The International Center for Research on the Management of Technology

Metrics to Value R&D: An Annotated Bibliography

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Abstract

As part of an effort to help our members understand better how to measure the value of R&D, the International Center for Research on the Management of Technology (ICRMOT) has sponsored a project to assess the state of the art in R&D metrics. This project has included (1) a series of qualitative interviews with Chief Technical Ofricers, Chief Executive Officers, and researchers at ten research-intensive international firms, (2) a review of the published literature, (3) the development of formal mathematical theory, and (4) empirical applications and tests of that theory (forthcoming).

This working paper provides an annotated bibliography for 147 articles published in the R&D, marketing, and economics literature. My goal is to provide the reader with a sampling of the various viewpoints on R&D metrics and on related material. I have attempted to describe the authors' conclusions and to indicate where additional data might be obtained. When feasible I have quoted directly from the article. In this way the reader can experience directly the flavor of the article and draw independent conclusions. (All such quotations are indicated by double quotes "....") Like all annotated bibliographies, these short descriptions can not substitute for a more comprehensive reading of the articles. However, I hope that they will help the reader decide which articles to pursue further.

In many places I refer to the "tiers" of R&D -- tier 1 is "exploring new concepts" (basic research), tier 2 is "selecting technology to match or create core technological competence," and tier 3 is applied research that is often joint with business unit "customers." This structure is described more completely in Hauser and Zettelmeyer (1996), which is available as an ICRMOT working paper.

It is my hope that this bibliography will grow. Please suggest additional references to the ICRMOT Web site (http://web.mit.edu/icrmot/www/) or to me (jhauser@sloan.mit.edu). A list of all ICRMOT working papers, and how to obtain them, is available at our Web site. Monitor our Web site for updates on this bibliography.

Acknowledgment

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Aaker, David A. and Robert Jacobson (1994), "The Financial Information Content of Perceived Quality," *Journal of Marketing Research*, 31, (May), 191-201.

One aspect of R&D that many firms try to measure is the impact that R&D has on the improvement of the quality of the firm's products. This paper examines whether one can measure quality and whether that measure has an effect on profit.

Specifically, the paper describes a stock-market analysis which indicates that a perceived measure of quality has a significant effect on stock price above and beyond current-period ROI and advertising. Advertising is not significant.

Data: There exists an EquiTrend survey of about feeling and quality with respect to 100 major brands in 33 categories. At least 1,000-2,000 households from 1989-1993.

Abt, R., M. Borja, M. M. Menke, and J. P. Pezier (1979), "The Dangerous Quest for Certainty in Market Forecasting," *Long Range Planning*, 12, 2, (April).

This article describes how Ciba-Geigy, Hoffmann-La Roche, and Sandoz made probabilistic forecasts. The authors argue that it is important to forecast the probability density function (pdf) rather than a point estimate. They then give a number of practical methods for obtaining a forecast of the pdf. These include practical suggestions on how to interview experts, how to combine expert judgments (Delphi), and how overcome the effect of central bias (use extreme scenarios). Furthermore, they build up the pdf from a variety of more micro events including a detailed representation of the marketing and sales models.

Acs, Zoltan. J. and David. B. Audretsch (1987), "Innovation in Large and Small Firms," *Review of Economics and Statistics*, 69, 567-575.

A test of the Schumpeterian Hypothesis (large firms are more innovative, imperfect competition promotes innovation). Explores when large firms are more innovative. The answer is when they are in markets characterized by imperfect competition. Significant variables in explaining the difference in innovation rate between large (500+ employees) and small firms are: capital output ratio, advertising intensity, concentration, unionization, and percent of industry accounted for by large firms.

Data: Points out a data source which is the count of innovations from the US Small Business Administration for 1982.

Acs, Zoltan J., David B. Audretsch and Maryann P. Feldman (1992), "Real Effects of Academic Research: Comment," *American Economic Review*, (March), 363-67.

This paper is a comment and reanalysis of the Jaffe (1989) study of the effect of university research on industry R&D. Whereas Jaffe used patents as the independent variable, Acs, et. al. uses a count of innovations that is available from the US Small Business Administration. For more discussion and equations, see Jaffe (1989) in this bibliography.

Most importantly, Acs, et. al. find a larger impact of university research on industry R&D and they find that this impact is bigger if the university is located close to the corporate R&D. Acs, et. al. also find that the results vary by whether the research is in electronics or in mechanical arts. One is routinized and the other is more entrepreneurial. "the importance of university spillovers relative to private-company R&D spending is considerably greater in the electronics sector when the direct measure of innovative activity is substituted for the patent measure."

Finally, Acs, et. al. suggest that the Jaffe results do not vary by year.

Adams, Scott (1995), "Manager's Journal: The Dilbert Principle," *Wall Street Journal*, May 22.

A manager wants to find and fix software bugs more quickly. He offers an incentive plan: $20 for each bug the Quality Assurance people find and $20 for each bug the programmers fix. (These are the same programmers who create the bugs.) Result: An underground economy in "bugs" springs up instantly. The plan is rethought after one employee nets $1,700 the first week.

Adler, Paul S., D. William McDonald and Fred MacDonald (1992), "Strategic Management of Technical Functions," *Sloan Management Review*, Winter, 33, 2.

Identifies four levels of performance or development -- isolated, reactive, proactive, and integrated. Paper contains an extensive bibliography.

"The technical function must set objectives that can guide resource allocation decisions, help ascertain how well it is fulfilling its mission, and align it with other functions' objectives and strategies."

Evaluations and rewards should be "administered consistently and fairly."

Good companies use "relevant information on markets, customer needs, competitors, and regulatory and environmental concerns. Also crucial is linking resource allocation decisions with the function's mission, objectives, and strategic plan."

"New product development projects at Xerox's Corporate Research Group are subjected to regular appraisal based on inputs from marketing and strategic planning." See also Mandell and Murphy (1989).

Aghion, Philippe and Jean Tirole (1994), "The Management of Innovation," *The Quarterly Journal of Economics*, 1185-1209.

This paper provides a theoretical mathematical framework to address whether R&D or business units should "own" the R&D function.

The analysis is based on bargaining and agency arguments. This paper describes the maximization problem and interprets the conditions (sometimes contingent upon relationships among the parameters).

They have one research unit (RU) and one customer (C), who input effort (e) and investment (E), for a probability of discovery p(e,E) = q(e) + r(E). The value of the innovation (V) is given but in a later section put under control. Both parties are risk neutral. The first best is then given by the maximum of pV-e-E. Because pV is a random variable, they can not contract on a deliverable, only the sharing rule.

Section II contrasts C-ownership (hence e=0) with RU-ownership with the assumption that C pays a license fee of V/2. This implies under-investment by both parties. See also Grossman and Hart 1986. Also the initial sharing rule can not influence the ex post bargaining game between RU and C because V is not contractible ex ante.

They provide results on co-financing, i.e., an outside investor. Transforms a discrete choice of governance (RU vs. C) into a continuous one, because the co-financing gives RU a fraction of value between RU-ownership and C-ownership.

Reviews the Schumpeterian Hypotheses. That is, R&D input (or output) is related to variables that alter the incentives for R&D -- scale, scope, and market power (larger V). Shows Schumpeterian hypothesis may not hold if the ownership structure is endogenous.

C-ownership is affected by a constraint on C's cash (to pay incentives). Inefficiencies suggest that new firms or firms tight on cash will farm out their R&D.

Introduces multiple innovations indexed by a real number t. Shows that conditions on t affect the type of ownership. Shows that the innovations for which the employee is hired should be owned by the employer if they make more use of the owners investment.

Next, t indexes time. Shows that if there are multiple users the property rights might be split between RU and C with each getting property rights to those activities in which it has a comparative advantage.

Next, they assume that discovery decreases with the size of the innovation and analyze incumbent vs. entrant to examine business units (business units) ability to license to entrant.

Allio, Robert J. and Desmond Sheehan (1984). "Allocating R&D Research Effectively," *Research Management*, (July-Aug.), 14-20.

Describes R&D management at Allied Corporation in the early 1980s. Stresses the role of strategic planning in determining R&D direction. "In most instances we find that functional strategies, including the R&D strategy, need to be determined by business strategy."

Postulates a relationship between R&D resource allocation and the maturity of the industry. That is, the amount allocated to the following categories shifts as the industry matures:

- exploratory research (electrode phenomena)
- new products -- existing market (new amorphous alloys)
- product extension (ANSO IV nylon carpet yarn)
- process improvement (solution mining of soda ash)

- raw material substitution (oil for natural gas to fire reformer furnaces)
- regulatory response (emission control and waste disposal)
- energy saving (double or triple effect evaporator)
- diversification (Alexandrite laser systems)

Core technology is (1) critical to maintaining competitive position or (2) providing significant technological underpinning for several businesses.

Athey, Susan and Armin Schmutzler (1995), "Product and Process Flexibility in an Innovative Environment," *Rand Journal of Economics*, 26, 4, (Winter), 557-574.

This article explores the conditions under which complementarities in the short-run lead to complementarities in the long-run.

The model is a two-period model. In the second period the firm makes (0, 1) decisions on whether to invest in "product design" and/or "process technology." For a given quantity sold, the authors assume that "design" increases the price that consumers are willing to pay and "technology" decreases the cost of production. The cost of moving from "none" to "some" for both "design" and "technology" is then a function of the "flexibility" that the firm has in either "design" or "technology." Flexibility is defined as that which lowers these costs.

The authors demonstrate general conditions for design and technology to be complements (supermodularity).

In the first period, the firm must make decisions on flexibility. The authors show that if the costs of flexibility are separable, then complementarity in the second period implies complementarity in the first period.

Adjustments in design and technology give benefits as defined above. The authors define investments in capabilities as improving the cumulative density function (stochastic dominance) of these returns and demonstrate the conditions that lead to flexibility and investment being mutually reinforcing.

The main contribution of this paper to R&D metrics is that it specifies general conditions on assumptions of flexibility and investment. It establishes the conditions that lead to complementarity. This could be important when specifying what needs to be measured when assessing the value of R&D.

Atuahene-Gima, Kwaku (1995), "An Exploratory Analysis of the Impact of Market Orientation on New Product Performance: A Contingency Approach, *Journal of Product Innovation Management*, 12, 275-293.

This is a questionnaire study of 275 Australian firms. Uses self-reported, multiple item constructs.

Key insights

- Shows a positive relationship between market orientation and new product performance.

- Market orientation has its greatest impact when the new product is incremental -- market orientation is not significant for radical innovations. (More exactly, the author divides the new products into two groups.)
- Market orientation has a greater effect when the perceived intensity of competition and industry hostility are high.
- Service is more related to new product performance in competitive environments.

Overall, this is evidence that market orientation is not a panacea. It is consistent with statements that research should not be entirely customer-funded.

Bachman, Paul W. (1972), "The Value of R&D in Relation to Company Profits," *Research Management*, 15, (May), 58-63.

Discussion of how to measure the return on research. He proposes the measure of: the profit from projects in the last five years divided by the cost of all projects in the last five years. He suggests the idea that one should compare profit from older operations to profit from more recent operations.

