The Evolution in Japan's Relative Technological Competitiveness Since the 1960s: A Cross-Sectional, Time-Series Analysis

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By focusing on Japanese investment in R & D, relative to those of France and the United States, this paper offers an unique perspective on the remarkable evolution in Japan's international technological competitiveness since the 1960s. The empirical findings, based on annual flow and stock measures of inputs to the R & D process, indicate that Japan's technological development over twenty-five years is particularly striking when compared to that of the United States. For France, a more recent period of relative technological decline is identified. More disaggregate comparisons reveal that Japan's technological challenge has been particularly acute in communications and electronic equipment, electrical machinery, computers, chemicals, automobiles, and precision instruments.

I. Introduction

The Post-War "Japanese economic miracle" has engendered a profound change in the balance of world economic power. At the same time, this transformation has been associated, particularly in recent years, with mounting trade and commercial policy frictions between Japan and its European and North American trading partners. Investment in technology may well be a critical factor in explaining certain of these developments, and thereby have profound implications for current, international economic policy debates. Yet, it is striking that there appears to be no existing disaggregate industrial study of the evolution, over any extended time period, in Japan's *relative* technological position

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As a Visiting Scholar at the Institute for Monetary and Economic Studies of the Bank of Japan, the author benefited from an unique combination of excellent facilities and a convivial environment for conducting much of this study. The research presented here is part of a larger project, which includes work undertaken by the author as a consultant to the Directorate for Science, Technology, and Industry of the O.E.C.D. Thanks are due to John Dryden, Francois Pham, and Alison Young of the Directorate for Science, Technology, and Industry for their clarification of a number of statistical questions. Bernard Franck and Gerard Pfann made several useful suggestions which enhanced this paper's revision. Among the research assistants who contributed to this project are Isabelle Cadoret, Eugene Canjels, Francois Henry, Serge Le Neindre, and Nadine Rety. The efforts of Eugene Canjels in this regard are particularly appreciated. Lilian Raetsen assiduously prepared the final version of the manuscript. Finally, financial support from the M.B.A. Institute (Paris) is also gratefully acknowledged. Any limitations of this paper are the author's alone.

internationally.

The role of technological innovation in influencing the relative performance of individual firms, as well as the overall international competitiveness of different economies has, of course, long been a high profile policy question for corporate and government officials alike. Nonetheless, much of the existing policy discussions and research regarding the relation between technological performance and competitiveness appear to have certain serious limitations. On the one hand, policy analysis and studies reflecting a more macroeconomic perspective, notably, for example, those proposed by Ergas (1984a, 1984b, 1986), have focused on quite general assessments of the relative technological positions of a number of countries, including Japan. They have considered why some countries innovate more than others and the extent to which governments' technology policies matter.[1] However, such aggregate comparisons between countries have typically been undertaken without extensive reference to specific statistical measures for different countries' industries over any reasonably long time period. Indeed, in light of the apparent aggregation issues, their overall validity would appear to be predicated on the implicit suppositions that there do not exist major disparities between economies in the technological intensities of different industrial sectors, that there is little variation in the size distribution of industries across countries, and that neither of these relations have significantly changed over time. Even well substantiated inferences based on countries' relative aggregate technological positions, risk to be erroneously generalized across industrial sectors, leading to unproductive or even perverse policies for specific sectors.[2]

On the other hand, much of the rather sophisticated econometric research concerning the links between technological innovation and corporate productivity, as represented by certain of the contributions to the volume edited by Griliches (1984), have examined statistical evidence for individual firms over relatively limited time periods. Furthermore, these studies most often only pertain to one, or a few industries, in a specific country.[3] Clearly, the generality of the empirical findings from such microecono-

[1]Issues related to the rationale for, and obstacles to, cooperative research and development policies by E.E.C. countries have recently been addressed by Jacquemin and Spinoit (1986).

[2]The importance of considering different structural implications of relative technological performance between countries, industries, and even groups of firms within an industry, has been recently highlighted in a comparative study of North American and French industries by Owen (1984). Specifically, that research stressed the impact of the higher levels of U.S. research and development expenditures, undertaken by firms in six out of forty manufacturing industries, when accounting for the relatively larger market shares enjoyed by American foreign subsidiaries over their competitors in those same six French industries. For subsequent reference, the actual sectors identified in that study consist of parachemicals, pharmaceuticals, petroleum and natural gas, office machines and computers, agricultural machinery, and machine tools.

[3]Other examples of such micro approaches based on individual firm data include the papers by Griliches and Mairesse (1983, 1985) and Mairesse and Cuneo (1985). Although the study by Griliches and Mairesse (1983) does consider a comparison of industrial data for fifteen French and American sectors, it relies on R & D proxies for a single year. Their assertion that relative sectoral technological ratios between these two countries remain fairly constant over time is not supported by certain of the empirical findings of the present study.

mic investigations is open to question. Basic methodological problems arise due to corporate acquisitions and mergers, as well as from the confidentiality of the statistics. These partially explain the major difficulties encountered by researchers in obtaining satisfactory data sets, which cover a large numbers of years. Consequently, it remains unclear to what extent these micro approaches adequately control for technological trends, or for a number of potentially relevant macroeconomic factors which may be influenced by the business cycle.

The technological evolution of different industrial sectors in a specific country has been considered by Mansfield (1971) and others, principally in a North American context. Recently, Mansfield (1987a, 1987b, 1987c) has focused more explicitly on industrial R & D comparisons between Japan and the United States. However, his work (1987a) on inter-industry productivity relies on R & D data for only a single year, while his statistical analysis (1987b) of a sample of firms in the Japanese and American robotics industry focuses on a five year period. Although the international statistical analysis of technological performance undertaken by the OECD (1986) does offer a longer-term overview of aggregate R & D trends, across a large number of member countries for the 1970s and early 1980's, a detailed examination of the relative evolution of sectoral R & D intensities between any of the member countries is not offered.

Thus, there would appear to be a potentially important lacuna in existing research, corresponding to the importance of positioning more precisely, not only the evolution in Japan's relative technological position internationally, but also those of the other major OECD countries. In addition, in the case of Japan, although there do exist a few studies of changes in the technological innovativeness of Japanese industries, these are not as yet readily accessible to international scholars.[4] The present empirical investigation, which builds on the paper by Owen (1987), responds to this pressing need for research. It examines Japan's investment in technological innovation, in both absolute terms and relative to R & D innovation in other countries, for a two and a half decade period spanning 1959 through 1984. Hence, distinctive features of the present cross-sectional, time-series investigation arise from both its concern with Japan's relative technological position and the scope of the proposed statistical analysis, which is in several respects more extensive than that of previous inquiries. The relative evolution of both flow and stock measures, based on annual inputs to the R & D process, are analyzed at a disaggregate level for approximately thirty industries, principally in manufacturing. The changes in these sectors' R & D intensities are then considered, not only in relation to the counterpart industries in the United States, but also in comparison with the technological

[4]The apparently most comprehensive, existing investigation of Japan's technological development, which was sponsored by the Economic Planning Agency of the Japanese government, has unfortunately not been translated from Japanese. A noteworthy, recent unpublished study by Goto and Suzuki (1987) investigates the relation between measures of the R & D capital of Japanese industries and their sectoral economic performance.

evolution of a major European country—France.

The organization of the rest of this paper is the following. In the next section the basic research objectives and statistical methodology are spelled out. After discussing certain of the analytical issues to be tested, the statistical and econometric methodology is presented. The tests, for investigating the extent of structural changes and trends in the different technological variables, are explained. They include the use of spline trends. The advantage of the overall statistical approach adopted here results from its generality. It offers a quite comprehensive framework for examining structural changes in the evolution of alternative technology measures—both between the three countries and for the different industrial sectors under consideration. In section III the actual empirical results are presented, and their implications are discussed in detail. A concluding section then summarizes these specific findings, while highlighting the basic contribution of the current study in relation to other research. As previously noted, distinctive aspects of the analysis include its relatively extensive nature, both with regard to the countries, industries, and time period under examination, and the unique focus on Japan's *relative* technological position. Nonetheless, the present paper constitutes only the first step in a much larger research endeavour which seeks to ascertain the relative contribution of technological changes in explaining not only disaggregated, inter-temporal international trade and investment flows, but also the overall macroeconomic performance of Japan, relative to those of the United States and Europe. Section IV outlines this further research agenda, while noting certain limitations of the statistical framework proposed in this paper. The latter remarks also suggest directions for continued empirical investigation of the evolution in Japan's relative technological position.

II. Objectives and Statistical Methodology

A. General Remarks

The central concern of the present research involves the identification of either consistent patterns over time, or significant changes, in the relative technological positions of different Japanese industrial sectors, both within Japan, and in relation to those of other major countries, as represented by France and the United States.[5] The statistical analysis, which depending on the countries involved starts in either 1959 or the 1960s, focuses on alternative inter-industry measures of inputs to the technological innovation process. A first specific question to be examined regards the nature of the cross-sectoral distribution of technological intensities for Japanese industries in given years. The identification of the extent of skewness and variance in this overall distribution of R & D

[5]As pointed out in the conclusion to this paper, the extension of this study, to consider the relative technological position of Japan compared with those of a number of other OECD countries, appears worthwhile. However, major obstacles arise in many cases with regard to the availability of consistent data series.

intensities across industries is an essential preliminary step to evaluating the effectiveness of a government's technology policies, as well as to assessing the usefulness of aggegrate characterizations of a country's relative technological position internationally. If a few high technology industries play a dominant role in defining a country's overall R & D position, and there are significant variations between economies in the ranking of their high-tech sectors, certain of the generalizations regarding the overall relative innovative performance of various countries appear to require major qualifications, and even to be potentially quite misleading. In this context, several of the conclusions proposed by Ergas (1984b) can be noted for subsequent reference. In particular, he finds that "The US retains a dominant position in OECD (technological) performance though it has lost considerable ground to Japan" and that among European countries, whose general "position has improved over time, but much less so than Japan's," France can be regarded as being a 'low' innovative performer.[6]

A second question, related to the distribution of inter-industry R & D intensities, concerns the comparability of the different Japanese sectors' relative and absolute technological positions over time. To the extent that there exist substantial intertemporal variations between certain industries in the proclivity of these to invest in R & D during different periods, stock measures may more accurately portray their overall technological positions. In this study such stock measures were obtained by accumulating the flow (annual) inputs for investment in technological innovation, under alternative hypotheses concerning the rate of their depreciation, and then deflating by a measure of each industry's size. Evidence of substantial changes in any of the parameters of the inter-industry distribution of flow R & D measures tends to suggest the potential usefulness of such stock technology indicators.[7]

A final concern, which undoubtedly represents the most distinctive feature of the present inquiry, relates to the comparison, over a quite extended period, of the technological evolution of industries in Japan, on the one hand, with those of France and the United States, on the other. Since the present research, along with the related study by Owen (1987), constitutes one of the first attempts to consider potential variations in the *international* technological positions of a country's industries over an extended time

[6]All citations are from the synopsis on page three of the study by Ergas. However, Ergas does note substantial differences between certain European industries. More specifically, he concludes that in Europe "fields related to biology and chemistry are strong; and aerospace is relatively weak" (p. 3). As reported later there are major discrepancies between certain of Ergas' technology rankings and those obtained in the present research. Furthermore, his study does not provide any analysis of technological indicators across a comprehensive set of manufacturing (or non-manufacturing) industries.

[7]It is worth noting that a number of existing studies of international trade, investment, and productivity growth have relied on cross-sectional technology indicators for a single year, when explaining flow or stock performance variables which typically span much longer periods. Examples of such research (for countries other than Japan) include the papers by Baldwin (1971, 1979), Caves (1974), Griliches and Mairesse (1983, 1985), and Owen (1982, 1984).

period, it may reveal certain fundamental trends which have previously been ignored. In light of possible discrepancies in the statistical procedures practiced in the three countries, the primary focus is on examining the rankings and relative technological positions of their industries. At any given point in time, *relative* differences, in either flow or stock technology measures, may be the sources of international, technological comparative advantage. The present research analyses the degree to which changes in such relative advantages can be attributed to the evolution of the distribution of inter-sectoral R & D intensities in Japan, as opposed to those for France and/or the United States. Nonetheless, it is apparent that to the extent international comparisons based on the *absolute* values of the technological indicators are credible, much stronger statements could be made regarding the evolution of technological competition between Japan and other countries. However, it remains the position of this author that, in the absence of a consensus by experts regarding the international comparability of the different countries' statistical sources, such an analysis of absolute technological measures must be undertaken with considerable caution. A final remark concerns the role of government funding of R & D, which could constitute an important factor in explaining each of these countries' technological positions. While this is of lesser direct importance in the Japanese context where government funding of R & D has historically played a secondary role, direct government support for the financing of technological innovation in France and the United States has been quite concentrated in a few sectors, most notably in the aeronautics industry.[8]

B. Statistical and Econometric Methodology

The flow and stock technology indicators, analysed in the next section, are standardized to take into account the industries' different sizes. These measures for the relative R & D intensity of each sector are based on either data on R & D expenditures in relation to total sales, or the ratio of the number of scientists and engineers to total employment. Such proxies for investment in technological innovation constitute traditional indicators, which have been analyzed in a number of previous studies relating research and development to international trade and industrial performance—including those by Baldwin (1971, 1979), Caves (1984), Griliches and Mairesse (1983, 1985), and Owen (1982, 1984). The question of the relation between such inputs to the technological innovation process and proxies for technological output, such as the numbers or estimated values of patents, is, of course, one which has been debated. In practice, however, the data series for these output measures preclude as extensive an international comparison across industries and

[8]See Owen (1987) for further discussion of this point.

time, as that undertaken here.[9] Moreover, inputs to the innovation process can be regarded as leading indicators for changes in countries' relative technological advantage.

The Japanese data series were available from 1959 through 1984 on a quite consistent basis for a set of thirty industry observations representing different levels of aggregation.[10] The industrial classifications and data sources are specified (along with those for the other two countries) in the Statistical Appendix. Of the Japanese industries, four are non-manufacturing sectors, sixteen are basic manufacturing industries, while there are eight further sub-classifications for chemicals, electrical machinery, and transport equipment. In comparison, there were a larger number of statistical problems, due to data availability and changes in classification schemes, in the case of the counterpart French and American statistics. These series start, respectively, in 1960 and 1964, and extend (if available) until 1984.[11] The twenty-five industry observations for France, and thirty-two for the United States, were converted to a pooled data base, comprising thirty-two sectors. This constitutes the basis for the subsequent comparative statistical analysis between the three countries, which thus covers twenty-six years for Japan, twenty-five for the United States, and twenty-one years in the French case. In order to facilitate the interpretation of the statistical results, the letters F, J, and U at the beginning of a technology variable name identify French, Japanese, and American series, while two digits at the end of each indicator designate the corresponding latest year of the data. Similar symbols are also used to indicate comparable technology variables in the three countries.

The notation used to identify the various technological indicators can be illustrated in the context of explaining the calculation of the stock value for a representative

[9]Furthermore, discrepancies in the patenting practices of different countries can introduce serious limitations to valid international comparisons based on patent statistics. Indicators which rely either on R & D expenditures or scientific employment data have the advantage that they avoid many legal intricacies associated with patent systems in different countries. Of course, questions regarding the international comparability of each country's criteria for allocating corporate expenditures or personnel to research and development also arise. Nonetheless, these are arguably of lesser significance than those invoked by international patent statistics. By focusing primarily on changes in the relative technological positions between the three countries, the importance of such issues concerning international statistical comparability is mitigated in the current research.

[10]An idiosyncrasy of the Japanese technological survey (cited in the Statistical Appendix) is that annual statistics relate to fiscal years, beginning in April and ending in March of the following year. Thus, for example, data series labeled in the current study as being for 1959, actually cover the period—April 1959 through March 1960.

