variances of net export reaction coefficients, F = 1.13, which is not statistically significant.

15. In the time series regressions of Table 2, all variables were measured annually, whereas the X variables here are measured only for some subset of the sample years -- in most cases, for a single year.

16. See Scherer and Ross (1990, pp. 635-636).

17. The weighted Yale variables are highly correlated from year to year. E.g., $r^{72,79}$ for the entire data set is 0.988, and $r^{79,85} = 0.978$.

18. A variable measuring changes in domestic industry concentration ratios between 1972 and 1982, aggregated to the company level using the w^{ijt} weights, had coefficients suggesting more submissive reactions in industries of rising concentration, but the effects fell short of being statistically significant.

19. This view is argued by Paul E. Gray, former president of MIT (1990, p. 43).

20. See Mansfield (1988, p. 226). A variable measuring the extent to which Yale survey respondents emphasized product standardization in their R&D had little explanatory power in either imports or net exports regressions.

21. A continuous variable measuring the ratio of companies' overseas R&D outlays to domestic sales, averaged over all years with reported data, had effects of the same signs as those observed with our earlier dichotomous classification, but they were not statistically significant in either the import or net export multiple regressions. A dummy variable identifying seven companies owned by foreign parents throughout the 1971-87 sample period had signs identical to those for U. S.-based R&D multinationals, but all coefficients were statistically insignificant.

22. For the average company, imports grew at a rate of 0.63 percent per year, with a standard deviation of 1.02 points. Net exports declined at an average rate of 0.42 percent, with a standard deviation of 0.99 percent.

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