Profit results from:

"1) the selection of research problems,
2) the solution of the problem, and
3) subsequent commercialization of the research results."

Baker, Norman R. and James Freeland (1975), "Recent Advances in R&D Benefit Measurement and Project Selection Methods," *Management Science*, 21, 10, 1164-1175.

This paper is now over 20 years old, but it does give some insight into what has and what has not changed. The focus is primarily on operations research type methods such as linear programming and chance constrained programming, but it does discuss many of the measurement issues. It indicates that, in 1975, there was "some level of dissatisfaction (with the methods) on the part of the R&D management."

"All of the benefit measurement methods proposed to date require some well-informed respondent(s) to provide subjective inputs regarding characteristics of the proposals under consideration."

Suggests that linear objective functions are better than multiplicative objective functions, but does not suggest that the objective functions are derived from "first principles."

"Many industrial organizations use one or more of the economic return approaches, especially in the evaluation of development and engineering proposals."

The trend in application appears to be away from 'decision models' and toward 'decision information systems.'" In part, because "the decision problem is characterized by multiple criteria, many of which are not easily quantified."

Suggests research on:

- uncertainty
- benefit as a function of allocation level
- benefit measures for a program or portfolio
- adaptive methods
- abstract analyses to suggest organizational structures and coordination processes

Baker, Norman R., Stephen G. Green, and Alden S. Bean (1986), "The Need for Strategic Balance in R&D Project Portfolios," *Research Management*, (June), 38-43.

This paper investigates the balance between process and product R&D. It is based on data from 211 projects in an IRI database. The data suggest that:

- product projects account for 81% of the projects in the portfolio
- process projects are more likely to succeed
- process projects are rater higher in their contribution to the firm
- product projects addressed market position and sales volume
- process projects focused primarily on cost
- process projects were more complex and more costly

"Having product projects account for 81% of the projects in the portfolio may be the result of a purposeful strategy that recognizes both their inherent riskiness and the need for the kinds of contributions they produce."

"(Process research) is driven by the relatively certain financial gain it promises, (product research) is necessary for the longer-term protection and enhancement of the firm's existing markets."

Bean, Alden S. (1995), "Why Some R&D Organizations are More Productive than Others," *Research Technology Management,* (Jan-Feb), 25-29.

Small sample, but some provocative conclusions.

Defines Total Factor Productivity = Net sales/f(labor, capital, material)

Shows

- TFP growth correlated with R&D Intensity, <u>but</u>
- Greater % in business units means less growth
- Longer planning horizons mean more growth
- More use of outside sources means more growth
- Expectations of managers good, government regulation bad

Data argue for the need for corporate, long-term funding, but any conclusions are subject to sample size caveats.

Bernstein, Jeffery L. and M. Ishaq Nadiri (1989), "Research and Development and Intra-Industry Spillovers: An Empirical Application of Dynamic Duality," *Review of Economic Studies*, (April), 249-69.

This paper is an econometric study of R&D spillovers in the chemical, petroleum, machinery and instruments industries. The data are from the National Bureau of Economic Research's R&D Master file for 1965-1978. The analysis is at the firm level (not project, program or BU) for 18, 5, 11, and 14 firms, respectively, in the four industries. The model is dynamic because the authors allow the stocks of physical and R&D capital to accumulate (with a fixed depreciation rate of 0.1). R&D spillover is the sum of spending by all firms in the industry other than the focal firm. Of this, a fixed percentage, θ, can be appropriated. The authors assume a quadratic model and solve the dual (rather than primal) program of minimized cost. In order to account for the endogeneity of output, they instrument the variable with lagged output.

The basic estimation suggests that "the spillover was a substitute for a firm's own R&D and physical capital investment and so the firm could afford to divert resources away from the accumulation of its own R&D and physical capital.

The short-run elasticities of R&D capital due to changes in spillover (total spending by other firms in the industry) were in the ballpark of 2-8%. For physical capital, variable cost, and average costs these elasticities were in the ballpark of 2-3%, 9-18%, and 4-12%. More details in the paper. Not surprisingly, the long-run elasticities were higher. They were 7-16%, 3-14%, 14-27%, and 9-22%, respectively.

R&D spillovers imply that the social returns to R&D might be higher than the private returns. The authors estimate that the difference between net social and net private returns are 67%, 123%, 30%, and 90% for the four industries.

The authors point out that their analysis is within each industry, but that spillovers can also be significant between industries. They suggest telecommunications and computers as an example.

Bitando, Domenic and Alan L. Frohman (1981), "Linking Technological and Business Planning," *Research Management* (Nov.), 19-23

This article advocates and presents examples of how strategic planning tools can be used to define strategic technical areas (STA). An STA is defined as "a combination of functional technical description and the product line it serves. Gives an example of how an STA can be too broad if it is defined relative to basic sciences (e.g., metallurgy) or if it is too specific as to preclude future creative solutions.

To develop STAs, the authors propose a combination of the BCG growth matrix, life-cycle planning tools, product-line portfolio tools. This leads to a product-line strategy which, in turn, leads to a technology strategy.

Block, Z. and O. A. Ornati (1987), "Compensating Corporate Venture Managers," *Journal of Business Venturing*, 2, 41-51.

This article reports on a survey of firms on how they compensate venture managers.

Incentives include: "milestone bonuses, equity, and/or options in the new venture, variable bonuses based on venture ROI."

The primary obstacle is internal equity.

"No evidence from this study that special incentives for venture managers affected the outcome in venture performance."

Criteria

- recognize the probability of management change
- incentives which promote early identification of need for change of direction or to abort
- focus on event completion
- relationship of reward potential to risk potential including job security
- achievability
- simplicity

Limits seem to be 50-400% of salary.

"Corporations with special incentives in place perceived equity as significantly less important than those that did not."

"take variability in the motivation of different individuals into account."

"Bonuses may be reduced or enriched by relating the amount to time of accomplishment, e.g., 5% of sales if reach $1 million by month 6 and 6% if same level is reached by month 4, or 3% if reached by month 9."

"To avoid creating an incentive for wasted dollars, cost dollars must also be part of the equation."

"The money can come from salary withholding."

Boblin, Nils H., Herman J. Vantrappen, and Alfred E. Wechsler (1994), "The Chief Technology Officer as an Agent of Change," *Prism*, (Fourth Quarter), 75-85.

This article summarizes some of Arthur D. Little's views on what is the "right stuff" for a Chief Technical Officer (CTO). According to the article, a CTO should

- ensure alignment of technological strategy with business strategy
- manage the strategic asset
- manage technology processes
- develop measures
- drive change.

Boer, F. Peter (1994), "Linking R&D to Growth and Shareholder Value," *Research Technology Management*, (May-June), 16-22.

Focuses on net-present-value (NPV) and financial models. The article shows that NPV is very sensitive to a change in growth rates, e.g., a change from a 10% growth rate to an 11% growth rate gives a 10.6% change in NPV. (This is fairly intuitive because the change is a 10% change in growth rate (1% is 10% of 10%). Shows that this implies that a 1% change in growth rate gives a 1.6% change in PE ratio.

Datum. Ratio of (Δsales)/(R&D spending) is between 1.5 and 2.0 at W.R. Grace.

Boschi, Roberto A. A., Hans Ulrich Balthasar, and Michael M. Menke (1979), "Quantifying and Forecasting Research Success," *Research Management*, (Sept.), 14-21.

This paper describes a methodology that is used to assess tier 1 projects in terms of probability of success and long-range market outcomes. The basic idea is to break the project into a series of phases such that, for each phase, the managers and researchers can estimate the likelihood that the stage is completed successfully. For example, they ask questions of the form "How many years T_1 of effort in Topic X are required to give 30% probability of producing a project? How many years T_2 to give 80%?" They report that "our experience in many companies has shown that researchers have a well developed sense for this type of estimate."

They then indicate how one can connect basic research (R) to projects (D) and how this affects the estimates. That is, they add years and lower the probability of success with norms such as a project of this type takes 5 years and has a 10% likelihood of success. They then link research success to market success using a method by Abt, et. al. (1979).

They feel that their method "has been found practical, understandable and inexpensive." "Without the techniques described in this paper the ultimate success (i.e., a market product) is a rare event coming to surface only seven to fifteen years after the initiation of research work. This means there is no real control and little correlation between research effort and commercial success often leading to frustration for the basic researcher and sometimes even leading him to focus on `private' objectives."

This paper also suggests that there are three stages or phases of R&D (in pharmaceutical industries) -- basic research, identifying the most promising compounds, and clinical development. This is consistent with the definitions of tiers 1, 2, and 3.

This paper also suggests that it is feasible to estimate (1) the probability of success of a program, (2) the time and cost, and (3) the expected market reward.

Bottum, Paul, George John, and Lu Qu (1995), "Externally Assisted Technology Development for New Products," Working Paper, Carlson School of Management, University of Minnesota, Minneapolis MN 55455.

A study of the (make+buy) vs. (make) decision. The authors argue (and confirm in the data) that (buy-only) is low incidence. 107 observations of 55 makes and 52 make+buys. The following variables were used (sig = significant, n.s. = not significant):

relative technological advantage	→ make	sig.
scale/size	→ make,	sig.
technological speed	→ make+buy, sig.	
time to payback	→ make+buy, n.s.	
diversity of knowledge bases	→ make+buy, sig.	
tacitness of technology	→ make,	barely sig.
unpredictability of technology	→ make+buy, n.s.	
asset specificity	→ make,	sig.
behavioral uncertainty	→ make,	n.s.
centrality	→ make,	n.s.
strategic value	→ make,	sig.
conservatism	→ make,	sig.

Boulding, William and Richard Staelin (1995), "Identifying Generalizable Effect of Strategic Actions on Firm Performance: The Case of Demand-Side Returns to R&D Spending," *Marketing Science*, 14, 3, part 2, (Summer), G222-G236.

Hypothesizes that firms will earn supranormal rents (as measured by price) if the firm has the *ability* or *motivation* (but not both). Ability measured by market position (strength). Motivation by insulation from industry competitiveness. Hypotheses are confirmed in an interesting econometric study using PIMS data.

Braunstein, David M. and Miren C. Salsamendi (1994), "R&D Planning at ARCO Chemical," *Research Technology Management,* (Sept-Oct), 33-37.

Proposes a planning framework that encourages the integration of R&D and business units. Framework urges a consensus. (Interesting use of decision trees.)

"The business centers generally prefer to deal with quick fixes for their technical problems, and have less interest in the longer term aspects that usually characterize a portion of the R&D function and which are needed for major innovations in product/process technology."

Brown, John Seely (1991), "Research that Reinvents the Corporation," *Harvard Business Review*, (Jan-Feb), 102-111.

John Seely Brown is director of Xerox PARC.

The article gives examples of how Corporate R&D can cooperate with business units and with customers to "co-produce" or co-innovate. It also stresses harvesting local innovation. Gives an example of machine that collects information on how it is used -- smart products.

"The most important invention that will come out of the corporate research lab in the future will be the corporation itself."

"We are trying to prototype a need or use before we prototype a system."

Brown, Mark G. and Raynold A. Svenson, "Measuring R&D Productivity," *Research Technology Management*, (July-Aug), 11-15.