[11]While disaggregated technology statistics are first available for France in 1964, the consistency of the French series prior to 1966 appears somewhat questionable, in view of substantial changes in industrial classifications. In the case of the American data, a number of complications arise for specific sectors as of 1981, due to the suppression of series on the grounds of confidentiality. For both countries there were some significant modifications in the industrial classification schemes during the period under consideration. Consequently, certain of the statistical findings reported later are based on varying numbers of observations for the different industries.

variable.[12] Let us consider a measure, JRSW#. This consists of the number of Japanese researchers in an unspecified year (designated by the symbol, #) for the ith industry (indicated by a number subscript), JNS#, as a fraction of the total number of workers in that sector, JTW#. In this case the specific formula applying for the stock value in 1984, under the assumption of a twenty-five percent depreciation rate, is the following:

$$JMSRSW84_i = \{JNS84_i + \sum_{n=1}^{26} JNS[84-N]_i (1-.25)^N\} / \{(JTW84_i + JTW83_i) / 2.\} \quad (1)$$

In the foregoing the expression, $JNS[84–N]_i$, is understood to be the number of Japanese personnel engaged in R & D in year 84–N for the ith industry. Note that a two-year moving average is used to deflate the number of R & D workers.

We turn now to a consideration of the econometric framework proposed for examining structural changes in the evolution of alternative technology measures. Let the symbol Y^{ijk} represent an ordered column vector containing the values of a particular, either absolute or relative, technological measure. The subscripts, which reflect the dimensionality of this (and other) vector(s) comprising N observations, will be suppressed, whenever unnecessary. The arrangement of the data in Y^{ijk} is lexographic, according to the superscripts i and j, which denote the ith industry and jth year, while k signifies a control group of observations.[13] The entries in Y^{ijk} can consist of either flow or stock technological indicators for Japan, or algebraic transformations of these, such as percentages. Examples include the variable, $JMSRSW\#_i$, or a ratio of such a standardized, Japanese stock series to the average of the comparable French and American ones, $JMSRSW\#_i / ((FMSRSW\#_i+UMSRSW\#_i) / 2.)$. Analogously, X^{ijk} is used to designate the matrix of associated M column vectors, which consist of independent variables used to explain the level of each similarly ordered (by superscripts i and j) entry in the Y vector. The independent variables in X^{ijk}, included in the subsequent empirical analysis, comprise a constant term, trend terms, and dummy variables.

Let us consider the econometric methods used to examine for structural changes in the evolution of alternative technological indicators. For illustrative purposes one of the specific tests reported later in Table 3 will be referred to. It pertains to a potential change in 1973 in the relative, stock technological position of Japan, compared to the average stock measures for France and the United States. The formal F-tests and likelihood ratio tests, for assessing whether a structural change has occurred during the sample period, are based on comparisons of constrained and unconstrained regression models. The different control groups, corresponding to designated sub-periods, can be represented by

[12]The Statistical Appendix summarizes further information regarding the notation, which pertains to the full set of data series examined in this study.

[13]Since the control period, k, is based on subdivisions of the j years, the maximal number of observations, N, in this vector amounts to i multiplied by j. This constitutes the total number, when there are data for all of the i industries in the full number of j years. However, in practice certain of these entries are suppressed; because either they are not pertinent to a specific statistical test under consideration, or there are missing data.

a series of individual equations. For illustrative purposes a specific example will be considered. It involves a single ith industry (arbitrarily represented by the superscript 1), which corresponds to the aggregate of all manufacturing and non-manufacturing industries. In this case the analysis covers a period from 1964 to 1984; and two independent variables consisting of a constant and trend term are included. The individual equations pertaining to our example can be designated as follws:

$$Y^{ij1}_{N1} = X^{ij1}_{NM}\ \beta^1 + \varepsilon^1, \qquad (2)$$

where i=1, j=9, N=9, and M=2.

$$Y^{ij2}_{N1} = X^{ij2}_{NM}\ \beta^2 + \varepsilon^2, \qquad (3)$$

where i=1, j=12, N=12, and M=2.

In the constrained version of the model, the foregoing two equations (related, respectively, to the sub-periods 1964–72 and 1973–84) are specified in terms of a single pooled regression covering the full sample period:

$$Y^{ij3}_{N1} = X^{ij3}_{NM}\ \beta^3 + \varepsilon^3, \qquad (4)$$

where i=1, j=21, N=21, and M=2.

This constrained regression, obtained by stacking the dependent variables as well as constant and trend terms from equations (2) and (3), can for simplicity be rewritten as:[14]

$$Y = X\beta^3 + \varepsilon^3 \qquad (4)'$$

If a dummy variable, d=( ), is then defined to equal zero for observations corresponding to the first control period, and one for those from the second, a fourth unrestricted equation can be estimated:

$$Y = X\beta^4 + d'X\beta^5 + \varepsilon^4 \qquad (5)$$

Note that the row vector containing the dummy variable, d', enters multiplicatively with respect to the matrix of independent variables, X, which in this instance consists of a constant term and trend. An evaluation of the extent of structural change during, the overall time period under consideration, can then be made on the basis of a standard F-test and/or likelihood ratio test. In addition, the statistical and economic significance of the coefficients, β^5, relative to those of β^4, require assessment. More specifically, the F-test involves a comparison of the sum of squared residuals from the unrestricted equation (5) with those from the restricted version, equation (4) (or (4)′), to test whether the

[14]In order to facilitate the interpretation of estimated results based on equation (4), it is useful to reindex the separate trend terms from equations (2) and(3) to a composite trend variable (ending with the total number of years, N).

constraint is significant. In particular, if an asterisk is used to distinguish the restricted from the unrestricted regression equations, the F-test is specified by $F(R,M+N-2R) = [(SSR^*-SSR) / R] / (SSR / (N_2+N_3-2R)$.[15] In this formula the symbols R and SSR designate respectively the number of restrictions (in this instance the number of independent variables, which in our example is two), and the sum of squared residuals. The number of observations in equations (2) and (3) are designated by respectively N_2 and N_3. Alternatively, the significance of a structural change can be tested by means of a likelihood statistic, equal to $2(L-L^*)$, where L and L^* represent the values of the likelihood functions for the maximums of the unconstrained and constrained models.[16]

The intepretation of the empirical findings presented in the next section is facilitated by a minor modification of equation (5). It involves a reindexation of the trend term contained in the second matrix of independent variables in equation (5) (which determine the values of the estimated coefficients in β^5). In doing so, the initial value for the trend term, corresponding to the first observation in the second control period, is set equal to one.[17] Such a spline trend reflects more readily any (potential) differential rate of growth for the technological indicators in the second sub-period; since its estimated β coefficient identifies the difference between the slope of the regression line in the second control period, from that in the first. The use of a spline trend and dummy variable, to distinguish the evolution of alternative technology measures during different time periods, proved to be particularly appropriate in light of a number of cases where a kink or other discontinuity more accurately characterized apparent non-linearities in the estimated equations. Such a representative empirical result (which approximates our specific example) is illustrated in terms of Figure 1.[18] In this figure b_1 and b_3 symbolize, respectively, the values of the constant term and the vertical discontinuity (if any), occurring in the hypothesized year for a structural change, T'. The slope of the trend term spanning the full sample period, b_2, determines the angle, α, of the first line segment, pertaining to the initial control period. Similarly, in light of our reindexation of the time dummy variable as a spline trend, the *sum* of the coefficients b_2 and b_4 defines the angle, γ, of the second line segment. On the basis of the discontinuous line depicted in Figure 1, we can conclude (for our specific example reported in Table 3) that the relative stock technological position for the aggregate of all Japanese industries, compared to the average of those for

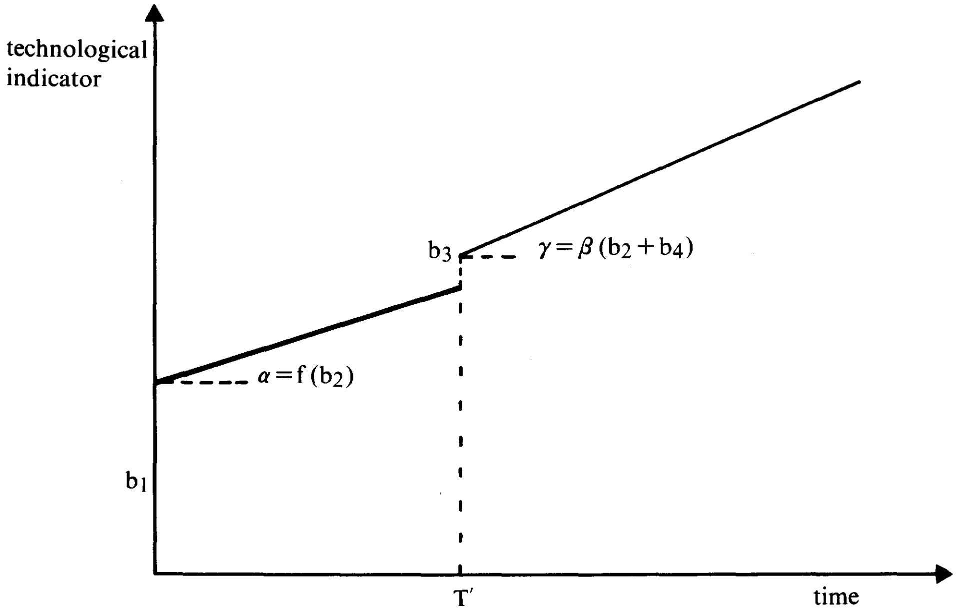
[15]For further information concerning the characteristics of this F-test, or of the subsequent likelihood ratio test, see, respectively, the papers by Chow (1986) or Gallant and Holly (1980).

[16]This likelihood ratio statistic can be evaluated on the basis of a chi-squared distribution, for which the number of restrictions corresponds to the degrees of freedom.

[17]See Mendis and Muellbauer (1984) for a discussion of the use of spline trends in a different context from the current one.

[18]This example consists of results reported in the first equation from the last column of Table 3. The estimated coefficients, which correspond to the constant term, dummy variable, time trend, and additional spline trend (labeled as time dummy), are all statistically significant. Their respective values are as follows: b_1=.2996, b_2=.0149, b_3=.0486, and b_4=.0066.

Figure 1.



France and the United States, has improved throughout the 1964–84 period. Moreover, this occurs at a substantially higher rate starting in 1973. Specifically, the slope of the line is 1.44 times greater in the second sub-period. There is also evidence, around the time of the oil crisis, of a small upwards discontinuity in the relative international technological position of Japan. Before examining in detail this major theme from the empirical findings presented in the next section, it is worth reemphasizing the generality of the overall statistical approach proposed here. The evolution of any particular combination of alternative technological measures from the three countries can be analyzed for specific industries and different time periods. Indeed, it will be shown that this aggregate result reflecting Japan's overall relative technological position masks quite varied developments in certain industrial sectors.[19]

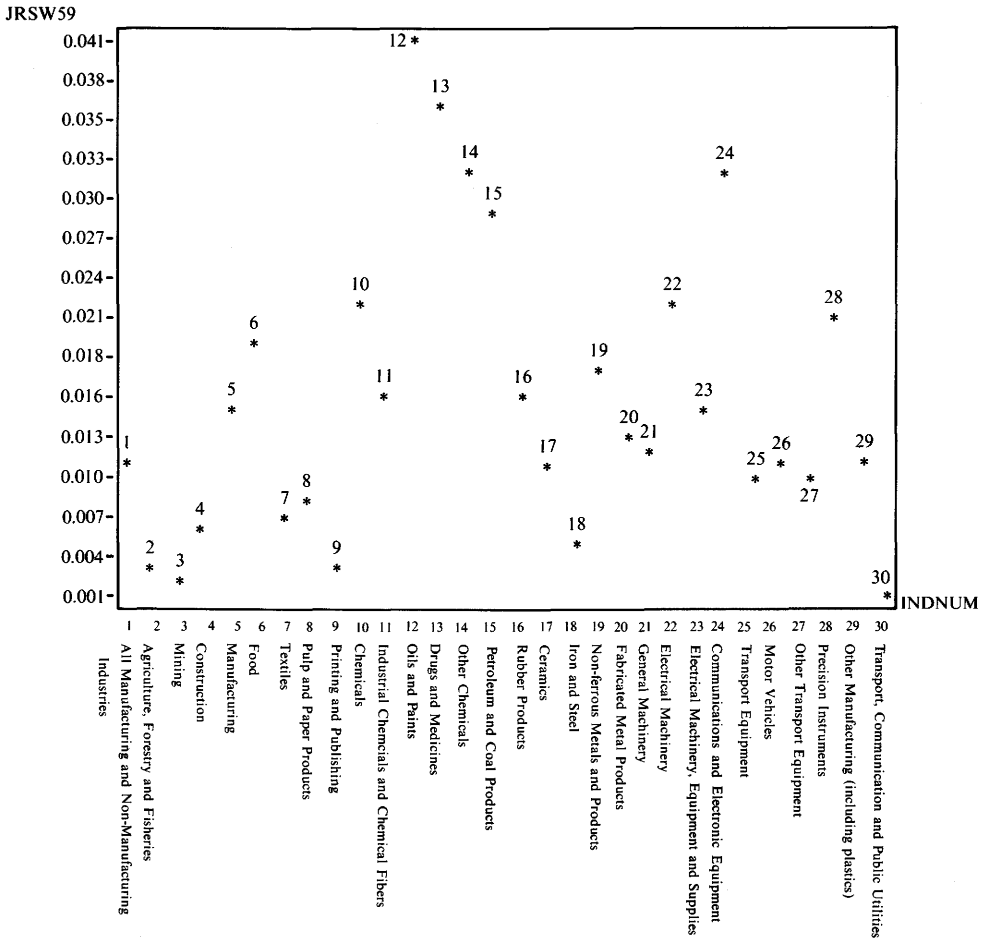
III. Empirical Results

A. General Remarks

The most important statistical findings of this study are reported in Figures 2 through 8, and Tables 1 to 7. The discussion of these results is divided into two parts. Initially, the

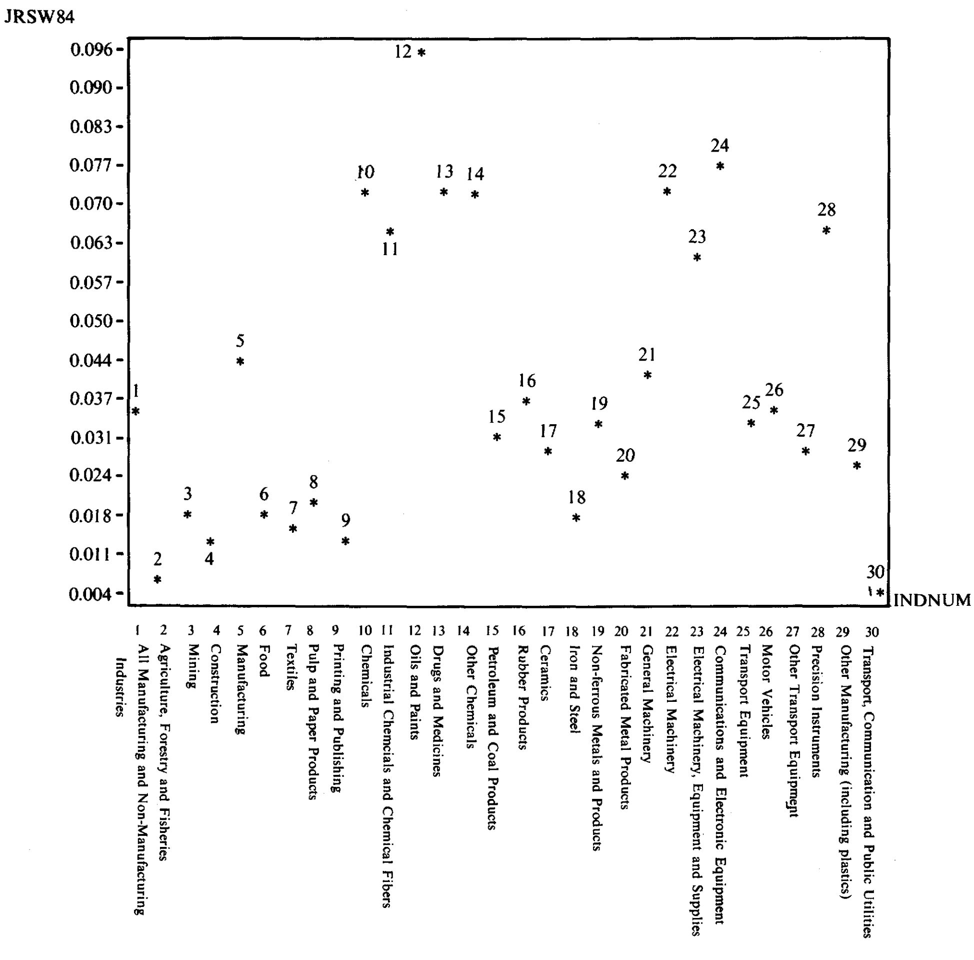
[19]In specific cases, for example, the slope of the line segment, corresponding to the second control period, actually changes signs. There are also instances of downward discontinuities.