The article begins with a graphic summary (Figure 1 in the paper) of the R&D laboratory as a system of inputs, processing system, outputs, receiving system, and outcomes. They differentiate outputs (publications) from outcomes (sales improvement). Stresses simplicity -- states that scientists and engineers whose performance is measured on 20-30 variables typically ignore most or all of the feedback they receive.

Datum. Only 20 percent of the R&D managers in major companies measure the productivity of R&D. See Schainblatt (1982).

Calantone, Roger J., C. Anthony Di Benedetto, and Ted Haggblom (1995), "Is Teamwork Worth all the Trouble?," *Visions*, 19, 4, (October), 16-17.

Table of correlations of new product success with

- organizational climate (flexibility) (.204)
- strategy integration (.329)
- marketing-R&D interface (.465).
- marketing-manufacturing interface. (.385)

Capon, N., John U. Farley, and S. Hoenig (1990), "Determinants of Financial Performance: A Meta-Analysis," *Management Science*, 36, 1143-1159.

Meta-analysis of those factors that impact financial performance.

"Dollars spent on R&D have an especially strong relationship to increased profitability."

Chester, Arthur N. (1995), "Measurements and Incentives for Central Research." *Research Technology Management*, (July-Aug), 14-22.

Chester describes a system at GM Hughes Electronics, a $14B company with a research budget of $1.4B. $700M will be directed with a system where the business unit determines how to spend the money. The remaining $700M is corporate funding.

Hughes adjusted the fixed component of salary to reflect the bonus.

Hughes calls it "results sharing."

There is a target-value function, but it is piecewise linear with the below target slope 1.5 and the above-target slope 2.0.

Business units evaluate R&D and, thus, set a portion of R&D's salary. This control actually gets buy-in from the business units.

Business units focus on customer satisfaction.

Financial measurements are low in the reward system to force a more long-term focus. This was the CEOs idea.

Some interpretations

- corporate funding is necessary for paradigm shifts.
- smart technical people are problem solvers and will figure out how to game the system, e.g., number of publications or patents
- "measuring and enhancing R&D productivity or R&D effectiveness have gained the status of survival tactics in the R&D community."

Data: The percent of corporate funding is given at a variety of large corporations.

Chester, Arthur N. (1994), "Aligning Technology with Business Strategy," *Research Technology Management,* (Jan-Feb), 25-32..

Datum. "Among the 30 largest aerospace and electronics systems companies, almost all have either one or two central corporate laboratories."

Fact: "Corporate research laboratories, according to my data, invariably have a line management structure that reflects technical discipline or specialty rather than the markets served by the corporation." Gives examples that this is true even though the organizational chart seems to say otherwise. E.g., Hewlett-Packard uses product-line names for research groups to remind researcher who their customers are, but the product lines are usually based on a single technology.

Reasons

- create technical synergy
- sustain key technical competence (critical mass)
- reduce duplication of equipment and staff
- flexible re-deployment of staff
- to fend off hostile takeover by business units (gives examples of why takeovers are bad)

"A research department that reports to a business unit rather than a corporate laboratory will develop a shorter time horizon, and will limit its focus to the charter of the business unit."

Chart: QFD-like matrix connecting technologies to markets. Gives examples of companies who use it. Concept of an Account Executive (AE) serving the business units.

Core competence.

- "The terms 'key technology' and 'core competence' are often used interchangeably, but in concept are quite different.
- "An important feature of the Kodak list is that it describes core competencies that the company *wants* to have, rather than just those it already has well in hand."
- "Rather than 'stick to the knitting!' the idea is 'learn to knit!'"

Cohen. W. M. and D. A. Levinthal (1989), "Innovation and Learning: The Two Faces of R&D," *Economic Journal*, 99, 569-596.

The key idea is that firms' spending on R&D makes them more able to absorb technological knowledge.

The basic model is:

$$z_i = M_i + \gamma_i(\theta \sum_{j \neq i} M_j + T)$$

where z_i=additions to the firm's knowledge, M_i=spending on R&D, T=extra-industry knowledge, θ=degree of industry spillover, γ_i=fraction of knowledge in public domain that the firm can exploit.

Comparative statics reverse some earlier analyses that suggest that spillovers reduce R&D spending. In general, the empirical analyses support the model's implications. For example, "an increase in (technological opportunity) associated with basic science elicits more R&D." "firms may conduct basic research less for particular results than to be able to identify and exploit potentially useful scientific and technological knowledge ..."

Business unit data on firm's R&D expenditures and sales are obtainable from the FTC Line of Business Program.

R&D Intensity (R&D spending as a percent of sales) = 2.31% among R&D performers and 1.81% overall.

Collier, David W. (1977), "Measuring the Performance of R&D Departments," *Research Management*, (March), 30-34.

Chief Technical Officer (CTO) of Borg-Wagner -- describes Borg-Wagner system

Tiers: Describes the tiers of R&D. Rewards them differently. Tier 1 is subjective, Tier 2 and 3 are more quantitative.

Internal Customer: Downstream rates Tier I on 1=not meet target, 2=meet target, 3=exceed target. "ratings help determine the annual bonus each of our department heads receives."

Return of research (ROR): return = EVIU * % of EVIU marketing is likely to capture * market size * expected market share. (EVIU = expected value in use.) The first two terms measure the impact of research on anticipated reservation price increase.

Measured RORs — Existing business -- product 135.95, process 13.06, protect sales 0.57, increases sales 1.43. New business -- product 13.38, process 4.42.

"trouble-shooting work isn't very cost effective, on the average, and we should be more selective in the projects we take on in this category."

Comanor, William S. (1986), "The Political Economy of the Pharmaceutical Industry," *Journal of Economic Literature*, 24, 1178-1217.

Review of the pharmaceutical industry. Uses a variety of data to calculate the returns to R&D. Returns to R&D may be low, but probably are about right.

Cooper, Robert G. and Elko J. Kleinschmidt (1995), "Benchmarking the Firm's Critical Success Factors in New Product Development," *Journal of Product Innovation Management,* 12, 374-391.

Study of 135 companies. The authors focus on the companies' performance rather than project performance. They begin with 10 performance measures which are factor-analyzed into two factors -- program profitability and program impact (sales, success rate, technical success, etc.). They identify four groups of companies -- solid performers, low impact performers, high impact technical winners, and dogs. Finally, they determine what distinguishes the solid performers from the dogs.

The drivers of performance are:
- high quality new product process
- clear and well-communicated new product strategy
- adequate resources (senior management attention, R&D, necessary people)
- senior management commitment
- entrepreneurial climate
- senior management accountability
- strategic focus and synergy
- high-quality development teams
- cross functional teams

Dogs had a lack of resources.

Corcoran, Elizabeth (1994), "The Changing Role of US Corporate Research Labs," *Research Technology Management,* (July-Aug), 14-20.

Journalist, visiting MIT. Says that US Corporate labs are shrinking and that may or may not be bad. She does a good job of presenting both sides of the story. (Has a side bar on the research of Edward B. Roberts.)

"research should play the corporate equivalent of first violin, subtly leading the company's prevailing themes and strategies"

From John Bush at Gillette: "It's the integration of activities -- from research to sales -- that is the innovative activity in a company."

General Electric — business units provide 1/2, corporate 1/4, outside 1/4, but there is also research in business units. Overall, 10% of General Electric's R&D is central.

From the Industrial Research Institute (Alden Bean) -- from 1988 to 1992, as a percent of sales

- basic research fell from 6% to 1.8%
- applied research fell from 21% to 17.8%
- new product development rose from 34% to 40.6%
- process fell from 20.8% to 19.1%
- technical services performed by R&D rose from 17-18% to 20.7% of R&D's budget

General Electric's Chief Technical Officer, Lewis Edelheit's priorities for central research

- educating and training people
- coordinating work across business units
- transferring best practices
- developing technology and solving problems

"A business unit typically works like a sprinter, racing from one opportunity to the next. Research, in contrast, is a marathon runner with a steadier pace and an eye on the horizon."

Interesting example of Bayer A. G. that isolated its central research labs in 1910 to its detriment.

Alcoa -- 2/3 of R&D spending is paid for by business units.

"No company can afford to be too late in catching a technological tsunami washing through its industry."

Cordero, Rene (1990), "The Measurement of Innovation in the Firm: An Overview," *Research Policy*, 19, 185-192.

List of measures. The author suggests one should measure during the planning stage, the control stage, and overall performance. Measures should include technical performance and commercial performance.

Curtice, Robert M. and George T. Kastner (1994), "Balanced Performance Measures: Tracking the Pathway to High Performance," *Prism*, (Fourth Quarter), 57-69.

Argues for a balanced scorecard. That is, obtain measures for all the stakeholders and include more than financial measures.

Deschamps, Jean-Philippe and Richard Granger (1994), "Managing Multinational Multicultural R&D," *Prism*, (Fourth Quarter), 61-73.

Interview with Craig Tedmon, the Chief Technical Officer of ABB. ABB spends about $1 billion in discretionary funds each year -- the majority within business units for new product development.

Has a senior technical officer (STO) for each business unit (actually business segment). However, STOs spend about 15-20% of their time working with corporate research people helping to integrate corporate research activities which are partially funded out of corporate funds. STOs are also responsible for strategy and development of a business.

Program managers have strong technical skills plus management skills.

"Contrary to folklore, business executives often have the longest-range perspective of anybody in the company." Uses this to counter the need of a corporate research laboratory to safe-guard the future.

In the last few years pushing corporate staff to go to customers -- external and internal.

Donnellon, Anne (1993), "Cross-functional Teams in Product Development: Accommodating the Structure to the Process," *Journal of Product Innovation*, 10, 377-392.

In-depth analysis of cross functional teams at four firms. Suggests that businesses should "reward teams not team members."

Edwards, Shirley A. and Michael W. McCarrey (1973), "Measuring the Performance of Researchers," *Research Management*, 16, 1, (Jan), 34-41.

A review article comparing different ways to measure performance including ratings, publications, citations, etc. Interesting correlations.

- overall job performance and number of publications -- .74 by Grasberg
- overall contributions and number of papers and reports -- .15 to .39 by Pelz and Andrews
- supervisor ratings are correlated with the quantity of work (.91), people skills (.86), creativity rating (.54), and likability (.54). Peer rating correlations were .94, .71, and .80 respectively for the first three. The most useful measure seems to be a multiple indicator combining peer, subordinate, and supervisor ratings.
- citations correlates (.47) with visibility of a scientist
- various scoring systems (book = x articles, correct for multiple authors, etc.) correlate (.71) with number of publications.

Ellis, Lynn W. and Carey C. Curtis (1995), "Measuring Customer Satisfaction," *Research Technology Management*, (Sept-Oct), 45-48.

Datum: 54 % of the 128 companies use a customer satisfaction index. (Mostly Industrial Research Institute firms.)

Customer satisfaction is related via regression to:

- Responsiveness
- Technology -- both capability (firm) and product specific
- Product quality and reliability

However, "customer satisfaction and financial performance did not show a positive relationship."

"There are three customers for the firm to address when measuring satisfaction: Consumers and end users, distribution chain customers, downstream operations in their own company."