Figure 2. Cross-sectional Plot for Japan of Number of R & D Workers as a Fraction of Total Workers in 1959
(JRSW59 Versus Industry Observation Number, Indnum)



focus is on Japan. The distributions of cross-sectoral technological intensities are examined at the beginning, middle, and end of the period under consideration: specifically, in 1959, 1972, and 1984. Subsequently, changes in the R & D intensity of disaggregate Japanese industries are assessed—both in absolute terms and relative to that of other sectors. In order to keep the exposition manageable, much of the discussion centers on the most technologically intensive industries. The second part of this section offers a comparative analysis of Japan's R & D position, in relation to those of France and the United States. Relative changes in the three countries' aggregate technological performance are examined for the entire period from 1964 to 1984. The most recent trend developments since 1982 are also highlighted. Subsequently, the quite varied, relative

Figure 3. Cross-sectional Plot for Japan of Number of R & D Workers as a Fraction of Total Workers in 1984
(JRSW84 Versus Industry Observation Number, Indnum)



technological development of specific high-tech industries are explored. Finally, one further preliminary remark concerns the choice of statistical results which appear in the ensuing graphs and tables. In general, there was a quite strong concordance between alternative indicators based on either numbers of researchers or R & D expenditures. In light of the more frequent statistical problems (associated with the suppression of certain data for the latter series), as well as the need to economize on presentational detail, results involving the statistics on scientists and engineers have been emphasized.[20]

B. The Technological Development of Japanese Industries

The highly skewed distribution of inter-industry R & D intensities in Japan is immediately apparent from Figures 2 and 3, which pertain to the initial and final years under consideration. In 1959, five industries had ratios of researchers to total workers that substantially exceeded two and a half times the 1.1 percent average for all Japanese industries; while another three or four sectors were approximately twice as technologically intensive. By 1984 the industry average for this indicator, JRSW84, had advanced dramatically to 3.45 percent. Similarly, the R & D expenditure based measure rises from .75 to 1.86 percent. Associated with this, from two and a half to more than threefold, increase in the alternative evaluations of Japan's overall technological performance, is a sharpened disparity between the technological prowess of seven industries (corresponding to nine observations).

Table 1 provides the actual values of these high-tech, Japanese industries' R & D intensities, as measured in terms of both the worker and expenditure statistics in 1960, 1972, and 1984. In the most recent year the principal technologically intensive sectors consist of communications and electronic equipment, different chemical based industries, including drugs and medicines, electrical machinery (equipment and supplies), and precision instruments. Although the general consistency between the workers and expenditure indicators is readily apparent from Table 1, there do exist some discrepancies regarding the relative ranking of certain industries.[21] In particular, on the basis of R & D expenditures, motor vehicles emerges in the group of top nine high-tech industries throughout the period; while industrial chemicals and chemical fibers has a somewhat lower position than when its technological intensity is measured on the basis of scientists and engineers.

Table 2 reports the stock value of the technological indicator, JMSRW84. It reconforms our identification of the leading technological industries in Japan, while also in-

[20]On the basis of Table 1, it is apparent that there do exist a few idiosyncrasies between these two sets of measures for a rather limited number of industries in the three countries. Nonetheless, in the Japanese case, for example, the overall cross-sectional correlation between R & D intensity indicators based on the flow values from these alternative sources is quite high. Specifically, for 1959, 1971, and 1983, the correlation coefficients between $JRSW\#_i$ and $JRIEC\#_i$ are respectively .64, .83, and .90 (based on twenty-one distinct manufacturing sectors). Similarly, the inter-temporal correlation for the aggregate of all Japanese industries, and these same two indicators, is .70. Comparable results also apply when considering technological stocks, or using these alternative measures to assess the relative technological position of Japan, in relation to France and the United States. See Owen (1987) for additional discussion regarding the similarities of the statistics on research workers to those involving R & D expenditures. One explanation for any perceived differences in these two indicators could relate to cross-sectional variations in capital/labor ratios.

[21]For example, the quite strong technological position of the fairly small, oil and paint industry may be influenced by the activities of one or more highly diversified firms.

dicating the lowest ranked sectors.[22] The disparity between these stock measures for the two groups is striking, and attains factors of as much as 15 to 25 times as great, in the case of specific comparisons between individual industries. Such large differences suggest the potentially misleading nature of an extrapolation from any characterization of Japan's aggregate technological position to the situation of specific industries. Nonetheless, as pointed out in Owen (1987) the inter-industry dispersion of R & D intensities in Japan is considerably less, throughout the entire sample period, than for either France or the United States.[23] Thus, Japan's remarkable technological development appears to be more broadly shared across industries, when compared with those of the other two countries.

It is also apparent from Table 1 that there have been some significant changes in the relative technological positions of certain sectors. Not surprisingly, communications and electronic equipment has emerged as a leading high-tech industry with 7.7 percent of its work force involved in research. Yet, similar levels can also now be boosted by several chemical branches, while precision instruments and electrical machinery (equipment and supplies) follow close behind, with levels of JRSW84 equal to 6.5 and 6.2 percent, respectively. On the basis of the R & D expenditure statistics, the Japanese motor vehicle industry has markedly increased its investment in technological innovation in recent years. The evolution of stock technology indicators for representative high, medium, and low-tech industries is depicted in Figure 4 for the entire period from 1959 to 1984. From this diagram the growing absolute difference in the technological effort by the leading sectors is readily apparent. While the aggregate R & D stock value surges by a factor of 16.6 between 1959 and 1984, those for chemicals and electrical machinery soar to levels which are, respectively, 17.6 and 23.4 times as great.[24] Another interesting feature portrayed in Figure 4 relates to the intersection of a number of the technology growth paths for given industries. This switching of relative technological intensities, which is particularly frequent in the 1980s, is somewhat analogous to factor intensity reversals. The possible implications for explaining changes in Japan's, and other countries', international trade flows merit further, both theoretical and empirical, analysis.

Table 3 offers the first series of results based on the econometric analysis, which was explained in the previous section. In the first two columns the extent of structural change,

[22]In order to illustrate the role of the depreciation rate in influencing calculations of stock technology measures, a fifteen percent rate has been used in Table 2. In the subsequent econometric analysis a somewhat higher rate of twenty-five percent was applied. While both values have been postulated as reasonable by certain technological specialists, a more rigorous analysis of technological depreciation could consider variable rates for different time periods and industries.

[23]More specifically, the ratios of the mean to the standard deviation for the distributions of flow R & D intensities (based on the workers data) were, respectively, 1.48 and .9 for Japan and France in 1984, and 1.19 for the United States in 1982. This dispersion measure rises somewhat for Japan and the United States since the 1960s, while falling for France.

[24]These stock values are calculated on an assumption of a fifteen percent depreciation rate.

Table 1. Matrix of R & D Intensity Rankings by Country and Selected Years for High Technology Industries During the 1960–84 Period—Based on Representative Flow Technology Indicators

a. France

Year	Technology Rank of Industry	Name	Value of Technology Indicators: In Terms of R & D Workers	Value of Technology Indicators: In Terms of R & D Expenditures
1964	1	Aeronautic Industry	.17892	.17486
	2	Precision Instruments	.09652	.07202
	3	Electrical Machinery	.09480	.08427
	4	Electronic Machinery	.09480	.08427
	5	Pharmaceutical Industry	.08031	.06297
	6	Chemical Industry	.06853	.02523**
	Average	Total for All Manufacturing and Non-Manufacturing Industries	.04126	.03176
	(5*)	Glass Industry	.03885*	.04113
1972	1	Aeronautic Industry	.27700	.22107
	2	Computing Machines	.12942	.09143
	3	Pharmaceutical Industry	.11516	.06488
	4	Engineering	.08882	.06433
	5	Chemical Industry	.07605	.02714**
	6	Rubber and Plastics	.07512	.03918**
	7	Electronic Machinery	.07383	.05880
	8	Iron and Steel and Fabricated Metal Products	.07201	.04595
	Average	Total for All Manufacturing and Non-Manufacturing Industries	.04512	.02769
	(6*)	Agriculture	.03392	.05318
	(7*)	Electrical Machinery	.05681	.04644
1984	1	Agriculture	.36587	.17204
	2	Aeronautic Industry	.23300	.17849
	3	Electronic Machinery	.16753	.14177
	4	Pharmaceutical	.14637	.12256
	5	Computing Machines	.10748	.05083
	6	Chemical Industry	.09190	.03797**
	7	Other Services	.08057	.07280
	8	Engineering	.07239	.04198**
	Average	Total for All Manufacturing and Non-Manufacturing Industries	.05628	.03645
	(6*)	Precision Instruments	.06479	.05639
	(8*)	Rubber and Plastics	.05690	.04819

[a] In the case of both Japan and the United States, their overall industrial classification schemes include a number of manufacturing industries which are further broken down into sub-categories. (See Statistical Appendix for further information in this regard.) Thus, there are potential overlaps between the technological indicators for these aggregate industries and those for the associated sub-categories. This interdependence of certain industrial classifications was not taken into account when assigning the technology rank for different industries, so that both the aggregate industries and their sub-classifications were counted as distinct industries.

b. Japan[a]

Year	Technology Rank of Industry	Name	Value of Technology Indicators	
			In Terms of R & D Workers	In Terms of R & D Expenditures
1960	1	Oil and Paints	.0398	.0100
	2	Drugs and Medicines	.0342	.0201
	3	Other Chemicals	.0339	.0191
	4	Communications and Electronic Equipment	.0259	.0220
	5	Chemicals	.0237	.0164
	6	Electrical Machinery	.0119	.0193
	7	Industrial Chemicals and Chemical Fibers	.0176	.0167
	8	Petroleum and Coal Products	.0172	.0250
	9	Precision Instruments	.0163	.0118
	Average	Total for all Manufacturing and Non-Manufacturing Industries	.0098	.0840
	(6*)	Electrical Machinery, Equipment and Supplies	.0139	.0166
	(8*)	Motor Vehicles	.0014	.0138
1972	1	Oils and Paints	.0683	.0208
	2	Drugs and Medicines	.0519	.0403
	3	Chemicals	.0441	.0224
	4	Other Chemicals	.0428	.0272
	5	Communications and Electronic Equipment	.0398	.0386
	6	Electrical Machinery	.0367	.0347
	7	Industrial Chemicals and Chemical Fibers	.0365	.0175
	8	Precision Instruments	.0344	.0260
	9	Electrical Machinery, Equipment and Supplies	.0338	.0306
	Average	Total for all Manufacturing and Non-Manufacturing Industries	.0185	.0131
	(8*)	Motor Vehicles	.0192	.0219
1984	1	Oils and Paints	.0962	.0276
	2	Communications and Electronic Equipment	.0768	.0426
	3	Drugs and Medicines	.0725	.0609
	4	Chemicals	.0719	.0322
	5	Other Chemicals	.0715	.0359
	6	Electrical Machinery	.0714	.0426
	7	Industrial Chemicals	.0654	.0229
	8	Precision Instruments	.0650	.0410
	9	Electrical Machinery, Equipment and Supplies	.0621	.0427
	Average	Total for All Manufacturing and Non-Manufacturing Industries	.0345	.0186
	(8*)	Motor Vehicles	.0354	.0280

c. United States[ab]

Year	Technology Rank of Industry	Name	Value of Technology Indicators: In Terms of R & D Workers	Value of Technology Indicators: In Terms of R & D Expenditures
1960	1	Aircraft and Missiles	.08190	.232
	2	Electronic Components	.06591	.131
	3	Electrical Equipment	.05294	.112
	4	Scientific and Mechanical Measuring Instruments	.04472	.086
	5	Industrial Chemicals	.04467	.057
	6	Other Electrical Equipment	.04213	.091
	7	Chemicals and Allied Products	.04188	.045
	8	Drugs and Medicines	.04110	.046
	9	Other Chemicals	.03640	.022**
	10	Professional and Scientific Instruments	.03571	.063
	Average	Total for All Manufacturing and Non-Manufacturing Industries	.02510	.042**
	(8*)	Optical, Surgical, Photographic, and Other Instruments	.02866	.053
	(9*)	Machinery	.02570	.047
1972	1	Drugs and Medicines	.07529	.065
	2	Aircraft and Missiles	.07337	.166
	3	Chemicals and Allied Products	.03897	.036**
	4	Electronic Components	.03833	.059
	5	Electrical Equipment	.03605	.071
	6	Other Electrical Equipment	.03275	.063
	7	Scientific and Mechanical Measuring Instruments	.03264	.041
	8	Professional and Scientific Instruments	.03255	.059
	9	Optical, Surgical, Photographic, and Other Instruments	.03251	.066
	10	Industrial Chemicals	.03237	.039
	11	Radio and TV Receiving Equipment	.03134	.016**
	12	Other Chemicals	.03056	.017**
	Average	Total for All Manufacturing and Non-Manufacturing Industries	.02485	.034
	(2*)	Office, Computing, and Accounting Machines	Not Available Separately	.111
	(3*)	Communication Equipment	Not Available Separately	.087
	(10*)	Machinery	Not Available separately	.043

[b] As is apparent from a separate Statistical Appendix, there are a significant number of missing observations for the United States in 1960, 1972, and 1983, relative to the potential total of thirty-two industries cited in the Statistical Appendix. In particular, the missing observations in 1960 and 1972 are respectively industry numbers 18, 19, 21, 22 and 25 for the former year, and industry number 19 in the case of the latter year. Yet, with the exception of motor vehicles and motor vehicles equipment in 1960, these missing observations correspond to sub-categories of more aggregate manufacturing industries for which other data are available. However, in 1983 the problem is much more acute, since a much larger number of observa-

Year	Technology Rank of Industry	Name	Value of Technology Indicators	
			In Terms of R & D Workers	In Terms of R & D Expenditures
1983	1	Aircraft and Missiles	.10220 (.08703)	.158 (.137)
	2	Office, Computing, and Accounting Machines	.07537 (.07049)	Not Available Separately .120
	3	Chemicals and Allied Products	.05353 (.04022)	.044 (.036)
	4	Communication Equipment	.04804 (.05360)	.131 (.091)
	5	Electrical Equipment	.04786 (.04134)	.086 (.066)
	6	Machinery	.04743 (.03362)	.058 (.050)
	7	Industrial Chemicals	.04341 (.03519)	.039 (.050)
	8	Other Electrical Equipment	.04115 (.03138)	Not Available Separately (.033)
	Average	Total for All Manufacturing and Non-Manufacturing Industries	.03421 (.02608)	.038 (.030)
	(3*)	Professional and Scientific Instruments	Not Available Separately (.03805)	.093 (.075)
	(5*)	Electronic Components	Not Available Separately (.04879)	.078 (.079)

U.S. Industries Having Above Average Values of the Technological Indicators in 1980 for which Data is Not Available Separately in 1983 (Excluding Textiles and Apparel, Rubber Products, and Scientific and Mechanical Measuring Instruments for which Data is Not Available in Either 1980 or 1983) consist of the following:

1980		Drugs and Medicines	.05760	.062
		Optical, Surgical Photographic, and Other Instruments	.04794	.069
		Industrial Chemicals	.03519	.033
		Other Electrical Equipment	.03138	.049
		Motor Vehicles and Motor Vehicles Equipment	.03126	.049
		Radio and TV Receiving	.02381	.043
		Scientific and Mechanical Measuring Instruments	Not Available Separately	.084
	Average	Total for All Manufacturing and Non-Manufacturing Industries	.026808	.030

tions have been suppressed. Specifically, neither of the technological indicators shown in this table were available for industry numbers 8, 11, 21, 26, 29, 30, and 31. In order to give a more complete characterization of U.S. technology in the 80s, industries which are not cited for 1983, but had at least one above average technological indicator value in 1980 have also been reported. No attempt was made to rank these latter observations. Finally, for the sake of comparability, the technological indicators for 1980 are also indicated in parentheses below the statistics for those industries where data were available in 1983.

Table 2. Inter-industry R&D Intensity Ranking for Highest and Lowest Technology Industries in France, Japan, and the United States – Based on the Stock Values in 1984 of a Representative Indicator, and Assuming a Fifteen Percent Rate of Depreciation

a. France

	Technology Rank of Industry	Name of Industry	Value of Technology Indicator (FMSRSW84)
Highest Technology Industries	1	Agriculture	1.73063
	2	Aeronautic Industry	1.46625
	3	Electronic Machinery	.89966
	4	Pharmaceutical Industry	.80157
	5	Chemical Industry	.54218
	6	Precision Instruments	.37513
	7	Rubber and Plastics	.35225
	8	Electrical Machinery	.31782
	9	Construction Materials and Ceramics	.28534
	10	Automobile Construction	.28472
	Average	Total for All Manufacturing and Non-Manufacturing Industries	.32926
Lowest Technology Industries		Textile Industry	.15323
		Energy	.14768
		Naval Construction and Other Transportation Equipment	.10813
		Agriculture and Food Industries	.10473
		Construction, Civil, and Agricultural Engineering	.06229

Notes: 1) As is apparent from a separate Statistical Appendix, there are a number of missing observations (due to the non-availability of data) for France and the United States, relative to the potential totals of respectively twenty-five and thirty-two industries. This problem is particularly acute for certain American series for which it was not possible to construct the technology stock indicator. These consist of industry observation numbers 3, 4, 8, 11, 12, 16, 18, 19, 21, 22, 23, 24, 25, 26, 28, 29, 30, and 31. Note that these missing indicators include motor vehicles and motor vehicle parts, as well as professional and scientific equipment. However, those for other traditionally high technology industries are reflected in the more aggregate observations, such as chemicals and allied products machinery, and electrical equipment, which are cited in the present table. In this context, footnote a from Table 1 also is pertinent here. Finally, the technology ranking of industries excludes the observation consisting of the average for all manufacturing industries.

2) The stock value of the technological indicator for industry i in, for example, France in 1984 is determined on the basis of the following formula:

$$FMSRSW84_i = FMRSW84_i/(FTW83_i + FTW84_i)/2.)$$

where $FMRSW84_i = FRDS84_i + FRDS\{84\text{-}N\}_i\,(1\text{-}.15)^N$

In the foregoing formula the expression $FRDS\{84\text{-}N\}_i$ is understood to be the number of French personnel engaged in R&D in year 84-N for industry i, while $FTW83_i$ ($FTW84_i$) is (as defined in Statistical Appendix B) the total number of workers in the ith industry. Note that a two-year moving average is used to deflate the number of R&D workers.

b. Japan

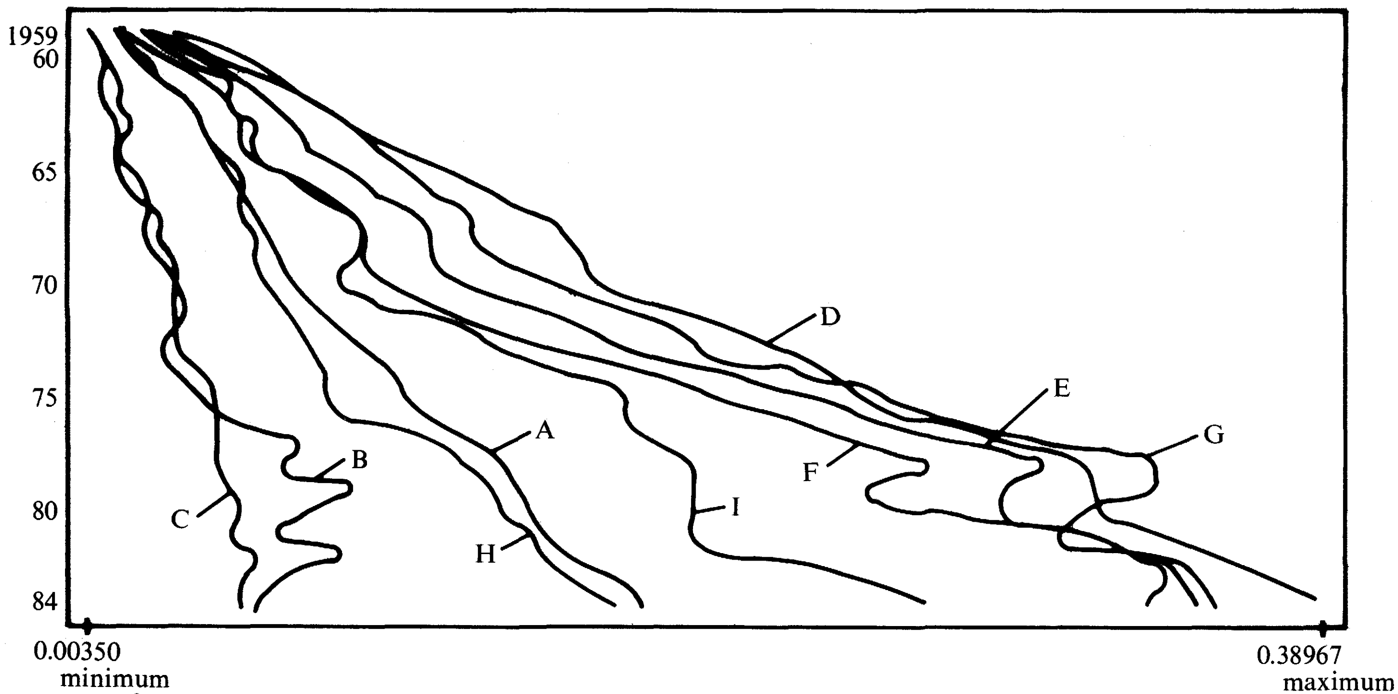
	Technology Rank of Industry	Name of Industry	Value of Technology Indicator (JMSRSW84)
Highest Technology Industries	1	Oils and Paints	.5333
	2	Chemicals	.3897
	3	Drugs and Medicines	.3786
	4	Industrial Chemicals and Chemical Fibers	.3682
	5	Other Chemicals	.3657
	6	Communications and Electronic Equipment	.3554
	7	Electrical Machinery	.3496
	8	Electrical Machinery, Equipment, and Supplies	.3399
	9	Precision Instruments	.2641
	Average	Total for All Manufacturing and Non-Manufacturing Industries	.1762
Lowest Technology Industries (in decreasing order)		Iron and Steel	.0936
		Construction	.0678
		Agriculture, Forestry and Fisheries	.0540
		Printing and Publishing	.0519
		Transport, Communication and Public Utilities	.0254

c. United States

	Technology Rank of Industry	Name of Industry	Value of Technology Indicator (UMSRSW84)
Highest Technology Industries (for which data is available)	1	Aircraft and Missiles	.61586
	2	Chemicals and Allied Products	.28373
	3	Electrical Equipment	.28095
	4	Machinery	.26839
	5	Industrial Chemicals	.25171
	6	Other Chemicals	.20474
	7	Petroleum Refining and Related Industries	.12488
	Average	Total for All Manufacturing and Non-Manufacturing Industries	.19131
Lowest Technology Industries (in decreasing order, for those sectors where data is available)		Paper and Allied Products	.08975
		Non-manufacturing Industries	.07236
		Primary Metals	.06722
		Food and Kindred Products	.04001

Figure 4. Time Series Plot, for Representative High, Medium, and Low Technology Japanese Industries, of the Growth in Their Technology Stocks as Measured by the Number of R & D Workers as a Fraction of Total Workers ($JMSRSW\#_i$)[a]

line A : All Manufacturing and Non-Manufacturing
B : Agriculture, Forestry, and Fisheries
C : Printing and Publishing
D : Chemicals
E : Electrical Machinery
F : Electrical Machinery, Equipment and Supplies
G : Communications and Electronic Equipment
H : Transport Equipment
I : Precision Instruments



[a]The more technical details regarding the calculation of these stock measures of each industry's technological intensity are discussed in the text on the basis of equation (1). A fifteen percent depreciation rate is assumed.

Table 3. Summary of Tests for Structural Change, During the 1959-84 Period, in Either the Levels of Growth Rates of Alternative Technological Variables for Japan in Comparison with France and the United States – Based on the Aggregate(s) of all Manufacturing and Non-Manufacturing Industries[a]

Year	Values of the:	Individual Country (and Variables):				Inter-Country Comparative Measures for:			
		Japan	Japan	United States	France	Japan and the United States	Japan and France	Japan in Relation to Both France and the United States	
		JRSW#	Growth Rate of JRSW#[b]	URSW#	FRSW#	Ratio of JRSW# to URSW#	Ratio of JRSW# to FRSW#	Ratio of JRSW# to the Average of FRSW# and URSW# (Flow Measure)	Ratio of $JMSRSW\#_1$ to the Average of $FMSRSW\#_1$ and $UMSRSW\#_1$ (Stock Measure)[c]
1973	Constant Term	.0084 (14.72)***	–.0013 (–.03)**	.0290 (33.90)***	.0408 (28.37)***	.2892 (10.31)***	.2455 (14.85)***	.2819 (15.18)***	.2996 (23.47)***
	Dummy	.0011 (1.32)	–.0363 (–.63)	–.0025 (–2.20)***	–.0031 (–1.81)*	.1431 (3.71)***	.0410 (2.07)*	.0596 (2.68)**	.0486 (3.18)***
	Time	.0006 (9.21)***	.0066 (1.42)	–.0003 (–2.66)**	.0006 (2.43)**	.0292 (8.27)***	.0158 (5.39)***	.0246 (7.45)***	.0149 (6.55)***
	Time Dummy	.0007 (6.34)***	–.0067 (–.83)	.0012 (7.01)***	.0002 (.79)	–.0109 (–2.05)*	.0008 (.24)	–.0063 (–1.61)	.0066 (2.43)**
	F-Statistic	23.56***	.74	25.99***	2.23	8.10***	2.15	5.73**	6.95***
	Likelihood Ratio	29.76***	1.70	30.74***	4.89*	14.29***	4.74*	10.82***	12.56***
	Adjusted R^2	.98	–.04	.73	.76	.96	.97	.97	.98
	Durbin-Watson Statistic	1.48	3.08	.87	1.46	1.67	2.66	2.67	1.10
	Number Obs.	26	25	24	21	25	21	21	21
1982	Constant Term	.0065 (10.98)***	.0316 (1.05)	.0275 (50.37)***	.0416 (48.12)***	.2533 (12.09)***	.2298 (18.85)***	.2753 (21.35)***	.2598 (24.79)***
	Dummy	.0011 (.51)	.1801 (1.13)	.0062 (3.24)***	.0008 (.28)	–.1591 (–2.12)**	–.0151 (–.38)	–.0644 (–1.54)	–.0140 (–.41)
	Time	.0009 (20.94)***	.0014 (.65)	–.0001 (–1.65)	.0004 (5.13)***	.0360 (22.56)***	.0199 (17.70)***	.0270 (22.65)***	.0236 (24.39)***
	Time Dummy	.0013 (1.33)	–.0012 (–1.17)	.0008 (.97)	.0016 (1.32)	.0079 (.23)	–.0019 (–.11)	–.0004 (–.02)	–.0091 (–.60)
	Likelihood Ratio	13.43***	1.60	37.48***	9.84***	14.52***	1.14	9.74***	4.43
	Adjusted R^2	.97	–.04	.79	.81	.96	.96	.97	.98
	Durbin-Watson Statistic	.84	2.83	.93	1.62	1.18	2.10	2.24	.49
Year Having Highest Value of Likelihood Test		1968	1974	1981	1978	1972	1969	1981	1977
	Constant Term	.0092 (15.04)***	–.0053 (–.14)	.0278 (51.52)***	.0416 (43.85)***	.3051 (10.90)***	.2816 (12.35)***	.2709 (21.24)***	.2774 (28.22)***
	Dummy	–.0011 (–1.70)	–.0840 (–1.48)	.0020 (1.31)	–.0034 (–2.05)*	.1580 (4.34)***	.0397 (1.95)*	–.0387 (–1.18)	.0648 (4.13)***
	Time	.0004 (3.95)***	.0073 (1.82)*	–.0001 (2.42)**	.0004 (3.81)***	.0258 (6.80)***	.0023 (.33)	.0277 (22.23)***	.0203 (16.43)***
	Time Dummy	.0008 (7.15)***	–.0026 (–.31)	.0020 (3.89)***	.0012 (3.57)***	–.0053 (–1.04)	.0169 (2.42)**	–.0109 (–.97)	–.0063 (–2.20)**
	Likelihood Ratio	38.93***	3.48	39.35***	11.75***	16.68***	6.64***	11.50***	14.67***
	Adjusted R^2	.99	.03	.81	.83	.97	.97	.97	.99
	Durbin-Watson Statistic	1.79	2.99	.96	1.72	1.72	2.36	2.42	1.01

[a]The designated years indicate the starting points from which a structural change is hypothesized to occur through to 1984. For France the starting year for the data sample is 1964, whereas the Japanese and American series begin in 1959 and 1960, respectively. Numbers in parentheses are T-statistics. Single, double, and triple asterisks are used to indicate the significance at respectively the 90%, 95%, and 99% levels for the T-statistics, likelihood ratios, and F-statistics. However, in the latter case significant values are only designated at the 95% and 99% levels. Two-tailed tests are used when examining the significance of the T-statistics. With a sample size of 26 observations the critical lower bound values of the Durbin-Watson Statistic, which delimit the inconclusive range for testing the hypothesis of zero autocorrelation, are approximately .93 and 1.14, at respectively the 99% and 95% significance levels. The upper limits, which correspond to a rejection of the hypothesis of positive autocorrelation, are 1.41 and 1.65. For the smaller French data sample the respective critical values are .80 and 1.03, for the lower bounds of the Durbin-Watson test, and 1.41 and 1.67, for the upper bounds.

[b]The annual growth rates are calculated starting in the year prior to the designated one.