European Industrial Research Management Association (1995), *Evaluation of R&D Projects*, Working Group Report No. 47.

This is a report from a task force consisting of Chief Technical Officers. It includes a categorization of methods and focuses more on the observable aspects of the methods (e.g., matrix vs. weighting, etc.). It includes 21 two-page case studies in which the actual firm name is not given. It also summarizes the lessons learned from the case studies.

One key idea is that there are at least three uses for metrics. The right metric varies by use. These uses are:

- pre-evaluation
- monitoring
- post-evaluation

Another key idea is that "learning" methods are replacing "judgmental" and "financial" methods. See table on page 24. The key idea is that learning methods are feedback systems. By learning the authors mean using statistics to study past successes and failures. Shows financial as "old hat."

"R&D evaluation is a systematic means of assembling information for decision making, taking into account the various relevant aspects of the R&D project. It is a subject of perpetual interest."

Deficiencies include "an inability to incorporate factors such as the potential for spin-off."

Methods vary by "type of innovation -- incremental, fundamental, and radical."

Portfolio evaluations "provides the means to align R&D with company strategy."

"It is sometimes questioned whether evaluation is worth the effort at all, given the uncertainties inherent in R&D."

Components of an R&D evaluation:

"• how valuable will the results be?
• how likely is it to succeed?
• how much will it cost?
• how does this project compare to others?"

Three methods of portfolio evaluation (2x2 matrices)

- expected value vs. probability of success
- technological position vs. maturity of the industry
- market familiarity vs. impact on competitive position

Important to manage the R&D pipeline.

"3 main components must be estimated for any project:
- project cost
- benefits
- probability of success"

Success is favored when "a superior product which delivers unique benefits to the user. In most cases, this is the dominant factor."

"Successful evaluation includes a check of consistency with business strategy ideas (does it fit?)."

"If research and development are treated as parts of a single portfolio, it is difficult to design a single evaluation process which is acceptable to research and to development groups ..."

"New business areas tend to show relatively low initial returns."

"Consensus is the enemy of new ideas."

"A home-grown method may be preferred because the lack of a single, universally recognized 'standard method'"

Freeman P. and A. E. Gear (1971), "A Probabilistic Objective Function for R&D Portfolio Selection," *Operational Research Quarterly*, 22, 3.

Proposes a variety of objective functions and mathematical programming methods for R&D portfolio selection. Suggests the maximization of the probability of exceeding an overall target of the R&D laboratory. Other objective functions include maximizing expected value, maximizing expected value with a constraint on variance, and maximize expected utility. Provides a hypothetical example.

Frohman, Alan L. (1980), "Managing the Company's Technological Assets," *Research Management*, (May-June), 20-24.

This article argues for a strategic perspective on managing the firm's technological assets. States that there are five categories to describe how business units are linked to R&D and to strategy. They are:

- leap of faith
- lack of faith
- technology driven
- customer driven
- strategic management

Leap of faith is totally trusting researchers, lack of faith is micro-management -- both are mis-focused. Argues that technology driven misses changes in market factors and in the environment but gets maximum utilization of technology resources and tends to spur technology advances. Argues that customer driven leads to short-term foci and uses up the stock of R&D. Argues that strategic management is best. The firm should strike a strategic balance, identify the technology know-how, map the functional competency profiles and, hence, manage the balance in the strategic areas of the firm.

Suggests three ways to change the balance. 1. Reward system -- "a performance appraisal which identifies the number of new ideas a person generates, the quality of the ideas, ..." 2. Hiring and selection process. Points out that the people hiring the new personnel determine the type of person hired. 3. "How the personnel perceive their jobs."

Foster, Richard N. (1982), "Boosting the Payoff from R&D," *Research Management*, (January)

Foster is a McKinsey director. Returns are S-shaped and costs are convex.

"Evidence suggests, and my experience confirms, that technological discontinuities are much more frequent and strategically important than commonly thought."

Foster, Richard N., Lawrence H. Linden, and Roger L. Whiteley, and Alan M. Kantrow (1985), "Improving the Return on R&D -- II," *Research Management*, (Mar-Apr), 13-22.

Survey of 64 companies to identify high-return activities. Includes tactical suggestions.

Thirteen high-return activities were identified. In rank order they are

1. identifying customer needs,
2. professional personnel quality,
3. coupling marketing to technical efforts,
4. identifying projects,
5. identifying technical possibilities,
6. demand outlook,
7. project staffing,
8. strategies of competitors,
9. coupling manufacturing to technical efforts,
10. project planning,
11. identifying limits,
12. project termination,
13. characterizing technology.

Galloway, E. C. (1971), "Evaluating R&D Performance -- Keep it Simple," *Research Management*, (March), 50-58.

Argues that R&D metrics should be kept quite simple and proposes a simple metric.

1. "Review the latest product list of the company and mark those products where R&D made a critical contribution.
2. "Total the profits from products on the critical list and compare it with previous years."

He then plots the simple metric vs. costs. Example, metric increases 3X while costs increase 2X.

Says that metric should be simple to communicate achievement outside R&D and to boost morale. Also "the R&D evaluation process is generally accepted to imprecise; so why not acknowledge this in the approach."

"(company management has) an understandable sense of uneasiness when dealing with R&D, where failures are taken for granted."

ROI formulae "always seem to be more contrived than convincing."

Gilman, J. J. and R. H. Berg (1978), "R&D: What Link to Profits?," *Management Review*, 67, (Sept), 23-26.

For 1976, R&D spending was correlated with income/sales and P/E ratios. The regressions were:

income/sales = 4.13 + .647*R&D/sales P/E = 6.8 + 1.1*R&D/sales

Grabowski, Henry G. and John Vernon (1990), "A New Look at the Returns and Risks to Pharmaceutical R&D," *Management Science*, 36, 804-821.

Uses the Capital Asset Pricing Model (CAPM) model to determine the real return to R&D in the pharmaceutical industry. Estimates it to be approximately 9%, the same as the industry's cost of capital. While this was true for the period 1970-1979, this was not uniformly true throughout the period. The average payback was 23 years; for 1970-1974 it was infinity; for 1975-1979 it was 17 years.

Graves, Samuel B. and Nan Langowitz (1993), "Innovative Productivity and Returns to Scale in the Pharmaceutical Industry," *Strategic Management Journal*, 14, 593-605.

This article presents a Poisson regression analysis of returns to scale for R&D spending in the pharmaceutical industry. The dependent variable is the number of new chemical entities (NCEs) of 16 firms over 19 years. The (significant) explanatory variable is the average R&D spending over the last 6 years. The basic results are that more spending leads to more NCEs, but at a decreasing rate (decreasing returns to scale).

Griffin, Abbie (1995), "Modeling and Measuring Product Development Cycle Time Across Industries," Working Paper, University of Chicago, Chicago, IL 60637 (June).

A cross-industry study of the determinants of cycle time. Uses 2SLS with instrumental variables to determine cycle time as a function of cross functional teams, newness, and number of functions involved. Provides norms and a methodology to develop those norms. The idea for R&D metrics would be to use historical data on a time series of outcomes to determine which indicators to use for that performance.

Griffin, Abbie, and John R. Hauser (1996), "Integrating Mechanisms for Marketing and R&D." Forthcoming at the *Journal of Product Innovation Management*.

This paper reviews the integrating mechanisms that are used and can be used to enhance communication and cooperation between marketing groups and R&D groups. It reviews existing methods, including "relocation and physical facilities design, personnel movement, informal social systems, organizational structures, incentives and rewards, and formal integrative management processes." In addition, the authors develop a causal map to organize and interpret existing and suggested research. For each aspect of the map, they review the evidence that is now available and suggest researchable hypotheses.

Griffin, Abbie and Albert L. Page (1995), "The PDMA Success Measurement Project: Recommended Measures for Product Development Success and Failure," Working Paper, University of Chicago, Chicago, IL 60637 (September).

A follow up study of the first Product-Success Product-Development-Management-Association (PDMA) study. In this case they ask 80 new product managers to indicate the measures they would use to judge the success of a project. The measures vary by the goal of the project (e.g., new to the company, cost reduction, repositioning) and generally include a customer-based, a financial, and a performance (met goal) measure.

They also relate the measures to overall company strategy using the prospector-analyzer-defender-reactor framework. The measures vary.

Griliches, Zvi (1980), "R&D and the Productivity Slowdown," *American Economic Review*, May.

Asks whether slowdown of the 1970s could be attributed to a slowdown in R&D. Answers no. This article, like others, treats R&D as a cumulative, $\Sigma w_t R_{t-i}$.

Griliches, Zvi (1990), "Patent Statistics as Economic Indicators: A Survey," *Journal of Economic Literature*, 28, 4, 16661-1707.

Comprehensive survey of the use of patents data in the analysis of economic issues.

Data. US data available on CD-ROM. International data available from Vienna. Patents now need to be renewed for a small fee.

What do patents indicate? Hope: Inventive activity. Not new knowledge (tier 1) or development (tier 3).

Patents and R&D. At cross-section there is a strong relationship between R&D spending and patents. Much weaker in time-series and close to contemporaneous. The relationships have declined over time.

Returns to scale. Depends upon the functional form used to estimate the model. The data are consistent with increasing, constant, and decreasing returns to scale.

Small vs. large firms. Discusses self-selection bias and gives evidence that it is real. Taking out small firms, constant returns is a reasonable interpretation. (Survivor bias favors small firms; most samples only include "interesting" small firms; propensity to patent may be smaller for large firms;

and small firms do a lot of unreported R&D.)

Value of patents. Estimates vary from $500K to $70K. (Raises the issue of whether value is defined as the net value to the patent holder or the value of all sales? It matters a lot in the figures reported.) Estimates are also low from patent renewal data. Perhaps patents capture only 10-15% of total value from R&D. In any case, it appears that there are a few really big hits and lots of small returns.

"most of the uncertainty with respect to the value of a patent is resolved during the first three or four years of its life."

"the relative importance of fluctuations in the market value of new patented innovations (is) about 1% of the total fluctuations in market value." Basically, there is lots of volatility. The author provides a detailed variance analysis.

Spillovers. Suggests citation-weighted patents. (Patent office cites other patents in awarding patents.) Citation-weighted patents are more closely related to output; patents more closely related to measuring input.

Decline (in the 1970s) of patents is an artifact of the patent-office process. Also, with larger markets, the same number of patents could have a proportionally larger effect.

Inventors face great uncertainty in valuing their patents.

(Tier 1) opens new "fishing" grounds.

Patents counts are not a good indicator in short-run changes in the output of R&D. (p. 1702)

Griliches, Zvi (1992), "The Search for R&D Spillovers," *The Scandinavian Journal of Economics*, 94, Supplement, 29-47.

Spillovers could be quite large. This article focuses on total R&D spending as an indicator of cumulative knowledge and concentrates on social welfare rates of return. See table on page S43. Social rates of return are in the order of 30-50%, some lower and higher.

Gross, Irwin (1972), "The Creative Aspects of Advertising," *Sloan Management Review*, 14, 1, (Fall), 83-109.