[c]The more technical details regarding the calculation of these stock measures of technological intensity are discussed in the text on the basis of equation (1). A twenty-five percent rate of depreciation is assumed.

in both the level and growth rate of the average R & D intensity of Japan's industries, is tested for 1973 (and onwards) and 1982. In addition, a search procedure was undertaken to find the years for which there are the largest structural breaks in the evolution of the dependent variables.[25] In the first instance the year having the highest value of the likelihood ratio test is 1968. On the basis of the first set of three equations, there is a clear indication of a structural change in the evolution of JRSW# in the 1959–84 period. This is reflected by the statistical significance, at the 99 percent confidence levels, of the likelihood ratio and F-statistics, as well as by certain significant values of the T-statistics.[26] Note, however, that in the case of the 1982 equation the Durbin-Watson test suggests the presence of autocorrelation in the residuals. The non-linearity of the estimated equation for 1968 is reflected by the marked difference between the initial slope of .0004 and that of .0012 for the second line segment. These values correspond in the first instance to the coefficient of the independent variable, time (earlier designated as b_2), and to the sum of this coefficient with that of the variable, time dummy (b_4).[27] Whereas the aggregate increase in the R & D intensity of Japanese industries in 1960 was estimated as 4.35 percent, the growth rate at the point of discontinuity in 1968 equals 9.4 percent.[28] However, by 1984 this annual rate had fallen back to 3.75 percent. Graphically, the estimated pattern of growth rates for the aggregate R & D intensity of Japanese industries (based on the 1968 equation) can be illustrated as in Figure 5. Not surprisingly, the second series of equations reported in column 2 of Table 3, which are designed to test for a consistent growth rate over the full sample period, prove to have a quite poor explanatory power. Also consistent with this scenario are the results from the last equation in the first column. These show non-significant coefficients for the dummy and time dummy variables, testing for a hypothesized structural break in 1982. Furthermore, there is a declining growth rate starting at 3.3 percent in 1982. In sum, while most of the 1960s appear to have been characterized by a steady increase in investments for technological innovation, amounting to approximately three or four percent per annum, there was a remarkable surge in the R & D intensity of Japanese industries at the turn of the decade. Indeed, the growth rates of JRSW# approached the double digits in the early 1970s. By

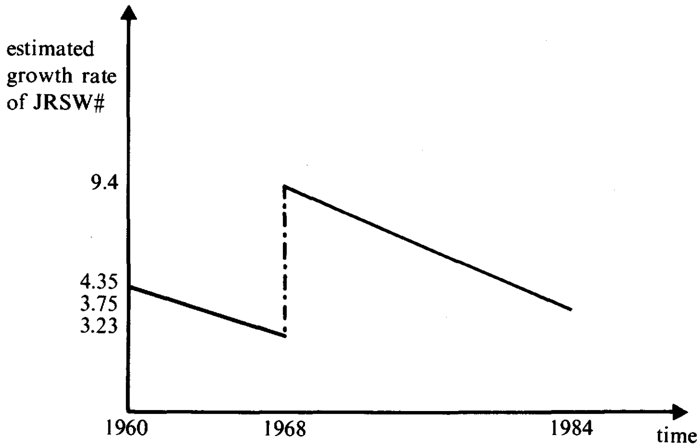
[25]Such a procedure permits some evaluation of the maximal potential differences in the extent of technological growth before and after the structural break occurs. In most cases, such a search for the equations with the largest structural break corresponded to maximizing their overall explanatory power.

[26]Single, double, and triple asterisks are used in this (and other) table(s) to designate significant statistics at, respectively, the 90, 95, and 99 percent confidence levels. Representative critical lower and upper bounds for the Durbin-Watson test are provided in footnotes to the tables. Since there are only a few instances where the Durbin-Watson statistic suggests the presence of autocorrelation, there is no further reference to this econometric problem in the text.

[27]The interpretation of the coefficients of the constant term and dummy as b_1 and b_3 is apparent.

[28]The calculation of this latter figure is based on the following: Growth Rate of JRSW68$=(b_2+b_4)/[(b_1+b_3)+(1968-1960)b_2]$. Subsequent calculations involve straightforward extensions of this formula, so that further explanations are omitted.

Figure 5.



the 1980s, however, this growth in Japan's technological performance had substantially slowed to the initial 1960s levels. It is quite striking that Japan's most dramatic technological build-up appears to have antedated somewhat the 1973 oil crisis. It remains for subsequent research to disentangle more fully the relative contributions of technological progress and higher energy prices in explaining Japan's post-oil crisis, industrial performance.[29]

Before contrasting the foregoing assessment of Japan's aggregate investment for technological progress with those for France and the United States, we shall scrutinize more closely the differing scenarios which apply for specific Japanese high-tech industries identified earlier. Table 4 offers the disaggregate econometric results for six industries, based on JRSW# from 1959 through 1984. For each of these high-tech sectors, equations were estimated under alternative assumptions of a possible structural change in either 1972 or 1971. In those three instances where there were any significant differences for the results in these two years, both estimated equations are reported.[30] In all but one case, involving drugs and medicines in 1971, there are significant structural breaks occurring (at the 99 percent confidence level) in the early 70s. Indeed, for all of these latter equations, the positive coefficients of the time dummy variables are both statistically significant and economically important, relative to the coefficient of the overall trend terms. In addition, with the exception of motor vehicles and industrial chemicals and

[29]See Jorgenson (1986), Jorgenson, *et al.* (1987), and Kuroda, *et al.* (1984), for discussions of this issue within an empirical framework, which, however, does not explicitly incorporate technological indicators such as those analyzed here.

[30]Quite similar results are also obtained if structural changes are postulated for 1968. For four of the estimated equations the likelihood ratio tests were, however, marginally more significant for the 1972 equations.

Table 4. Summary for Selected, Japanese High-Technology Industries of Tests for Structural Change, During the 1959–84 Period, in the Levels of a Representative Flow Measure of Their R & D Intensity[a]

Industries \ Value of	Year	Constant	Dummy	Time	Time Dummy	Likelihood Ratio	Durbin-Watson	Adjusted R^2
Industrial Chemicals and Chemical Fibers	1972	.0151 (18.29)***	−.0025 (−2.24)**	.0014 (13.45)***	.0012 (7.37)***	32.41***	1.36	.99
Drugs and Medicines	1972	.0306 (20.01)***	.0042 (1.98)*	.0012 (5.97)***	.0005 (1.59)	7.60**	1.92	.96
	1971	.0319 (25.29)***	.0065 (3.98)***	.0009 (4.99)***	.0007 (2.96)***	19.39***	2.15	.97
Electrical Machinery, Equipment and Supplies	1972	.0101 (5.94)***	.0090 (3.85)***	.0013 (6.08)***	.0008 (2.42)***	18.91***	1.94	.97
Communications and Electronic Equipment	1972	.0226 (9.99)***	.0056 (1.80)*	.0010 (3.43)***	.0022 (5.12)***	23.42***	1.40	.96
Motor Vehicles	1972	.0121 (10.60)***	.0008 (.48)	.0003 (2.23)**	.0010 (4.56)***	17.94***	1.74	.92
	1971	.0125 (10.75)***	.0007 (.49)	.0002 (.149)	.0010 (4.91)***	19.23***	1.77	.92
Precision Instruments	1972	.0150 (7.80)***	.0054 (2.03)*	.0005 (2.00)*	.0014 (3.95)***	18.10***	1.09	.93
	1971	.0154 (7.55)***	.0034 (1.27)	.0004 (1.47)	.0016 (4.43)***	17.49***	1.41	.92

[a]The hypothesized year for the structural changes in the level of JRSW# for the jth industry is 1972, except for those industries where there was a notable difference between the estimated results for 1972 and 1971. All of the reported estimates are based on twenty-six observations. Whenever pertinent, the remarks in footnote a of Table 3 also apply here.

fibers, there are supplementary upward shift effects, as reflected by the coefficients of the dummy variable. These reinforce the positive slope changes in the second periods. Particularly noteworthy is the size of the positive coefficient for the dummy variable in the electrical machinery (equipment and supplies) equation, which is almost equivalent to the constant term.

The empirical findings in Table 4 clearly also reflect a certain diversity in the estimated growth rates of the R & D intensities for the six Japanese industries. A convenient way for assessing these quantitative differences is by examining in each instance the estimated growth rates, for the ratios of researchers to total workers, in 1959, 1972, and 1984. These figures (based on the 1972 equations) are summarized as follows:[31]

Table 5. Estimated Growth Rates of R & D Intensity for Specific, Japanese High-Tech Industries in 1959, 1972, and 1984

Industries \ Year	1959	1972	1984
Industrial Chemicals and Chemical Fibers	9.3	8.4	4.2
Drugs and Medicines	3.9	2.4	1.9
Electrical Machinery, Equipment and Supplies	12.9	5.8	3.4
Communications and Electronic Equipment	3.8	7.1	3.8
Motor Vehicles	2.5	8.1	2.1
Precision Instruments	3.3	7.1	3.8

The much higher investment for technological innovation undertaken by two out of the six industries in the 1960s is particularly striking. Yet, while the high rates of growth in the R & D intensity of industrial chemicals and chemical fibers, and electrical machinery (equipment and supplies) are sustained in the 1970s, these fall off to more moderate levels in the 1980s. The latter are quite comparable to those previously estimated for the aggregate of all Japanese industries. More generally, there is also a marked decline in the 80s for the other industries cited in Table 5, from previously higher rates in the early 70s.[32] Although it remains to be seen to what extent such lower growth rates of investment in R & D in the 1980s may still be relatively high in international terms, the

[31]Other than the non-significant trend terms for motor vehicles and precision instruments, the calculated growth rates are quite similar for the 1971 and 1972 equations. Based on the 1971 estimate, the growth rate in 1985 for motor vehicles of 3.9 percent is slightly higher than the rate calculated from the 1972 equation. Similarly, in the case of precision instruments the rates of 10.4 percent in 1971 and 4.4 percent in 1971 are somewhat larger.

[32]The relatively large and positive coefficients for the dummy variables in the equations, relating to drugs and medicines, electrical machinery (equipment and supplies), communications and electronic equipment, and precision instruments, indicate higher actual growth rates in the early 1970s, than those calculated in Table 5.

question of the timing of Japan's technological build-up around the late 1960s and early 1970s merits further investigation. For the moment one can only speculate whether Japan's technological surge during this period may have been to some degree facilitated by its relative technological position, compared with those of the United States and Europe. Perhaps in the 1980s, further growth in technological investment may be less profitable in light of Japan's technological prowess in certain product lines of such industries as electrical machinery. Of potential relevance to these issues, concerning possible explanations for the evolution in Japan's technological position, is the distinction between applied and basic R & D. This has received much emphasis in the previously cited work of Mansfield, comparing Japan and the United States. A continued investigation of additional data series, further broken down according to different R & D categories, constitutes a clear research priority. Finally, one further remark concerns the relation between the disaggregated findings for high-tech industries and the earlier discussion involving the average for all Japanese sectors. Since these two sets of results are, with the exception of industrial chemicals and chemical fibers, and electrical machinery (equipment and supplies), fairly similar, the more aggregate characterization of Japan's overall technological development appears broadly applicable across most of the twenty-five distinct manufacturing and non-manufacturing industries incorporated in the empirical analysis.

C. The Relative International Technological Position of Japan

An examination of Tables 1 and 2 reveals both similarities and differences in given years, between the relative technological rankings of the individual Japanese industries, as compared with those for France and the United States. In addition, there are more numerous dissimilarities in the absolute values of alternative R & D indicators, for specific bilateral or trilateral comparisons involving individual industries. In this latter regard, it is the relation between the values for the technological intensities of the given industries and the overall industry averages in each country which is of particular interest in the current analysis, since this offers some basis for standardizing such international comparisons.[33]

[33]Some idea of the potential quantitative importance of possible discrepancies in the statistical and survey practices between the three countries, can be deduced on the basis of the entries in Table 1. Among other reasons, these can arise from differences in attributing the contributions of either workers or expenditures to research and development in specific industries. Observe that the averages for all Japanese industries, based on both sets of measures, are initially lower in the 1960s and 1970s than the counterpart indicators for the United States. By the mid–1980s, however, the research workers based measures are roughly the same, while the American R & D expenditure intensity for all industries still continues to be more than twice that for Japan. Note, nonetheless, that the 1984 R & D intensity of all Japanese industries, based on the expenditures data, is still 2.2 times greater than that for 1960. (In the case of the statistics involving numbers of researchers the comparable progression is by a factor of 3.5). The average values of the scientists and engineers indicator for France, on the other hand, remain throughout the entire period substantially higher than those for the other two countries. In contrast, the averages based on R & D expenditures are fairly similar to those for the United

Whereas, for example, the aeronautics industry is consistently placed as either the most, or second most, R & D intensive sector in both France and the United States, it is one which has only known rapid growth in Japan in recent years.[34] The electrical machinery industry in France during the 1970s and 1980s no longer enjoys the same high-tech, sectoral ranking as do its Japanese and American counterparts. Similarly, the R & D intensity of the French precision instruments industry falls considerably after the 1960s. On the other hand, the French agriculture sector appears as a leading investor in technological innovation in the 80s, perhaps due to research relating to the development of bio-technologies.[35] In the United States the computer and chemical industries are particularly well placed in the 1980s, while petroleum refining figures seventh on the basis of the stock measures presented in Table 2.

Nonetheless, the basic congruence between the three countries in the list of most R & D intensive industries remains apparent. Thus, a more insightful analysis of the evolution of Japan's relative technological position needs to highlight changes within each of the three countries in the relative positions of particular sectors over the 1960 to 1984 period, along with quantitative differences in their R & D intensities. Certain comparative observations can, of course, be deduced by first undertaking for France and the United States separate detailed examinations of the evolution in the technological intensities of specific high-tech sectors. However, while such detailed analyses, similar to that earlier proposed for Japan, appear worthwhile, they are undoubtedly too ambitious for one paper. Consequently, the principal focus here will be on a juxtaposition for the three countries of the evolution in the R & D intensities of specific industries. This composite overview of Japan's relative international technological development is based in large part on an analogous econometric analysis to that undertaken for Japan. However, the variables are now constructed by taking either bilateral or trilateral ratios of the Japanese technological indicators to those for France and/or the United States. Once again, in the interest of economizing presentation, and also because of fewer missing observations, this empirical investigation relies on the research workers based indicators.

Several fundamental remarks can be made by first considering the evolution, over the sample periods, of the aggregate technological intensities of French and American

States, while also remaining twice that for Japan. Clearly, in the absence of any consensus by international experts, regarding the comparability of the procedures used for compiling these technology statistics, extreme prudence must be exercised, when undertaking any international comparisons involving absolute values of the reported R & D intensities.

[34]The significant role of the French and American governments in the funding of research and development in this industry has already been noted. Also observe that this industry's relative R & D position in France tends to undermine the validity of Ergas' evaluation (1984b) of the French aerospace sector as "relatively weak".

[35]The ranking of this sector may be influenced, however, by the exclusion of the total sales of certain firms, since only those firms which undertake a significant amount of research and development are included in the reported firm sample. Such a statistical problem may be more acute in industries having a large proportion of small firms.

industries, in relation to that for Japan. Figure 6 permits an initial analysis of Japan's relative technological position from 1964 through 1984. It juxtaposes the *absolute* values of the stock R & D intensities for the three countries. In doing so, the diagram clearly underscores the issue of the comparability of the three sets of data sources. If the statistical methods used in their compilation are accepted as equivalent, France would be portrayed as having been technologically dominant since the end of the 1960s. However, it also is the case that much of the progression in the French indicator can be attributed to a few years in the 60s.[36] As of the mid–1970s there is a clear slow-down in the increase in this stock technology measure for France. In comparison, the continued steady progression in the stock values for Japan's overall R & D intensity leads by the early 80s to a position of near parity with that of the United States. This marked improvement in Japan's relative technological standing, compared to that of the United States, results as much from a stagnation in the 70s in American investment for technological innovation as from the high growth rate in the proportion of researchers to total workers in Japan. Yet, in the early 1980s there is also evidence of an upswing in the R & D intensity of American industry.

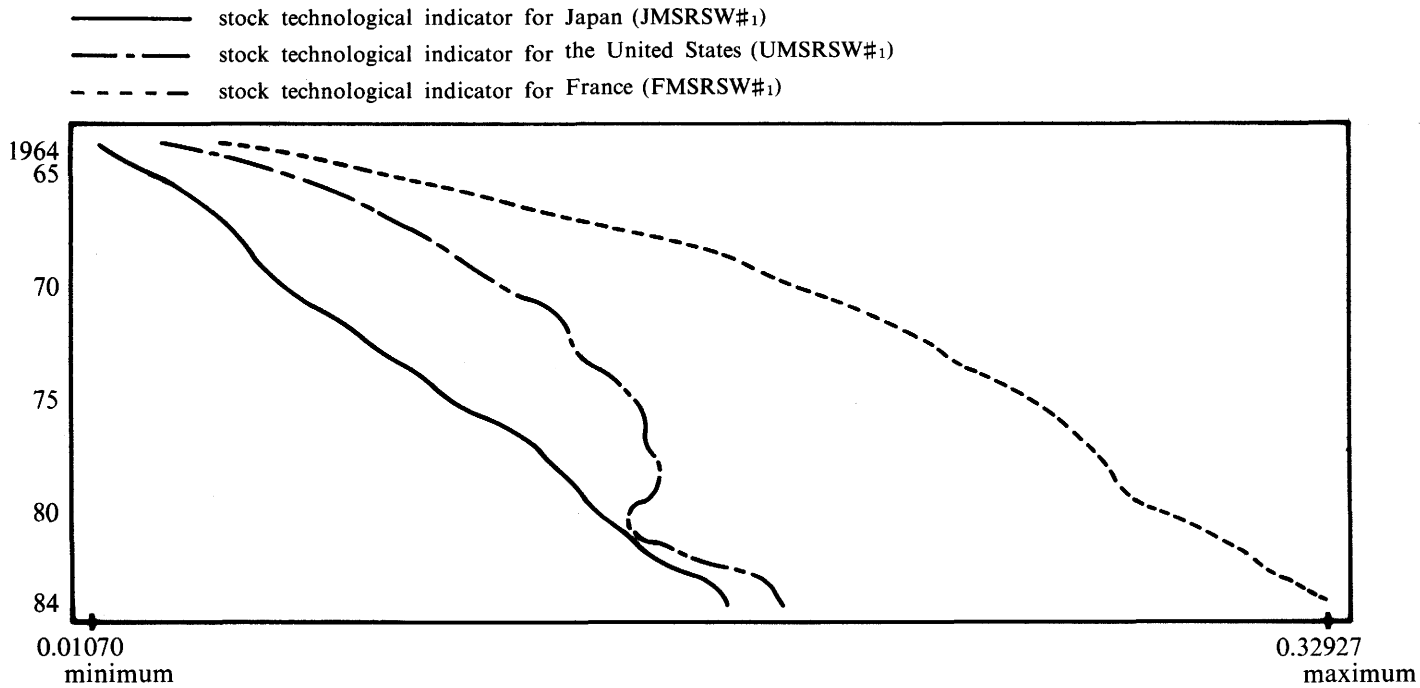
Figure 7 highlights the profound change, since approximately 1970, in Japan's relative international technological position. It depicts *relative* technological indicators, consisting for each country of the ratio of its overall stock R & D intensity to the average of those for the other two economies. In the case of Japan this relative measure comprising all industries (symbolized by the subscript 1) was previously identified as $JMSRSW\#_1/((FMSRSW\#_1+UMSRSW\#_1)/2)$. The technological stocks in this expression are defined in terms of analogous formulas to that given in equation (1).[37] Note the sharp decline, from the mid–1960s until the early 1980s, in the United States' relative technological position. On the other hand, France's relative position, which originally improved in the late 60s, has since substantially deteriorated, particularly in the 80s. The French relative technological indicator also appears more cyclical than those for the other two countries.

In Figure 8 each of the three countries' relative technological indicators have been standardized in terms of index numbers having a value of one hundred in 1972. This illustrates the implications of one hypothetical judgment regarding the comparability (in 1972) of the American, French, and Japanese statistical sources. Remark that the arbitrary choice of this particular base year determines the quantitative values for the three curves' slopes, and hence their overall positions. However, the signs of their slopes, along with the direction of the changes in each country's relative technological position, are unaffected by any specific standardization. Thus, we can conclude that there has been a prolonged and steady improvement in Japan's relative technological position, compared

[36]Perhaps some qualification may be appropriate for these earlier years, since this period corresponds to a time when there were several major revisions in the French industrial R & D, publication series.

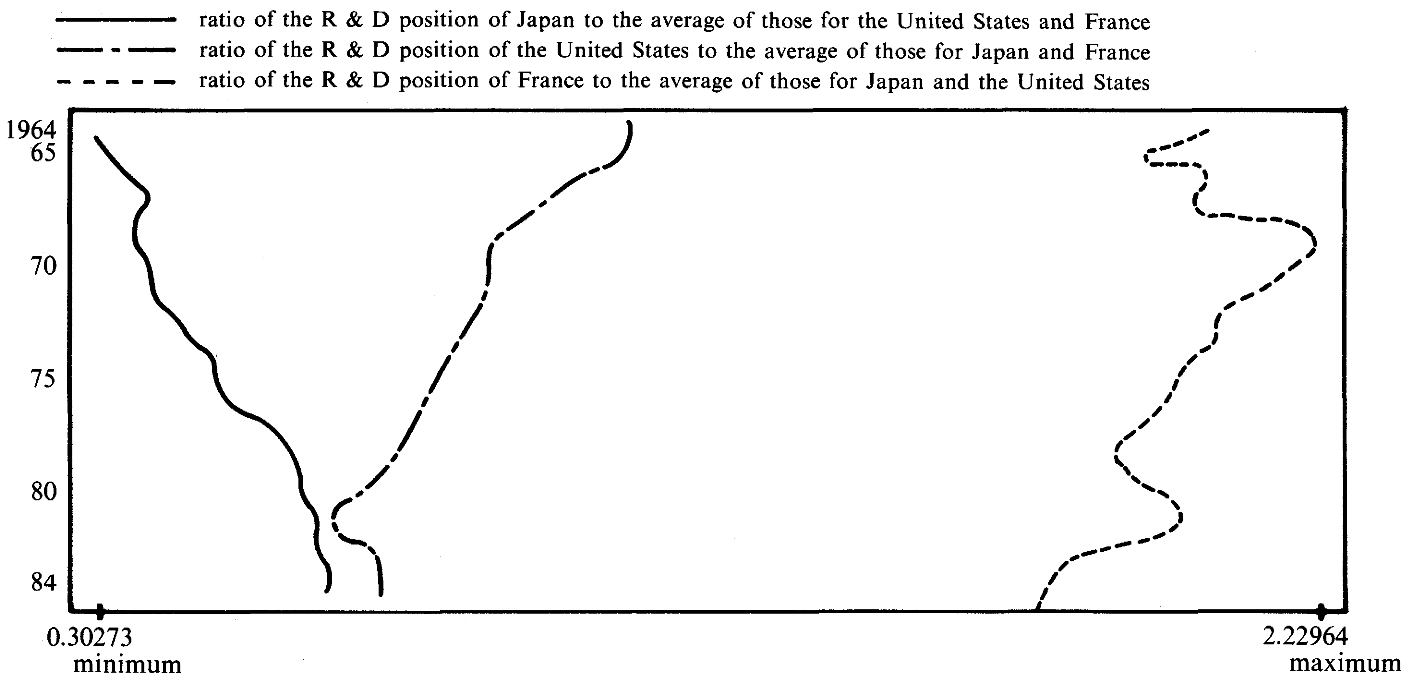
[37]Note, however, that a fifteen percent annual rate of depreciation is assumed in Figures 6 through 8.

Figure 6. Time Series Plot for 1964 through 1984 of the Technological Stocks for the Aggregate of All Industries in Japan, the United States, and France—as Measured by R & D Intensity Indicators Based on the Ratio of Researchers to Total Workers[a]



[a]This stock technology indicator is defined on the basis of equation (1), analogous formulas also apply for those for France and the United States. A fifteen percent annual rate of depreciation is assumed.

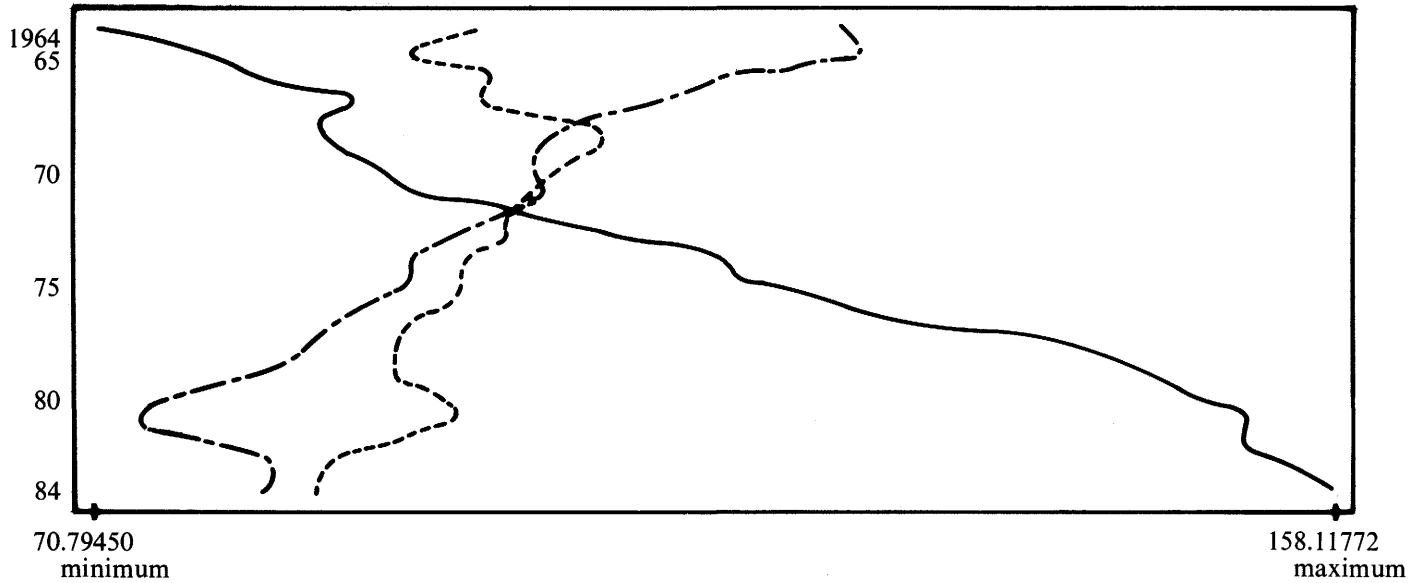
Figure 7. Time Series Plot for 1964 through 1984 of the Relative Technological Positions of Japan, the United States, and France—as Measured by the Ratio of the Stock Values of the R & D Intensity of All Industries in a Given Country to the Sum of Those for the Other Two Countries[a]



[a]The comparative indicators shown here involve R & D intensity measures based on the data on researchers and total workers. The comparative indicator for Japan consists of JMSRSW#1/(FMSRSW#1+UMSRSW#1/2), while those for the other two countries are defined analogously. The stock technology values are, again, determined on the basis of formulas comparable to that given in equation (1). A fifteen percent annual rate of depreciation for these technological stocks is assumed.

Figure 8. Time Series Plot for 1964 through 1984 of the Relative Technological Positions of Japan, the United States, and France—as Measured in Terms of Index Numbers based on the Ratio of the Stock Values of the R & D Intensity of All Industries in a Given Country to the Sum of Those for the Other Two Countries[a]

——— index for the R & D position of Japan relative to the United States and France
—·— index for the R & D position of the United States relative to Japan and France
- - - index for the R & D position of France relative to Japan and the United States



[a]The relative technological indicators for each country have been standardized to have the same index value of 100 in 1972. The footnote from Figure 7 also applies here, with regard to the definition of these comparative indexes.

to those of France and the United States.[38] While the 1960s was actually a period of relative decline for Japan, compared to France, the origins of Japan's current technological prowess appear to date from the previously identified period of rapid build-up in Japan's investment for technological innovation. This started at the end of the 60s. Since approximately that time there has also been a stagnation in France's relative technological position, while there is evidence of a deterioration in France's international technological competitiveness in the early 80s. These developments for Japan and France translate into a striking decline in the United States' relative technological position, during much of the more than two decades under consideration. Of course, a full assessment of the magnitude of this, and other, change(s) depends on the absolute values of the technological indicators, which are not evaluated in the present study.

The additional econometric analysis presented in Table 3 permits a more precise analysis of the evolution in the three countries' technological performance. The third and fourth columns in this table report equations pertaining to the flow measures of the aggregate R & D intensities of American and French industries. In comparison with the results for Japan, it is immediately apparent that the growth rates for the other two countries are considerably lower during most of the period. On the basis of the 1973 equation, the initial rate for the United States in 1960 is estimated as −1.0 percent. Although the growth rate of American investment for technological innovation subsequently becomes positive, the 4.0 and 2.8 values, in respectively 1973 and 1984, are well below those previously identified for Japan. Yet, the American equations for 1981 and 1982 suggest that most of this growth can actually be attributed to a spurt of higher R & D intensities in the early 1980s. In addition to the significance of the likelihood ratio tests, this remark is supported by the annual growth rates estimated in the 1981 equation, which range from 7.4 to 6.0 percent, between 1981 and 1984. Note, furthermore, the relatively large and statistical significant coefficient for the dummy term in the 1982 equation. In the French case the estimated annual growth rates, of the ratio of researchers to total workers, are uniformly low. This confirms our earlier characterization that France's investment in technological innovation has been relatively stagnant since the 70s. The 1973 and 1982 equations suggest values consistently inferior to one and a half percent, whereas in the 1978 equation estimated rates, varying between 3.65 percent in 1978 and 3.0 percent in 1984, are associated with a downward shift in the dummy coefficient.

The remaining columns in Table 3 report equations involving comparative technology measures, which reflect changes in the overall R & D intensity of Japanese industries in relation to those of the United States and/or France. These further empirical results are quite consistent with the previous econometric findings, and confirm the remarkable

[38] Note that the use of a later (earlier) base year than 1972 yields a steeper (flatter) curve for the R & D position of Japan relative to those of France and the United States.

progression in Japan's international technological competitiveness. Yet, the magnitude and timing of such a relative change in Japan's position varies considerably, according to whether the comparison is with the United States or France. In the American case the 1960s through to the mid-70s clearly stands out as the period in which there was the largest relative technological advance by Japan. While the estimated annual growth rates, for the ratio of JRSW# to URSW# in the 1972 equation, decrease from 8.5 percent in 1960 to 3.3 percent in 1972, the coefficient of the dummy variable indicates a large upward shift corresponding to the point of the structural break. Although there is also evidence in more recent years of a continued relative progression in Japan's position compared to that of the United States, this rate declines to 2.6 percent by 1984. This slowdown is confirmed in the 1982 equation where the annual rates of change in the 80s are estimated at around four percent. However, the growth rate is actually lower since there is a negative coefficient for the dummy variable.

In comparison with the American experience, the most significant period of decline in France's relative R & D position to Japan's appears to have taken place at the end of the 60s and during the 70s. While there is initially no significant trend in the 1969 equation, explaining the ratio of JRSW# to FRSW#, the estimates for the subsequent improvement in Japan's relative technological competitiveness range from 5.3 percent per annum in 1969 to 2.9 percent in 1984. In the 1982 equation the initial growth rate in 1964 is 8.7 percent, whereas it varies between 3.4 and 3.2 percent from 1982 onwards. At the same time that the latter rates are higher than those for the United States during the same period, observe that the coefficient of the dummy variable in the French equation is not significant. This latter remark, along with a comparison of the coefficients and growth rates in the two different 1982 equations, substantiates the earlier observation that the 80s have been associated with a greater decline in France's relative technological position to Japan, than in that of the United States. In this respect, note further that the estimated values for the constant terms in the equations of Table 3 offer some basis for standardizing comparisons between the results relating to different countries. An analogous examination of the 1973 equations, comparing Japan alternatively to the United States and to France, also suggests that Japan's initial technological advance in the 60s was greater relative to that of the United States, than to that for France. However, in the most recent years under investigation the opposite conclusion applies.