This is the classic $E = e_n \sigma_E \rho R$ model. E=the expected effectiveness of a campaign (project), e_n=the expected value of the maximum of n draws from a standardized normal, σ_E=the variance in the effectiveness, ρ=correlation of true score and effectiveness (from a bivariate normal), and R=the reliability of the test ($R = \mathrm{sqrt}[\sigma_{true}^2/(\sigma_{true}^2 + \sigma_{error}^2)]$). Derivation is in the appendix.

While derived for advertising, this equation is obviously relevant for evaluating R&D projects.

Grossman, Sanford and Oliver Hart (1986), "The Costs and Benefits of Ownership: A Theory of Lateral and Vertical Integration," *Journal of Political Economy*, 94, 691-719.

The authors analyze the issues of ownership and contractibility in a formal (fairly general functions) manner and interpret which of two parties should own what and when. ("Ownership is the purchase of these residual rights of control.") The basic result is that 1. if firm i's outcomes do not depend on firm j' actions then non-integration is close to first best and 2. if firm j's outcomes are hardly affected by either firm's actions, then firm i should own firm j. The second basic result is that: "Firm 1 control will be desirable when firm 1's ex ante investment is much more important than firm 2's (so that firm 2's under-investment under firm 1 control is relatively unimportant), and when over-investment by firm 1 under firm 1 control is a less severe problem than under-investment by firm 1."

Many results draw their intuition based on the first-order conditions for joint vs. non-integrated optimization.

Contains an example from the insurance industry.

Gumbel, E. J. (1958), *Statistics of Extremes*, (New York: Columbia University Press).

Useful reference for e_n, the expected value of the maximum of n draws from a standardized normal distribution. See Gross (1972).

Hall, Bronwyn H., Zvi Griliches, and Jerry Hausman (1986), "Patents and R&D: Is There a Lag?," *International Economic Review*, 27, 2, (June), 265-283.

This paper uses econometric analysis to find a contemporaneous effect of R&D and patents. (See Griliches 1990 for review.)

"This finding suggests another way of looking at the process; in large industrial firms the fraction of R&D expenditures devoted to development rather than basic or applied research tends to be well over 50% (NSF 1982). It seems reasonable to suppose that successful research leads both to a patent application and to a commitment of funds for development."

Hauser, John R., Duncan I. Simester, and Birger Wernerfelt (1994), "Customer Satisfaction Incentives," *Marketing Science*, 13, 4, 327-350.

Customer satisfaction is an indicator of future sales. By measuring and rewarding based on customer satisfaction the firm can align the short-term vs. long-term employee decisions with those of the firm.

Each and every day, customer contact employees must make decisions between allocating effort to "ephemeral" activities and "enduring" activities. Ephemeral activities such as sales pressure enhance today's sales, but do not build customer relations for future sales. Enduring activities may not affect today's sales, but they build customer relations so that future sales are easier and more profitable. If the firm only rewards employees based on sales -- that is, rewards on today's sales today and on tomorrow's sales tomorrow, then the authors show that the employees will be more short-term oriented than the firm would like. The firm addresses this short-termism by rewarding on customer satisfaction. With the right weights, the firm can align employee tradeoffs with those that are most profitable for the firm.

The authors develop a formal mathematical theory and use that theory to suggest the characteristics of the measures that the firm should take and how those measures should be used in a reward system. These recommendations include: "measure customers, former customers, *and* potential customers; measure satisfaction with competitors' products; disaggregate satisfaction to reflect better the performance of employee groups; and, when different customer segments have different switching costs or they vary in the precision with which their satisfaction can be measured, then measure the segments separately and assign different weights in the incentive plan."

Hauser, John R., Duncan I. Simester, and Birger Wernerfelt (1996), "Internal Customers and Internal Suppliers," *Journal of Marketing Research,* (August or November).

While customer satisfaction incentives can be used to encourage customer-contact employees to focus on more long-term actions, not every employee is a customer-contact employee. In particular, most R&D groups develop concepts, technology, products, or services that are used by the business units to serve the external customer. These business units are R&D's internal customers.

The authors explore how one might develop systems in which the internal customer rates R&D based on how well R&D helps the internal customer serve its (external) customer. In other words, if R&D does its job well, then the business unit will be better able to serve its customers. The authors further illustrate that the rating can be explicit or implicit. By implicit the authors mean that the firm observes a decision by the internal customer, such as the sales targets it accepts, and rewards the internal supplier accordingly.

However, the problem is not as easy as it sounds. If there are only a few internal customers, then there is an ongoing relationship between the rater and the ratee. The authors show that in any internal customer-internal supplier system the rater and ratee have incentives to cooperate in setting the rating. However, they show that this may not be bad. The firm can anticipate that cooperation and take it into account when setting rewards. Indeed, the cooperation may make it easier to design the incentive system.

Finally, the authors suggest two practical internal customer-internal supplier incentive systems. "In one system the internal customer provides the evaluation implicitly by selecting the percentage of its bonus that is based on market outcomes (say a combination of net sales and customer satisfaction if these measures can be tied to incremental profits). The internal supplier's reward is based on the percentage that the internal customer chooses. In the second system, the internal customer selects target market outcomes and the internal supplier is rewarded based on the target"

Hauser, John R. and Florian Zettelmeyer (1996), "Managing the Three Tiers of R&D," ICRMOT Working Paper, M.I.T., Cambridge, MA 02142. (March).

This paper develops a formal mathematical theory to explore R&D metrics.

It begins by reviewing the results of "43 intensive interviews with Chief Technical Officers, Chief Executive Officers, and researchers at 10 research-intensive international organizations." See Zettelmeyer and Hauser (1995). "Those interviews suggested that there are three interrelated "tiers" of R&D -- (1) basic research programs, (2) evaluation of research concepts to match or build core technological competence, and (3) applied research projects for or with business units. The three tiers are evaluated and managed differently."

For tier 3, the tier closest to the customer, the authors derive a formula to value R&D projects. The formula takes into account the option-value concept that the business unit need invest further in only those projects that are promising. It need not invest further in those that are not. The formula also takes into account scope -- the fact that a successful project in one business unit may be applied elsewhere in that business unit and in other business units. The authors then use the formula to demonstrate why firms use "subsidies." That is, why a percentage of applied R&D is funded from central coffers. A formula for the optimal subsidy is given. (All concepts are based on the qualitative interviews and are feasible in terms of measurement.)

For tier 2, the tier that matches research to core competence, they demonstrate that if the firm rewards only on market outcomes, then this distorts project selection. That is, some projects are rejected falsely and some projects are selected when another project would have been better for the firm. Basically, false rejection and false selection are due to short-termism and risk aversion and lead to a tendency to reject projects that are long-term and risky. This phenomenon alone would lead the firm to reject market outcomes as a metric and use, instead, indicators such as patents, publications, citations, and peer review. On the other hand, these incentives might distort the effort that the researchers put into each project. This tension leads the firm to use a combination of both market outcomes and indicators in order to balance effort allocation and project selection.

"Tier 1 provides the ideas and science upon which R&D rests. Because it is so removed from market outcomes, there is a tendency to identify and reward creative people rather than to evaluate research programs based on market outcomes." The authors show that "tier 1 should be managed for a high variance portfolio of negatively correlated alternative programs."

This tendency to bet on people leads the firm to focus on rewarding these researchers for the ideas they develop. The authors show that "rewarding tier 1 managers and researchers only for internal ideas leads to an over-emphasis on internal research empires and a tendency to reject outside ideas ("not invented here"). It may also lead to too few ideas being investigated by tier 1."

They close by reviewing metrics that firms now use and suggesting how the theory can be used to evaluate those metrics.

Henderson, Rebecca and Iain Cockburn (1994), "Measuring Competence?: Exploring Firm Effects in Pharmaceutical Research," (September), Working Paper, MIT, Cambridge, MA 02139.

The focus of this paper is to measure a firm's core competency. The particular sample is pharmaceutical firms. The authors find support for "architectural competency."

The metric used is patent counts.

The authors break competency into "component competence" -- the competence of the researchers -- and "architectural competence" -- the way things are managed. They find that firms which reward scientists for contributions to science, firms that do not rely on dictators to allocate funds, and (n.s.)

firms that manage research as a coherent whole will be more successful.

Henderson, Rebecca and Iain Cockburn (1994), "Scale, Scope, and Spillovers: The Determinants of Research Productivity in Drug Discover," NBER Working Paper 4466. Revised September 1994.

This is a careful empirical study of pharmaceutical research. The basic hypothesis is that there are economies of scope that result from knowledge spillover when a firm runs a variety of research programs. This is, in many ways, stronger than the economies of scale that result from fixed facilities like libraries. They demonstrate that there are many firm-specific effects and that these result from the economies of scope. This article explains why aggregate models of research dollars vs. research output may under-estimate the elasticities.

This paper is one of the few to separate "research" from "development."

This paper is also useful because of its use of the Poisson model (resulting from a Bernoulli process with low outcome probability). They also test the negative binomial process that comes from compounding a gamma with a Poisson process.

Having multiple programs is not enough. While many large programs lead to economies of scope, many small programs increase coordination costs.

This article contains a number of valuable references to the econometrics of R&D literature.

Herbert, David A. (1970), *Order Statistics*, (New York: John Wiley and Sons, Inc.).

Useful reference for e_n, the expected value of the maximum of n draws from a standardized normal distribution. See Gross (1972).

Herzberg, Frederick (1987), "One More Time: How do you Motivate Employees?," *Harvard Business Review*, 109-120.

Stresses the importance of job enrichment and motivation rather than KITA (kick in the ass) motivators. A predecessor of empowerment. It is important to identify who serves whom rather than who supervises whom.

Hill, Scott Douglas (1995), "Core Competencies and Customer Responsiveness for Two U.S. Army Laboratories," S.M. Thesis (MOT), MIT, Cambridge, MA 02142.

Thesis with questionnaire to Army Research Lab (ARL) and the Missile Research, Development, and Engineering Center (MRDEC).

Interesting data on customer retention versus perceived customer responsiveness. The relationship is significant for MRDEC, not for ARL. The former is applied, the latter basic research.

Hodder, James E. and Henry E. Riggs (1985), "Pitfalls in Evaluating Risky Projects," *Harvard Business Review*, (Jan.-Feb.) 128-136.

This article discusses the pitfalls of using discounted cash flow (DCF) methods and suggests how one might overcome the pitfalls. There are three pitfalls that are discussed.

"We disagree with the contention that DCF techniques are inappropriate for evaluating long-term or strategic investment proposals. We do believe, however, that companies often misapply or misinterpret DCF techniques."

1. Failure to take inflation into account in forecast revenues. Suggestion -- focus on real rates of return as benchmark or take inflation into account. Points out that failure to take inflation into account favors short-term projects.

2. Excessive risk adjustments. As the project progresses, management makes a number of decisions that change the risk. E.g., they proceed to phase II only if phase I is successful. However, once phase I is successful it is less risky. They suggest breaking a project into phases and considering the price at which a project can be sold if it is successful. Alternatively, recognize that the risk premiums change over time based on the outcomes of the projects. E.g.,

   $$(1 + r_t) = (1 + RF)(1 + \Delta_t)$$

   where r_t = the real (risky) discount rate, RF = risk free discount rate, and Δ_t = the risk premium. These vary over time as management takes actions based on the outcomes of previous phases.