The last two columns in Table 3 portray Japan's technological performance in relation to the average R & D intensity of French and American industries. The use of both flow and stock indicators permits an evaluation of the cumulative effects on Japan's international technological competitiveness of different R & D investment rates during various sub-periods by the three countries. Familiar themes are the remarkable relative advance by Japan in the 60s and early 70s, and the continued, but slowed, progression in later years. Whereas a number of the equations suggest initial annual growth rates in 1964 as high as ten percent, more moderate rates of around three percent are consistently obtained for the 80s. While there are no major discrepancies between the flow and stock equations, some differences do arise with regard to the estimated rates for the improvement in Japan's technological position, particularly in the earlier years. Specifically, these tend to be somewhat lower when based on the stock results. In the case of the 1977 stock equation, for example, an initial rate of 7.3 percent in 1964 declines to 2.0 percent by 1984.

A final series of econometric results are presented in Table 6. These permit an assessment of the extent to which the trends in Japan's overall international technological competitiveness also characterize specific high-tech industries. The analysis is undertaken for both flow and stock measures of the relative R & D intensity of the indicated Japanese industries, compared with the average of those in the comparable French and American sectors.[39] Although some simplification is involved, a convenient way to highlight the principal findings from this more disaggregate investigation is to focus on the estimated annual rates of change for various years, as well as the timing and magnitude of any structural breaks. Table 7 summarizes such estimates for the initial and final years under investigation, along with an intermediate year corresponding to the hypothesized time of structural change. Whenever statistically significant, the sign of the coefficient for the dummy variable in each equation is also provided.

Before discussing the scenarios for the individual industries, two general features of these results can be noted as particularly striking. First, even for such a selected group of high-tech sectors, there is clearly a large diversity of empirical findings. Indeed, the current analysis of Japanese industries' relative competitiveness reveals a much greater heterogeneity of changes, than was the case for the disaggregate growth estimates in Table 5, which only involved Japan. Second, the flow and stock estimates presented in Table 7 are quite apparently different for certain of the sectors. Such results underscore the potential differences which may emerge from subsequent econometric studies where flow and stock technology indicators are used to explain industrial and international economic performance. Since a fairly high depreciation rate of twenty-five percent has been assumed in the calculation of these relative stock indicators, there also remains the further question of conducting a sensitivity analysis with regard to the implications of hypothesized lower rates of depreciation. Clearly, the appropriate rates could vary according to the industries under consideration. Possible statistical explanations, which can account for the differences in the flow and stock estimates in Tables 6 and 7 include the smoothing effect of stock calculations in those instances where there are either large variations in the data series or outlying observations. As a consequence, the influence of abrupt changes in flow indicators tends to appear with a lag in the stock equations.

[39]A search procedure was again used to identify in each case the equation having the largest value of the likelihood ratio test. Due to problems with missing data, the number of observations varies for certain industries.

Table 6. Summary for Selected, Japanese High-Technology Industries of Tests for Structural Change, During the 1964-84 Period, in Both Flow and Stock Measures of Their Relative R & D Intensity Compared with the Average of Those in the Comparable Sectors in France and the United States

a. Flow Measures Involving the Ratio of JRSW# to the Average of FRSW# and URSW#[a,b]

	Year Having Highest Value for Likelihood Test	Constant Term	Dummy	Time	Time Dummy	Likelihood Ratio	Durbin-Watson	Adjusted R^2	Number Obs.
Electrical Machinery, Equipment and Supplies	1977	.2108 (3.61)***	.357 (4.06)***	.0889 (10.33)***	-.0958 (-5.46)***	22.28***	1.44	.96	18
Communications and Electronic Equipment	1971	.1256 (2.06)*	.2499 (4.48)***	.0698 (3.79)***	-.0700 (-3.72)***	33.64***	1.62	.91	19
Computers	1975	.2488 (3.72)***	-.0050 (-.14)	.1527 (3.61)***	-.1215 (-2.86)***	10.47***	1.72	.95	12
Industrial Chemicals and Chemical Fibers	1977	.5232 (17.77)***	.1035 (2.20)**	.0251 (6.76)***	-.0069 (-.80)	5.32*	1.67	.93	21
Drugs and Medicines	1975	.5296 (33.48)***	.0787 (3.50)***	.0016 (.70)	-.0016 (-.41)	11.54***	2.35	.76	20
Aeronautics	1969	.0518 (5.75)***	.0135 (1.68)	-.0032 (-1.16)	.0103 (3.75)***	12.91***	1.84	.96	21
Motor Vehicles	1976	.4962 (13.55)***	.1610 (2.98)***	.0132 (2.66)**	-.0060 (-.65)	8.93**	1.78	.85	21
Precision Instruments	1972	.4477 (8.04)***	.1857 (3.20)***	.0218 (1.52)	-.0083 (-.54)	12.04***	2.05	.88	17

b. Stock Measures Involving the Ratio of JMSRSW# to the Average of FMSRSW# and UMSRSW#:[c]

	Year Having Highest Value for Likelihood Test	Constant Term	Dummy	Time	Time Dummy	Likelihood Ratio	Durbin-Watson	Adjusted R^2	Number Obs.
Electrical Machinery, Equipment and Supplies	1974	.5188 (7.92)***	.2188 (2.85)**	.0053 (.41)	.0587 (3.85)***	15.95***	1.09	.95	19
Communications and Electronic Equipment	1972	.2890 (4.86)***	.2960 (4.97)***	.0239 (1.57)	−.0294 (−1.84)*	26.41***	1.34	.85	19
Computers	1980	.4454 (23.62)***	−.0704 (−2.52)**	.0310 (7.36)***	−.0026 (−.32)	8.79***	1.76	.93	12
Industrial Chemicals and Chemical Fibers	1978	.4885 (30.39)***	.1039 (3.70)***	.0243 (12.85)***	−.0083 (−1.45)	12.92*	1.53	.98	21
Drugs and Medicines	1975	.5606 (38.48)***	.0790 (3.81)***	−.0031 (−1.46)	.0061 (1.70)	17.41***	1.55	.76	20
Aeronautics	1975	.0433 (11.10)***	.0237 (4.44)	−.0009 (1.56)	.0068 (7.79)***	39.48***	1.15	.98	21
Motor Vehicles	1977	.5165 (25.59)***	.2285 (7.09)***	.0044 (1.74)	−.0127 (−2.16)**	29.38**	1.36	.91	12
Precision Instruments	1972	.6729 (23.00)***	.1704 (5.59)***	−.0272 (−3.61)***	−.0437 (−5.41)***	25.33***	1.87	.93	17

[a]Whenever pertinent, the remarks in footnote a of Table 3 also apply here.

[b]Although the basic sample period extends for twenty-one years from 1964 through 1984, there are a number of industries for which data is missing for one or more years. In the case of electrical machinery (equipment and supplies), communications and electronic equipment, and precision instruments, 1966 is the first year for which data is available. In addition, for the first of these three industries, the 1983 observation was unavailable. For the stock equation this missing value was interpolated. Data was also missing for precision instruments after 1982. In the American and French statistical sources, the computer industry was not distinguished as a separate sub-category prior to 1973. The Japanese data for this sub-sector are based throughout the period on the more aggregate communications and electronic industry. Finally, statistics pertaining to drugs and medicines in 1984 were not available for all three countries.

[c]The calculation of these stock technology variables is based on a depreciation rate of 25 percent. Whereas the initial starting point for the calculation of the sectoral technological stock in both Japan and the United States in 1960, that for France in 1964.

Table 7. Estimated Growth Rates of the Relative, Flow and Stock R&D Intensity of Specific High-Tech Japanese Industries, Compared with the Average of Those in the Comparable Sectors in France and the United States[a]

Industries	Years	Growth Rate	
		Flow Equations	Stock Equations
Electrical Machinery, Equipment and Supplies	1966	42.2	.0
	1977	−.4	
	1974		8.0
	1984	−.5	4.4
	Dummy[b]	+	+
Communications and Electronic Equipment	1966	55.6	.0
	1971	−.03	
	1972		−.5
	1984	−.03	−12.7
	Dummy	+	+
Computers	1973	61.4	7.0
	1975	5.6	5.2
	1980	3.7	4.3
	1984		
	Dummy	0	−
Industrial Chemicals and Chemical Fibers	1964	4.8	5.0
	1966	2.6	2.6
	1984	2.2	2.3
	Dummy	+	+
Drugs and Medicines	1964	.0	.0
	1975	.0	.0
	1983	.0	.0
	Dummy	+	+
Aeronautics	1964	.0	.0
	1969	19.9	
	1975		10.1
	1984	5.0	5.3
	Dummy	0	0
Motor Vehicles	1964	2.7	.0
	1976	1.6	
	1977		−1.7
	1984	1.4	−1.9
	Dummy	+	+
Precision Instruments	1966	.0	−4.0
	1972	.0	2.4
	1982	.0	2.0
	Dummy	+	+

[a]These growth rates are calculated on the basis of the results presented in Table 6. Consequently, the flow measures involve the ratio of JRSW# to the average of FRSW# and URSW#, while the stock indicators consist of the ratio of JMSRSW# to the average of FMSRSW# and UMSRSW#. The calculation of these latter variables assumes a 25 percent depreciation rate. The specific years reported include the initial and final dates for which data was available, as well as an intermediate year corresponding to the time of a hypothesized structural break.

[b]This entry provides the sign of the coefficient for the dummy variable. Non-significant values are designated by a zero.

This section concludes with an examination of the evolution in the international technological competitiveness of the specific Japanese industries considered in Tables 6 and 7. As previously mentioned, the discussion focuses on the estimated growth rates reported in Table 7. In the case of electrical machinery, equipment and supplies, the divergence in the flow and stock results can be attributed to a very precipitous build-up in Japan's relative position to France and the United States. According to the flow indicator, this remarkable change, which originated around 1969 and continued until 1978, involved an increase by a factor of 354 percent.[40] Prior and subsequent to this period, there was little change in Japan's relative competitiveness, except for a slight decline in the 80s. Consequently, while the extremely high estimated growth rate of 42.2 percent per annum validly reflects the dramatic advance in this Japanese industry's international competitiveness between 1969 and 1978, it does not accurately characterize earlier years. However, following a large increase in its relative R & D intensity in 1978 (which is captured by the coefficient of the dummy variable), the Japanese electrical machinery industry appears to have attained a ceiling in its international technological competitiveness. The stock equation, in the other hand, suggests a slower and more prolonged build-up through to the 80s. Yet, such a specification does not successfully identify the slowdown, and even slight decline in the stock relative indicator values for the most recent years.

As suggested by the estimation of Table 7, there is a certain parallel between the technological scenarios for the Japanese communications and electronic equipment industry, and that for electrical machinery. The annual flow growth rate of 55.6 percent, along with the large positive value of the dummy coefficient in 1971, correspond to a precipitous technological development between 1968 and the time of the first oil shock. Japan's relative international technological position in communications and electronic equipment improved between 1968 and 1973 by 345 percent. The likely association between this technological development and Japan's international prowess in this industry is readily apparent. Yet, it is intriguing that the actual value of this relative indicator attained a value of .81, which is considerably lower than that for electrical machinery. The periods subsequent to both major oil price hikes are characterized by two major cycles in which Japan's international technological position fell somewhat. This explains both sets of negative growth rate estimates for the flow and stock equations. The adjustment growth path based on the stock specification again varies significantly from that based on the relative flow indicators. In this instance, the stock equation identifies a particularly large structural increase around 1972.

[40]The figures for all reported percentage changes correspond to the ratio of the end-of-period value for the relative technological indicators to that in the beginning-of-period. Although, as previously indicated, considerable caution must be exercised when interpreting absolute values of the technological indicators, it is noteworthy that the relative flow measure for electrical machinery sector increases from .46 in 1969 to 1.64 in 1978.

In computers and industrial chemicals and chemical fibers, the picture is one of a much slower, but sustained technological development in relation to those of France and the United States. For the case of computers, while there is a particularly large improvement in Japan's relative technological investment immediately after the first oil shock, the decade starting in 1973 witnessed an improvement in the flow relative indicator by 206 percent, to a high value in 1983 of .87. The quite similar flow and stock growth estimates for industrial chemicals and chemical fibers indicate a steady, but somewhat slower, progression for much of the period, at annual rates of between 2.6 and 2.2 percent. As a consequence, the overall increase in the relative flow indicator, between 1964 and 1984, amounts to 216 percent.[41] Nonetheless, there is evidence of a slowdown in Japan's advance in this industry as of 1981.

Each of the remaining high-tech industries in Table 7 exhibit certain idiosyncracies with regard to the timing and magnitude of Japan's technological advance. For drugs and medicines there is only a twenty percent difference between the value of the relative flow indicator for 1964, and its historical high of .65 in 1981. The major period of relative progression by Japan centers around 1975, which corresponds to the statistically significant structural break. Prior to and following this date there are a series of short cyclical swings, which are, of course, somewhat diminished by the use of the relative stock measure. In aeronautics, the role of direct R & D subsidies by the American and French governments, which have tended to be quite cyclical, has already been noted. While the values of the relative flow measures are markedly lower than those for the other industries under consideration, this sector experienced the largest single percentage growth rate. The value of the relative flow indicator rises dramatically by 455 percent between 1968 and the end-of-the-period when it equals .17. Because a number of sort cyclical fluctuations, however, an analysis of the relative stock indicator for aeronautics suggests a later starting point around 1974, for this build-up.

Relative to the other seven industries, motor vehicles is characterized by the largest cyclical fluctuations in the relative technological competitiveness of Japan. Two of these appear to originate around the time of the oil price rises in 1973 and 1979.[42] Nonetheless, two quite distinct sub-periods are apparent. Until 1973 there was a moderate, but steady, improvement in the Japanese automobile industries' relative technological position. On the basis of the flow equation these annual growth rates are estimated at between 2.7 and 2.1 percent. After the sharp turn-about subsequent to the first oil crisis, a remarkable upswing occurred in 1976. This development is captured by the relatively large, positive values of the dummy coefficients in both the flow and stock equations, although the latter occurs with a one year lag. The subsequent cyclical movement in the Japanese motor vehicles industry's technological competitiveness yields lower positive growth rates,

[41]The flow value of this relative indicator in 1981 is 1.08.

[42]Between 1973 and 1975 the value of Japan's relative flow indicator for motor vehicles fell by 25 percent.

according to the flow specification. However, since the stock series does not weigh as heavily a final upswing in 1984 (corresponding to a relative flow value of .95), the stock equation yields negative growth rates for the 80s.[43] Taken together these two distinct sub-periods translate into a 186 percent increase in the relative technological position of the Japanese automobile industry.

Finally, distinctive features of international technological competition in precision instruments also relate to the identification of two distinct sub-periods, and to the marked overall progression of Japan. Although there is no identifiable trend in the estimated flow growth rates prior to and after 1972, the large and positive coefficient of the dummy variable corresponds to the distinction of two quite different sub-periods. During both of these, however, there are several short cyclical variations in both the flow and stock technological indicators.[44] Nevertheless, the overall relative progression, between 1966 and 1980, by the Japanese precision instruments industry amounts to 215 percent. Observe that the smoothing effect of the relative stock calculations yields, alternatively, negative and positive, annual growth estimates before and after 1972.

Perhaps the most appropriate conclusion to the presentation of these more disaggregate empirical findings is to stress both the quite eclectic nature of the different scenarios for individual high-tech industries, but also to emphasize the pervasive nature of Japan's international technological advance. Furthermore, a comparison of the growth rates for the R & D intensity of Japanese industries, with those relating to the evolution of their international technological competitiveness, has revealed a much greater divergence of cross-sectional estimates for the latter. The identification of sectoral trends in relative R & D development between countries, which often occur during different time periods and are frequently non-linear, suggests a potentially rich research agenda. Apparent directions for continued investigation include further refinement of the estimates for the relative technological changes between the industries in the three (and other) countries, and an analysis of the associated implications for their international industrial competitiveness. In the next section some more specific avenues for such additional work are identified.

IV. Conclusions and Research Agenda

A key contribution of the present study arises from its unique focus on the evolution, over more than two decades, in the relative technological position of Japan compared to both that of the United States and a major European country—in this instance, France. In addition, the statistical analysis of absolute changes in the technological intensity of

[43]The latter are clearly a result of the previously identified cycle, associated with the second oil price rise.

[44]For example, in the most recent year for which data is available (1982), there is a downturn of 16 percent, relative to the highest relative flow value of .97 in 1980.

Japanese industries is more comprehensive than that undertaken in existing research by Japanese economists. Furthermore, the latter is not readily accessible to Western scholars. The present investigation of alternative technological indicators, for a disaggregated set of approximately thirty industries in the three countries, yields a number of new insights. Among these distinctive findings is the general remark that Japan's heightened international technological competitiveness, across a wide set of industries, is not just a development of the 1980s, but rather results from a prolonged and sustained build-up in investment in technological innovation. Indeed, between 1969 and 1984 there was more than an hundred percent increase in the principal flow indicator ($JRSW\#_1$) used to measure the overall R & D intensity of Japanese industries. Nonetheless, the current research suggests that the most profound change in Japan's technological position occurred in the late 60s and early 70s. The formal econometric analysis presented in the previous section suggests that for the aggregate of all Japanese industries the rate of growth of their R & D intensity may have attained annual rates of as much as 9.4 percent in 1968, while falling back to a more moderate level of 3.75 percent in 1984. Thus, the most remarkable period of Japanese investment in technological innovation appears to have antedated the first oil crisis.

Japan's striking technological advance has translated into a deterioration of the overall relative technological position of the United States during most of the twenty-five years under consideration. This devolution in the United States' relative technological competitiveness appears as much due to a stagnation in the 70s in America's R & D effort, as to the very high growth rates in the technological intensity of Japanese industries. However, there is evidence that the United States has been able to maintain somewhat better its position in the early 1980s. By comparison, on the basis of the results reported here for France, the fall off in Europe's comparative research and development position appears to stem from a more recent relative stagnancy in the level of investment for technological innovation. While this decline has occurred since roughly 1970, the French loss of technological competitiveness appears increasingly acute in the most recent years under investigation. Nonetheless, over the approximately two decades from 1964 through 1984, the overall deterioration in the United States' relative technological position to Japan appears to exceed that for France.

A number of more detailed remarks can be made on the basis of the disaggregate sectoral analysis. These concern not just Japan's cross-sectoral distribution of R & D intensities in a specific year and its evolution over time, but also extensive comparisons to the degree of technological innovation in the equivalent American and French industries. While the highly asymmetric distribution of technological intensities between industrial sectors characterizes all three countries, the dispersion of Japanese investment in R & D is substantially less than for either France or the United States. This suggests the relatively pervasive degree of technological progress across Japanese industries. Nonetheless, it is worth re-emphasizing that a relatively small group of high-tech industries in each country accounts for much of the investment in R & D. Although there is little evidence of technological intensity reversals between different Japanese industries for the earlier years under investigation, such changes do occasionally appear in recent years. The subsequent analysis for a group of high-tech Japanese sectors, of the estimated growth rates in their R & D intensity, highlighted the particularly impressive performance of electrical machinery and industrial chemicals during the 60s and early 70s. In the latter period other industries which boosted quite large increases in their degree of investment for technological innovation included communications and electronic equipment, motor vehicles, and precision instruments. Yet, it is striking that all of these high-tech industries experienced slow-downs in their rates of R & D intensity in the most recent years under consideration. The extent to which such lower growth rates of investment for technological innovation can help explain recent trends in Japan's productivity growth merits more explicit consideration beyond what has been undertaken in existing research.

In light of the significant differences between the countries in the technological ranking of their industries, the present study has identified sectors corresponding to those where each of the three countries may enjoy potential comparative and/or absolute technological advantage internationally. Yet, while the analysis of the evolution in the international technological competitiveness of specific Japanese industries has revealed a quite eclectic set of individual scenarios, it strongly confirms the pervasive nature of Japan's technological challenge. This disaggregate examination of changes in relative technological indicators, which is a quite distinctive feature of the current research, involved comparisons of the R & D intensity of specific Japanese industries with the average of those for the equivalent American and French sectors. During different subperiods, the relative technological indicators for the Japanese aeronautics, electrical machinery, communications and electronic equipment, chemical, computer, precision instruments, and motor vehicle industries advanced by factors ranging between 455 to 186 percent times their beginning-of-period values. However, a full characterization of these sectoral trends in Japan's R & D development relative to those in the other countries is complicated by both the non-linearity of many changes, and the existence for certain industries of cyclical movements. A consequence of the latter is that the distinction between flow and stock indicators, along with the role of the appropriate rate(s) for depreciating technological stocks, assumes a much greater importance when analyzing the evolution of the relative technological positions of different sectors, than when examining growth rates for the R & D intensity of industries in a given country.

Taken together the foregoing empirical conclusions appear to contradict a number of the propositions maintained by Ergas (1984b) and others, on the basis of their aggregate assessments of different countries' innovative performance. In addition, the analyzed trends and variations in both absolute and relative technology measures potentially undermine the validity of certain results reported in cross-sectional commodity trade or industry studies, such as those undertaken by Baldwin (1971, 1979), Caves (1984), Griliches and Mairesse (1985), Mansfield (1987a), and Owen (1982, 1984). The latter have used inter-industry R & D indicators for a single year to proxy the contribution of technology towards explaining different aspects of economic performance over more extended time periods. In addition, it is worth emphasizing that the existing research on determinants of international trade flows has focused almost exclusively on the role of absolute technological variables, without considering adequately the potential significance of the evolution in relative technological measures between different countries.[45] While such approaches may have been legitimate in the immediate Post-War period, when American technology was more dominant internationally, their more recent appropriateness appears particularly suspect in view of the findings of the present study. Thus, a pressing topic for further investigation involves situating the contribution of relative inter-industry R & D indicators for understanding the changing pattern of Japanese and other countries' trade and foreign direct investment flows, as well as other dimensions of their international industrial performance.[46] More generally, the conclusions of this paper also point to the potential importance of technological factors in understanding certain of the origins of current commercial policy tensions.

The focus of the present study, on the changing international pattern of technological performance between Japanese industries and their French and American counterparts, constitutes only the first stage in a larger research project. An apparent direction for possible further inquiry involves the incorporation of other countries in the analysis. In many cases, however, as extensive investigation as that proposed here, may be seriously hampered by the unavailability of disaggregate data series. While the current study has scrutinized the actual evolution in the relative technological competitiveness of Japanese, American, and French industries, no attempt has been made to examine factors which could explain the observed developments. Such an assessment constitutes an essential preliminary step prior to defining effective corporate and government policies for promoting technological innovation in these three countries. Furthermore, the relative technological trends identified in this study did not distinguish between applied and basic research and development. Yet, as suggested by the previously cited work of Mansfield,

[45]As previously noted, Owen (1984) identified the importance of relative technological levels between different American and French manufacturing industries for explaining the intersectoral pattern of foreign direct investment in France. However, this analysis of stock investment levels did not address any of the questions related to the evolution of technology internationally, or its effects on inter-industry foreign direct investment flows. Audretsch and Yamawaki (1986) have recently investigated the importance of using both American and Japanese R & D variables, when explaining these countries' bilateral trade. Yet, the present research suggests that a limitation of their approach involves the reliance on relative technological indicators for a single year.

[46]Ongoing research, which is to be reported in a subsequent paper, has also confirmed the significance of such relative technology variables, when explaining Japanese, American, and French trade flows. The issue of the appropriate lags and discount rates (for depreciating technological stocks), which best capture the effects of R & D on international trade shares, assumes an important role in this further work. See Dixit (1987) for the identification of other factors besides research and development which may influence Japanese-American trade in high-tech industries.

such a distinction appears to assume considerable importance when comparing the technological development of Japan and the United States. Inter-industry variations in the relative proportions of applied and basic R & D between countries appear critical to assessing the contribution of technological change in accounting for international patterns of productivity growth. Other possibilities for refining relative indicators of different countries' technological innovativeness include estimating spillover and indirect effects of R & D between industries.[47] Finally, any clarification of differences in statistical procedures between countries could lead to stronger statements regarding their relative technological positions.

At present, there appear to be a number of competing perspectives which try to account for Japan's impressive growth and international economic performance in recent years. On the one hand, more microeconomic standpoints have tended to emphasize such factors as research and development, commercial policies, marketing techniques, firm structure, or other aspects of Japanese industrial organization. Another approach has focused on international comparisons of estimates for the relative contributions of labor, capital and technological change, when explaining Japanese and other countries' productivity and economic growth. On the other hand, certain macroeconomists have stressed the role of short-term movements in such variables as relative prices, wages, interest rates, and exchange rates.[48] To the extent that indicators of Japan's and other countries' relative technological position provide a valid characterization of instances of either absolute or comparative technological advantage, and can be incorporated in international macroeconomic modeling, they could contribute to understanding the conundrum posed by quite disparate paradigms for understanding the "Japanese economic miracle."

[47]Studies for the United States by Bernstein and Nadiri (1988) and Davis (1982, 1983), which examine, respectively, spillover and indirect effects, have substantiated their important influence on sectoral R & D measures.

[48]See, for example, the paper by Branson and Love (1987). The inter-relation between financial variables and the relative productivity and competitiveness of American and Japanese manufacturing industries has been recently examined by Marstan (1986, 1987). However, his analysis does not specifically consider the effects of technological innovation in the evaluation of inter-sectoral capital stocks.

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Statistical Appendix

A. Breakdown of Industrial Classifications by Country

Japan:[1]

Observation Number	Name of Industry
1	Table for all manufacturing and non-manufacturing industries
2	Agriculture, forestry and fisheries
3	Mining
4	Construction
5	Manufacturing
6	Food
7	Textiles
8	Pulp and paper products
9	Printing and publishing
10	Chemicals
11	Industrial chemicals and chemical fibers
12	Oils and paints
13	Drugs and medicines
14	Other chemicals
15	Petroleum and coal products
16	Rubber products
17	Ceramics
18	Iron and steel
19	Non-ferrous metals and products
20	Fabricated metal products
21	General machinery
22	Electrical machinery
23	Electrical machinery, equipment and supplies
24	Communications and electronic equipment
25	Transport equipment
26	Motor vehicles
27	Other transport equipment

[1]Those industries whose names are indented constitute sub-categories of the preceding industry. Hence, for Japan there are four non-manufacturing industries and sixteen distinct manufacturing sectors. Three of the latter are further broken down into a total of eight sub-divisions.

28	Precision instruments
29	Other manufacturing (including plastics)
30	Transport, communication and public utilities

France:[2]

		(in French)
1	Total for all manufacturing and non-manufacturing industries	
2	Agriculture	(Agriculture)
3	Agriculture and food industries	(Industries agricoles et alimentaires)
4	Energy	(Energie)
5	Construction materials and ceramics	(Matériaux de construction et céramique)
6	Extraction and preparation of metals and initial transformation of metals	(Extraction, préparation, et première transformation des métaux)
7	Iron and steel and fabricated metal products	(Fonderie, travail des métaux)
8	Construction machinery	(Construction mécanique)
9	Electrical machinery	(Matériel électrique)
10	Electronic machinery	(Matériel électronique)
11	Computing machines	(Matériel de traitement de l'information)
12	Chemical industry	(Industrie chimique)
13	Pharmaceutical industry	(Industrie pharmaceutique)
14	Rubber and plastics	(Caoutchouc et plastiques)
15	Textile industry	(Industrie textile)
16	Aeronautic industry	(Construction aéronautique)
17	Automobile construction	(Construction automobile)
18	Naval construction and other transportation equipment	(Construction navale et autres matériels de transport)
19	Precision instruments	(Instruments et matériels de précision)
20	Glass industry	(Industrie du verre)
21	Other industries	(Industries diverses)

[2]For France there are five non-manufacturing and eighteen manufacturing sectors.

22	Construction, civil and agricultural engineering	(Industrie de mise en oeuvre du bâtiment et du génie civil et agricole)
23	Transportation services	(Services de transport)
24	Engineering	(Ingenierie)
25	Other services	(Autres Services)

United States:[3]

1	Total for all manufacturing and non-manufacturing industries
2	Food and kindred products
3	Textiles and apparel
4	Lumber, wood products, and furniture
5	Paper and allied products
6	Chemicals and allied products
7	Industrial chemicals
8	Drugs and medicines
9	Other chemicals
10	Petroleum refining and related industries
11	Rubber products
12	Stone, clay, and glass products
13	Primary metals
14	Ferrous metals and products
15	Nonferrous metals and products
16	Fabricated metal products
17	Machinery
18	Office, computing, and accounting machines
19	Other machinery, except electrical
20	Electrical equipment
21	Radio and TV receiving equipment
22	Communication equipment
23	Electronic components
24	Other electrical equipment
25	Motor vehicles and motor vehicles equipment
26	Other transportation equipment
27	Aircraft and missiles
28	Professional and scientific instruments

[3]For the United States there are seventeen basic manufacturing industries, of which five are further broken down into a total of thirteen sub-divisions.

29	Scientific and mechanical measuring instruments
30	Optical, surgical, photographic, and other instruments
31	Other manufacturing industries
32	Manufacturing industries

B. Notation and Variable Definitions

The letters F, J, and U are used at the beginning of a variable name to distinguish respectively French, Japanese, and American data series. Each variable ends with two digits (represented by the symbol #) which indicate the appropriate year pertaining to a specific data series. A subscript, i, which is suppressed in this appendix, further identifies observations for specific industries. It is understood that statistics for the indicated variables were collected for as complete a set of industries as possible. In light of certain discrepancies between the three countries' industrial classification systems, the comparative analysis reported in detail in section III. C. involved a merge file. All of the data initially used in this study were obtained from the three official published sources listed in the Statistical Bibliography. The responsible government agencies for France, Japan, and the United States are, respectively, the Ministry of Research and Technology, the Statistics Bureau of the Management and Coordination Agency, and the National Science Foundation.

Principal Measures of Inputs to the Process of Technological Innovation (by country):

	Variable Name	Definition
France:	FRIE#	Overall budget of total R & D expenditures, FRDE#, divided by the total sales of an industry, FS# (available from 1964 through 1984).
	FRSW#	Proxy for the R & D intensity of an industry, based on the number of the personnel engaged in R & D, FNS#, as a fraction of the industry's total workers, FTW# (available from 1964 through 1984).
Japan:[4]	JRIEC#	Total R & D expenditures within companies ("intramural") in an industry as a percentage of that industry's total sales, where this measure is based on "cost". The latter includes the aggregate expenses for labor costs and materials, as well as the depreciation of tangible fixed assets (available from 1959

[4]A separate variable reflecting government funding of R & D was not included in the statistical analysis for Japan since this series was negligible during most of the time period under consideration.

through 1984).

JRIED# Total R & D expenditures within companies ("intramural") in an industry as a percentage of that industry's total sales, where this measure is based on "disbursement." The latter includes aggregate expenses for labor costs and materials, as well as actual current-period expenditures on fixed assets (available from 1968 through 1984).

JRIEDT# A measure of R & D expenditures relative to an industry's total sales, which is comparable to the variable, JRIED#. However, the present variable is generated by relying on separate series for R & D expenditures and total sales (rather than relying on the published ratio which is used for the variable, JRIED#), (available from 1959 through 1984).

JRNS# Proxy for the R & D intensity of an industry, based on the number of regular researchers, JNS#, divided by the total workers in that industry, JTW# (available from 1959 through 1984).

United States:

URDGI# U.S. Federal Funds for R & D, URDG#, as a share of an industry's total sales, UTS# (available from 1961 through 1983).

URIEC# R & D (total) funds as a percent of net sales in R & D performing manufacturing companies, broken down by industry. This measure excludes actual capital expenditure, but includes a measure of their depreciation. It includes both operating expenses on R & D within a company and in other companies (available from 1957 through 1983).

URSW# Proxy for the R & D intensity of an industry, based on the full-time-equivalent number of R & D scientists and engineers, UNS#, as a fraction of the total workers in that industry, UTS# (available from 1960 through 1984).

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