   Points out that typical analyses are based on random walk (not optimized) assumptions, hence $\Delta_t = \Delta \ \forall \ t$. References a Alexander Robicheck and Stewart Myers article in the *Journal of Finance* (December 1966). Nice to see the MIT connection.

3. Failure to recognize that shareholders can diversify some or all of the risk. Even if this were not true, the R&D portfolio itself diversifies some of the risk. Because most managers do not recognize this, they are too risk averse.

   "While excessive risk adjustments are certainly not unique to R&D proposals, the problem can be more severe here because R&D projects involve large and obvious uncertainties. The key is that these risks are likely to be highly diversifiable. Failure to recognize this fact represents a systematic bias against R&D projects."

Hodge, Melville H., Jr. (1963), "Rate Your Company's Research Productivity," *Harvard Business Review*, 41, 8, (Nov.-Dec.), 109-122.

Interesting historical article in which the author rates firms by their publications. It would be interesting to compare the 1962 rank by publication with the firms' performances over the last 32 years. However, this is harder than it sounds because of all the mergers and acquisitions. Also some of his sample includes not-for-profit organizations.

Gives reasons why commercial success is hard to measure:

- hard to trace
- focuses on product interests
- denies value of "negative" research
- evaluates all functions leading to success
- focuses on applied research

Holak, Susan L. and Donald R. Lehmann (1990), "Purchase Intentions and the Dimensions of Innovation: An Exploratory Study," *Journal of Product Innovation Management*, 7, (March), 59-73.

Evaluates a "path" regression model in which relative advantage, compatibility, communicability, complexity, divisibility, and perceived risk impact on purchase intention of an innovation.

The value of this article for R&D metrics is that it explores how one might use intentions data to get an estimate of future market potential. "The ultimate success of new product R&D depends as much on customer acceptance as on technological breakthroughs."

Holmstrom, Bengt (1989), "Agency Costs and Innovation," *Journal of Economic Behavior and Organization*, 12, 3, 305-327.

The article is motivated with the stylized fact that small firms are responsible for a disproportionate share of innovative research. He then tries to explain that fact with formal models. (See alternative analyses of this stylized fact in Griliches 1990 and Mansfield 1981.)

The article deals with effort vs. choice.

"The main theme is that the large corporation has emerged primarily to serve production and marketing goals and that in pursuing those objectives effectively it has to organize in a way that compromises innovation incentives. Providing incentives for both types of activities within one organization is more costly than providing them through separate organizations. Ultimately the reasons for this can be traced back to the loss in reliable performance measures that attend integration."

Basic model payoff = effort + error. Shows risk tradeoff. Then considers a monitoring variable, $y=e+a$ where a in normal. States that the optimal schedule is $\alpha x+\gamma y+\beta$. States that "a more uncertain technology is more costly from an incentive point of view and might be passed up in favor of more routine ones despite their lower returns." "Overlapping or competing projects could make sense, since they would reduce the incentive costs even if duplication might otherwise be technologically wasteful."

Suggests that constraints (restrictions) might be necessary if outside activities are attractive, constraints will be more effective if the performance measures are poorer.

The next result shows that if there are more than two agents, projects assigned to one agent are uniformly more risky than the projects assigned to the other. One interpretation is that one organization should deal with innovation and another with routine tasks.

He covers coordination with relation specific assets -- integration is favored when there is a need to invest in relation specific assets and where there is a need to improve coordination in decision making. He dismisses these for innovation.

"Even the best intentioned firm does not know capital costs, as accountants would be the first to tell." "It is when financial accounts are integrated that the difficulties of measurement become consequential and severe."

"If the subordinate and superior form a team they can always extract the maximal bonus from the firm. Consequently, monitoring information will have to be ignored. ... In order to reduce potential or actual collusion, the firm will want to place constraints on the monitor's scope of discretion." Argues that this favors rules and regulations which "inhibit or discourage activities that are exceptional."

Argues that market expectations make it rational for management to be short-term oriented.

Hultink, Erik Jan and Henry S. J. Robben (1995), "Measuring New Product Success: The Difference that Time Perspective Makes," *Journal of Product Innovation Management*, 12, 392-405.

Follows up on the Griffin and Page (1995) study of new product metrics. The key new idea is that the firm places different emphasis on different metrics depending upon their time perspective -- short-term or long-term.

Customer satisfaction was the most important measure, regardless of time perspective.

Irvine, John (1988), *Evaluating Applied Research: Lessons from Japan*, (London: Pinter Publishers).

This is the report of a study commissioned by the UK Department of Trade and Industry to review the Japanese practices when evaluating government funded research. The study includes both research at government laboratories and research at company laboratories.

"As in other countries, R&D evaluation has now become an important policy issue for the Japanese government."

"The Japanese government over recent years has begun to place greater emphasis on achieving `value-for-money' in its expenditure on research." "attention is most importantly directed on the continuing `mission relevance' of institutes."

"great stress is invariably placed on ex-ante evaluation coupled with relatively informal routine monitoring or research progress." "In recent years, routine monitoring has increasingly been complemented by more formal mid-term and ex-post evaluation," Publications and patents, but not citations and peer review are used widely as indicators. One reason for the lack of use of citations is that the *Science Citation Index* does not include Japanese journals.

"It is accepted practice in major applied research programs to build evaluation into projects even before they begin."

"The procedures used by companies for evaluating research are generally more systematic than those employed within the government."

Companies satisfied with the way government agencies evaluate collaborative research programs but were dissatisfied with evaluation of the government's own institutes.

"creativity can be impaired if evaluation is undertaken too mechanistically"

"undue pressure to demonstrate immediate technological outputs may stifle longer-term research where the commercial impact is often diffuse and unpredictable"

"The Japanese have developed a highly effective system for planning, managing and evaluating research intended to make incremental contributions to science and technology. Their major aim now is to overcome some of the inherent conservative tendencies of this system in order to develop a more appropriate environment for achieving similar levels of success in creative longer-term research."

"one of the major problems in developing guidelines for evaluation arose from the fact that different criteria need to be employed for different types of research." Classifies research with a 2x2 matrix of applied vs non-applied and basic vs. non-basic.

"longer-term research has been growing in importance over recent years, and now accounts for between ten and thirty percent of central research laboratory activities." Companies use technological forecasting, e.g., NEC monitors over 30 core technologies and predicts both medium and long-term development of the basic technologies. "The impression given by those interviewed was that the procedures currently used by companies to evaluate longer-term research are not wholly satisfactory, and that improved methods are needed."

Criteria for applied research

- relevance to company's needs
- competitiveness of technology
- investment required
- likely ROI
- technological competence of company to undertake the project
- technological uncertainty
- impact on other technology areas
- by-products and externalities

"if there is one all-important lesson to be drawn from Japan, it is the benefits that flow from achieving close integration of the planning, management, monitoring and evaluation of research." "In short, evaluation, should, whenever possible, be built into the management of applied research before a project begins. It should not just be added on at the end for auditing purposes as often happens in the United Kingdom and most other Western nations."

Jaffe, Adam B. (1986), "Technological Opportunity and Spillovers of R&D: Evidence for firms Patents, Profits, and Market Value," *American Economic Review*, (December), 984-1001.

This is an econometric analysis of the effect of spillovers on firms' patents and profits. The data consist of 328 patent classes from 1969-1979 of 1700 manufacturing firms in an NBER data set. The author classifies the 328 patent classes into 49 categories and computes a potential spillover pool from firm i to firm j) as the correlation between the firm's of percent allocations to categories. Spillovers to a firm is then R&D spending weighted by this measure. Then, after considering the error structure and endogeneity of variables he estimates the direct effect of R&D (log R&D), (2) the indirect of the spillovers [log (R&D) x log (pool)] and (3) the direct effect of other firm's R&D.

For patents there is a direct elasticity of .352 for R&D and, for the average firm, a total elasticity of 1.1. Thus, the effect of spillovers is large. "Because the total relevant R&D is large relative to any firm's own spending, spillovers are important even though the implied value for (appropriability is small)."

For profits the results suggest that the direct effect of other firms' R&D is negative but that the <u>net</u> effect is positive. That is, the effect of spillovers more than makes up for the effect of competitors getting stronger. However, this is for the average firm. For firms with larger expenditures, the net effect is larger; for firms with small expenditures, the net effect is smaller. It is negative for firms about .5 standard deviations below the mean. "Comparing firms whose neighbors do a lot of R&D to those whose neighbors do little, the former are characterized by lower profits and market value if they do little R&D themselves, but a higher return to doing R&D.

Finally, there is evidence that firms change their patterns of spending over time (as measured by the vectors of fractional allocation to R&D categories). This suggests that they might respond to profit opportunities by changing their core technological competences. However, as the author discusses, the evidence of this is not unequivocal.

Jaffe, Adam B. (1989), "Real Effects of Academic Research," *American Economic Review*, (December), 957-970.

This is an econometric analysis of the effect of university research on new industrial products. Specifically, he uses patents as the measure of new product output. See Acs, Audretsch and Feldman (1991) for a reanalysis with an alternative measure of innovative output -- the number of innovations recorded in 1982 by the US Small Business Administration. The basic equation is:

$$\log(\text{patents}) = \beta_1 \log(\text{industry R\&D}) + \beta_2 \log(\text{university research}) + \beta_3 \log(\text{univ. res.}) \log(\text{proximity of univ. to industry}) + \text{error}$$

In addition, there are indirect effects in that industry R&D affects university research and university research affects industry R&D. The estimation requires instrumental variables and careful attention to the error structure. The unit of observation is the state, the year, and the area of research (drugs, chemicals, electronics, mechanical arts). (Industry R&D is not available by area, hence modifications are made in the estimation.) The time periods are 1972-77, 1979, and 1981. The estimation covers 29 states.

The basic result is that there are both direct and indirect effects of university research. The direct elasticity varies by research area -- .10-.30 for drugs, .08-.28 for chemicals, .09-.16 for electronics, and insignificant for mechanical arts. However, "there is only weak evidence that spillovers are facilitated by geographic coincidence of universities and research labs within the state." The indirect effect is large, approximately .60.

"Establishing causality with statistics is a tricky business, but it appears that university research causes industry R&D and not vice versa."

[The Acs, et. al. study establishes a larger elasticity with their measure and the proximity variable is significant.]

Kekre, Sunder, Mayuram S. Krishnan, and Kannan Srinivasan (1995), *Management Science*, 41, 9, (September), 1456-1470.

Uses ordered probit to determine the key drivers of customer satisfaction for software products. Ties these to QFD. Large data set of 2500 IBM customers. Shows that key drivers are more than just reliability.

Kiely, Tom (1994), "Innovation Congregations," *Technology Review*, (April), 54-60.

About teams in the development of new product. Mentions Hoechst Celanese Corporation (HCC) and Xerox.

"We want to pick the right ideas to work on and knock the marginal ideas out of further consideration as soon as possible." From a manager at Monsanto.

"Some research employees at HCC have turned down invitations to champion their ideas noting the career ladder within research is predictable, but that in intrapeneurial teams is not."

"You have to be the kind of person who is willing to take risks and can live with the emotional ups and downs of a project." From an HCC mechanical engineer.

King, Jean (1987), "A Review of Bibliometric and Other Science Indicators and Their role in Research Evaluation," *Journal of Information Science*, 13, 261-276.

Review of bibliometric indicators (e.g, counting publications and citations). Citations, peer review, and patents are likely to be common R&D metrics. It is important to understand their advantages and limitations.

Datum: Labor costs account for more than half of total R&D expenditures

Measures of esteem should be:

- relatively inexpensive
- routinely applicable
- capable of focusing on any clearly defined field

There is the issue of the shrinking length of papers to the "Least Publishable Unit."

Journal Citation Report gives yearly impact features for journal covered by the *Science Citation Index.*

Mapping research with co-citation, co-word, and bibliographic coupling.

Koenig, Michael E. D. (1983), "A Bibliometric Analysis of Pharmaceutical Research," *Research Policy*, 12, 15-36.

Combines careful measures and in-depth knowledge of the pharmaceutical industry to study the ability of bibliometric measures to measure R&D output.

Interesting results:

- bibliometric measures correlate with R&D output -- number of approved drugs and a research score
- expert judgment correlates with R&D output
- (from a factor analysis -- hence an indication of inter-correlation of explanatory variables)
  - factor 1 -- biomedical research citations and some clinical and chemical
  - factor 3 -- expert judgment, however some biological citations
  - factor 2 -- mostly clinical and chemical citations
  - factor 4 -- output measures

Step-wise regressions suggest that star articles (> 4 citations) are a better correlate of research output than journeyman articles (2-4 citations), but the regressions are not univocal.

Citations explain additional variance above and beyond budget.

Interesting facts.

- average of 1.83 citations per article, only about half of all articles are cited
- typical article reaches its peak citation in the third year
- focus on star articles

Krause, Irv and Liu, John (1993), "Benchmarking R&D Productivity: Research and Development; Case Study," *Planning Review*, 21, 1, (January), 16.

Fifteen well-known industrial R&D organizations (interviews with Chief Technical Officers) were benchmarked in a "best practices" study by the planning forum. Definition of "best practices" and "good performance" are not given directly. Article summarizes 13 best practices and supports them with quotes.

Some examples.

Best practice 4: "Funding for basic research comes from corporate sources to ensure a long-term focus, where funding for development comes from business units to ensure accountability." Gives at least three reasons.

- "another firm allocated some corporate money for development efforts that businesses would not necessarily elect to fund, but which corporate management felt were important to the company as a whole"
- "corporate funding for development projects that cross business unit boundaries."
- economies of scale of a central facility

Best practice 5: Basic research at a central facility, development distributed at business unit sites.

Best practice 8: Analytical tools -- portfolio analysis, decision risk analysis, correlation, screening

"Most participants -- including the high performers -- indicated that they were constantly looking for better ways to analyze and manage projects."

Best Practice 12: "Some basic research is performed internally, but there are also many university and third-part relationships."

Krogh, Lester C., Julianne H. Prager, David P. Sorensen, and John D. Tomlinson (1988), "How 3M Evaluates Its R&D Programs," *Research Technology Management,* (Nov-Dec), 10-14.

Describes 3M's technical audit program. Audits are done for each program by external (to the program) and internal people -- but all 3M people. The criteria (p. 11) are broad and include both technological and business measures.

Datum: 3M asks audits to predict the probability of success (meeting 3M financial criteria). This predicted probability correlates highly with success. Other predictors include:

- competitive position of 3M business unit
- 3M performance vs. competition
- degree technology related to 3M's existing technical base.
- degree market related to 3M's existing business base.

Audits communicate to management and provide cross-fertilization.

Kuczmarski, Thomas D. (1992), *Managing New Products: The Power of Innovation*, 2nd Ed. (Englewood Cliffs, NJ: Prentice-Hall, Inc.), Chap. 7, 228-244.

This chapter suggests tying pay to performance and discusses self-selection on risk.

"Obviously, the type of person who is content with a virtually guaranteed 5 percent base salary increase and a bonus based on 15 percent of base salary will not be willing to move into a performance-driven compensation plan."

- a company tested a new performance-based incentive system for new product managers yielding five new-to-the-company products with $40M in revenue.
- "If new product people get rewarded on market performance, then they need to manage the entire process."
- Proposes a system called "phantom stock investment" that looks like a linear internal customer system.
- "new product projections could end up being 'sandbagged' in order to meet bonus award targets."
- Suggests that the firm shares gains (from new products) with the downstream managers (p. 238).
- Cites "venture funds" at 3M and Iroquois Brands.

Lawton, Leigh and A. Parasuraman (1980), "The Impact of the Marketing Concept on New Product Planning," *Journal of Marketing*, 44, (Winter), 19-25.

Tests whether adoption of the marketing concept makes firm more innovative in product development.

"To date, theoretical speculation suggests that the adoption of the marketing concept should influence new product planning. However, the empirical findings of this study find no evidence to support this contention."

Mansfield, Edwin (1982), "How Economists See R&D," *Research Technology Management*, (July), 23-29.

Review article.

Data:

- 60% of R&D projects reached technical completion
- 30% were commercialized
- 12% earned an economic profit

"One survey of executive opinion has noted the widely held belief that the economic success rate of R&D projects would increase by half if marketing and production people fully exploited them."

"statistical data from 1948-1966 strongly link an industry's rate of productivity increase with the extent to which its R&D was long term."

"the nature of these evaluations is different for a research as opposed to a development project."

(Relative to OR models) "Sophisticated types of models have not been extensively used."

"the median private rate of return was about 25%, the median social rate of return was about 70%." See Exhibit II (p. 28) for rates of return on 37 innovations.

Mansfield, Edwin (1981), "Composition of R&D Expenditures: Relationship to Size of Firm, Concentration, and Innovative Output," *Review of Economics and Statistics*, (Nov).

Data on spending by firm (108 firms) on

- basic research (4.7%)
- research on projects lasting more than 5 years (32%)
- research on entirely new products or processes (33%)
- research on projects with less than a 50% chance of success. (23%)

Percent is the % of company-financed R&D.

"whereas the largest firms seem to carry out a disproportionately large share of the basic research (and perhaps long-term R&D) in most industries, there is no consistent tendency for them to carry out a disproportionately large share of the relatively risky R&D or the R&D aimed at entirely new products and processes."

"more concentrated industries devote a smaller, not larger percentage of R&D expenditures to basic research."

"Holding a firm's R&D expenditures constant, its innovative output seems to be directly and significantly related to the percentage of its R&D expenditures to basic research."

Mansfield, Edwin (1980), "Basic Research and Productivity Increase in Manufacturing," *American Economic Review*, (December).

Includes a table of the four types of risky research for 1967, 1977, 1980. There is a decline in the percentage spent on basic R&D.

"My results indicate that there is a statistically significant relationship between the amount of basic research carried out by an industry or firm and its rate of increase of total factor productivity, when expenditures on applied R&D are held constant."

McGrath Michael E. and Michael N. Romeri (1994), "The R&D Effectiveness Index: A Metric for Product Development Performance," *Journal of Product Innovation Management*, 11, 213-220.

Introduces Pittiglio Rabin Todd & McGrath's (PRTM) R&D Effectiveness Index.
(all % are calculated as a % of revenue)

EI = [(% new product Revenue) * (% profit + % R&D)]/(% R&D)

(Does not give credit to R&D for revenue on other products.)

States that index is highly correlated with revenue growth and profit. Note that the index uses profit in the numerator. They recognize this, but claim that the magnitude is surprising.

McCright, John S. (1994), "Start-ups Get Key Answer: Study Finds Ratio for Marketing Costs," *Boston Business Journal*, 14, 13, (May 13-19).

Successful firms spend as much on marketing as on engineering. Unsuccessful firms do not. (Write up of a study by Ralph Grabowski.)

Mechlin, George F. and Daniel Berg (1980), "Evaluating Research -- ROI is Not Enough," *Harvard Business Review*, 59, (Sept-Oct), 93-99.

Mechlin was Chief Technical Officer of Westinghouse, Berg was a Dean at Carnegie.

"There can be no shortcut, no easy formula, for assessing the value of corporate research."

Scope -- developed for one use; applied for that use and another seemingly unrelated use. Also states that central lab can estimate scope by working with the technical staffs of various divisions. Includes an example. Also includes spillover example from lunch room discussions.

Limitations of ROI

- time span (19.2 years at Westinghouse)
- unpredictability of results
- preventing cyclic fluctuations in facilities & personnel devoted to research
- value of the customer service function

Suggested metrics

- periodic reviews
- group responsible for commercialization must contribute to the cost of research,
  - "Improving judgment in this fashion is not without its cost, for discretion of this sort does tend to bias project choice toward low-risk and relatively short-term efforts"
- discretionary choice (subsidy)
  - "As a practical matter, to ensure that the research laboratory has an appropriate mix of short- and long-term projects, it is important that the researcher themselves select a certain fraction of the projects on which they work."
- recognize product life cycles
- product line contribution
- ROI from self-developed products

Meinhart, Wayne A. and John A. Pederson (1989), "Measuring the Performance of R&D Professionals," *Research Technology Management*, (July-Aug) 1989, 19-21.

Focuses primarily on performance appraisals of the research professional. Based on a survey or instruments at 20 organizations makes some recommendations.

MBOs were the overwhelming favorite. Appraisals based on behavioral criteria (BARS), although popular in the literature were rarely used. Suggests that it is important that approaches be tailored to each situation and to each researcher -- unique attributes for each researcher and rewards that are individualized.

Menke, Michael M. (1994), "Improving R&D Decisions and Execution," *Research Technology Management*, (Sept-Oct), 25-32.

Suggests that one use Total Quality Management tools for improving R&D management.

Meyer, Marc H., Peter Tertzakian, and James M. Utterback (1995), "Metrics for Managing Research and Development," ICRMOT Working Paper #124-95, Massachusetts Institute of Technology, Cambridge, MA 02142.

The authors begin by proposing a taxonomy of R&D measurements which they summarize with a 5x5 matrix of {comparative, scoring, benefits contribution, schedule analysis, individual & group analysis} crossed with {product planning, development control, R&D cycle performance, market cycle performance, full life cycle performance}. They provide references for each cell in the matrix.

They then argue that metrics must include a consideration of product platforms. ("The technological foundation of the product family we define as the product platform.")

The metrics they propose are:

platform efficiency = (R&D costs for follow-on product)/(R&D costs for platform)

platform effectiveness = (sales of a follow-on product)/(R&D costs of a follow-on product)

Both measures can be aggregated across products within a platform and platform versions within a product family. All measures are net present values based on the Consumer Price Index.

They demonstrate these metrics for three case examples -- products within a platforms, platform versions within a family, and comparison of product families. In each example the metrics help the authors quantify qualitative descriptions of the history of the product development. Based on these case examples the authors argue that these measures provide valuable diagnostic information to managers who must make decisions with respect to product platforms.

Miller, Roger (1992), "The Influence of Primary Task on R&D Laboratory Evaluation: A Comparative Bibliometric Analysis," *R&D Management*, 22, 1, (January), 3.

Paper attempts to compare bibliometric analysis to "organizational studies." (Bibliometric analysis is the counting of publications and citations.)

- Count "highly cited" papers -- 10 or more citations.
- Labs that publish many papers do not necessarily have more citations than labs that publish fewer high impact papers.
- Can rate journals by influence. List obtained from The Institute for Scientific Information.
- "Studies assessing the appropriateness of bibliometrics conclude that they provide rough measures of research output."

Other metrics include:
- Strategic audits
- Constituency reviews
- Scientific peer reviews
- Cost-benefit analyses
- Organizational studies

Conclusions
- Compare results only for similar types of laboratories, e.g., tiers.
- "Bibliometric indicators are complementary to, but not substitutes for, traditional means of evaluating research laboratories."
- Especially for Tier 3, measure other outputs such as reports or product evaluations, not just publications.
- Adjust for mature vs. emerging fields

Mitchell, Graham R. and William F. Hamilton (1988), "Managing R&D as a Strategic Option," *Research Technology Management*, (May-June), 15-22.

Argues that R&D should be looked upon as a "call option." That is, the corporation invests in R&D with the recognition that they do not have to invest in further development until later. They recommend:
- When R&D is recognized as a call option, the volatility of ultimate return is good because you can truncate at the price of the option.
- A call option will favor technology that is viable over a longer time horizon.

Moenaert, Rudy K., William E. Souder, Arnoud De Meyer, and Dirk Deschoolmeester (1994), "R&D-Marketing Integration Mechanisms, Communication Flows, and Innovation Success," *Journal of Product Innovation Management*, 11, 31-45.

This article collects data on project centralization and project formalization.

The data collection includes 40 technologically innovative Belgian companies, matched sets of successful/unsuccessful projects, one R&D and one marketing person per project. Correlation matrix on commercial success, project centralization, project formalization, interfunctional climate, R&D role flexibility, marketing role flexibility, whether marketing received information from R&D, and whether R&D received information from marketing.

Morbey, Graham K. (1988), "R&D: It's Relationship to Company Performance," *Journal of Product Innovation Management*, 5, (March), 191-200.

Provides data on R&D spending (spending as a percent of sales) vs. profits and vs. sales growth from 1976 to 1985.

"The study shows little correlation between R&D intensity and growth in profitability. Also, it is apparent that sales growth and increasing profitability do not lead to increased allocations for R&D in most industries."

There are interesting research opportunities to model the interrelationships among these decisions and their relation to market structure.

Moser, Martin R. (1985), "Measuring Performance in R&D Settings," *Research Management*, (Sept-Oct), 31-33.

Based on a questionnaire to 400 R&D managers the author presents a summary of how often they use various performance measures. The results on a 1-7 scale with 7=always and 1=never are:

1.	quality of output or performance	5.7
2.	unit's degree of goal attainment	5.7
3.	amount of work done on time	5.1
4.	unit's level of efficiency	4.6
5.	percentage of project completions	4.5
6.	percentage of results adopted by company	4.3
7.	frequency of cost overruns	3.7
8.	number of patents or copyrights	3.7
9.	percentage of project approvals	3.4
10.	number of technical reports produced	3.3
11.	unit profitability	3.1
12.	number of papers presented at professional meetings	3.1
13.	number of professional rewards or honors	3.0

Negroponte, Nicholas (1996), "Where Do New Ideas Come From," *Wired*, (January), 204.

An essay which argues that it is difficult to manage research because downsizing and right-sizing lead companies to be too short-term oriented. Further argues that, to be innovative, a research organization must have as many varied perspectives as possible. Suggests that research universities are the best source of ideas because they encourage varied perspectives and risk-taking. If they do not succeed in a project, they still have their primary output -- graduates.

Nelson, Richard. (1959), "The Simple Economics of Basic Scientific Research," *Journal of Political Economy*, 67, 297-306.

This is an interesting historic perspective. It was published in 1959, but many of the issues apply well to the 1990s.

"Since Sputnik it has become almost trite to argue that we are not spending as much on basic scientific research as we should." In 1953 $435M was spent on basic research, $5.4B on total R&D -- this makes an allocation of about 8% to basic research. About 60% of basic research is performed by universities, government labs, and not-for-profit organizations.

Scope. Carothers' research on linear superpolymers that led to Nylon. "the research was in a new field of chemistry, and Du Pont believed that any new chemical breakthrough would probably be of value to the company."

"A firm with a narrow technological base is likely to find research profitable only at the applied end of the spectrum." "a firm producing a wide range of products resting on a broad technological base may well find it profitable to support research toward the basic-science end of the spectrum."

Talks about free riding on others' basic research and the need for industry consortiums. Sees role of universities to do basic research for social welfare.

Packer, Michael B. (1983), "Analyzing Productivity in R&D Organizations," *Research Management*, (Jan-Feb).

Proposes "output mapping." Output mapping is the factor analysis of a customer ratings followed by a preference model. Gives as an example the telecommunications factors from Urban and Hauser (1980, revised 1993).

"The productivity analyst thus appears to be caught between the Scylla of unreliable subjective or intuitive methods and the Charybdis of somewhat irrelevant structured indicator methods."

Packer was with MIT's Laboratory for Manufacturing and Productivity.

Page, Albert L. (1993), "Assessing New Product Development Practices and Performance: Establishing Crucial Norms," *Journal of Product Innovation Management*, 10, 273-290

Survey of 168 Product Development Management Association members on new product practices and performance. Some highlights:

- 76% use multi-disciplinary teams
- 56% have new product strategy, 55% have new product process, 33% have neither
- 76% use a formal financial measure of performance
    - Includes a table of criteria that are used to measure new product performance
- 11 ideas for one success
    - 100 enter, 26.6 tested, 12.4 introduced, 9.4 succeed
- Ave: 37.5 new product per company in 5 years., median 20
- Success rate of 58% at introduction, 55% profitable
- 32.6% of sales from internal new product within last 5 years, 8.9% from acquired

Compensation

- 47% straight salary
- 51% salary plus bonus
    - company profitability 20%
    - individual performance 20%
    - complete project successfully 16%
    - performance of new product 7%
    - other 13%
- Awards
    - promotion/career advancement 13%
    - financial incentives -- 8% major, 8% minor
    - nonfinancial awards and recognition 10%

- largest $3,000

Panzar, John C. and Robert D. Willig (1981), "Economies of Scope," *The American Economic Association Papers and Proceedings*, 71, 20, 268-272.

Gives formal definition of economies of scope as subadditivity (across products) of the costs of producing those products. Shows that (strong) economies of scope imply multiproduct firms; (weak) economies of scope are necessary for multiproduct firms. Economies of scope can also come from the cost of acquiring inputs (especially human capital). Shows that in vertical chains, multiproduct firms will occur at some point in the chain.

Pappas, Richard A. and Donald S. Remer (1985), "Measuring R&D Productivity," *Research Management*, (May-June), 15-22.

Defines five stages of R&D

- Basic research
- Exploratory research
- Applied Research
- Development
- Product Improvement

Argues that the evaluation method varies by stage. Argues that one should use qualitative measures in basic research, quantitative measures in product improvement, and semi-quantitative measures in between.

Union Carbide uses an "R&D Categorization Questionnaire." that assigns research efforts to categories. Describes "peer rating approaches."

Quotes Foster (1982) that the effort-vs.-performance curve is s-shaped.

Parasuramen, A. and Linda M. Zeren (1983), "R&D Relationship with Profit and Sales," *Research Management*, 26, (February)

Uses *Business Week* data on R&D Scorecard to compute lagged correlations of R&D spending with profits and with sales. Claims that the effect on sales is stronger than the effect on profit. There are some lagged effects that are significant, but the correlations are all large suggesting joint effects (endogeneity).

Parry, Charles W. (1985), "The Role of R&D in a Basic Industry," *Research Management*, 28, 4, (July-August), 27-29.

Parry was the CEO of the Aluminum Company of America.

"how do you avoid being trapped by the social and economic realities -- which are pretty much beyond your control? I believe the best answer is that you stay on top of your markets, and you fund the research that has the best chance to lower costs, renew old products, or develop new ones."

"The EPS (earnings per share) mindset won't permit the expenditure of research dollars on high risk projects."

"Included in (our R&D investment) is a continued emphasis on product development and research in broad based materials technology."

Patterson, William. (1983), "Evaluating R&D Performance at Alcoa Laboratories," *Research Management*, (March-April), 23-27.

Describes a system that was implemented at Alcoa in 1975. The system was implemented in response to the "pressure of escalating R&D costs." "Alcoa Laboratories has found that evaluating the economic impact of major technical accomplishments is helping to demonstrate the financial rewards of a strong R&D program to corporate management."

Basically, industrial engineers attempted to determine the value of a research project. The NPV of the project was compared to the NPV of the cost. Early attempts found that benefits did not always materialize, thus, subsequently, benefits were not claimed until they began to materialize. Even so, about one-third of major accomplishments were not quantifiable.

Claimed advantages

- legitimitizing R&D
- feedback to decision makers
- economic focus
- implementation focus
- 80/20 rule identified -- 80% of benefits come from 20% of projects
- "Projects with long-range impact often are subject to the tyranny of the urgent."

Problems

- audits of sales-related activity suffered from inaccurate assessment
- distortions caused by interdependence of technical accomplishments
- difficult to factor in capital requirements for implementation

"The simplest approach to evaluation of R&D results consists of annually tallying discernible outputs of the R&D organization such as patents, publications, reports, etc. Dividing each by the average number of scientific personnel employed during the year yields a productivity measure that may be monitored over time."

Such "tangible indicators usually are indirect measures of R&D success."

Uses a 12% cost of capital.

Pittiglio Rabin Todd & McGrath (PRTM) (1994), "R&D Effectiveness Index: A Metric for Product Development Performance," *Insight*, 5, 3, 1-12.

R&D Effectiveness = (% new product revenue) x (% net profit + % R&D expense)/(% R&D expense)

Only 39% had an index greater than 1.0, only 21% greater than 1.25.

See McGrath and Romeri (1994) for more details.

Porter, John G., Jr. (1978), "Post Audits -- An Aid to Research Planning," *Research Management*, (January), 28-30.

Describes a system that Mobil had used since 1960 in which post audits estimate of applied R&D are used to estimate the value of completed developments. Anticipated benefits were:

- motivate researchers
- identify high business risks (projects likely to succeed technically but not commercially)
- demonstrate research productivity
- identify productive research
- increase confidence in predictive evaluations

Post-audits have taught Mobil to look for potential failure that

- require large capital outlays
- are outside the main stream of the company's interests
- have poorly defined targets
- involve small products or processes

Formula is Research Return Ratio (RRR) = (Potential value)*(probability of success)/(probable cost).

Ranftl, Robert M. (1986), "Seven Keys to High Productivity," *Research Management*, (Sept-Oct), 11-18.

Ranftl is a corporate director at Hughes Aircraft and president of his own consulting firm. Here he gives some general guidelines.

- "On the other hand, if one's job does not provide fulfillment, a person will frequently divert his or her attention and energies to personal and outside pursuits."
- Twenty effective job assignment practices including
  - "Focus on end results giving the employee as much freedom and opportunity for work-planning and decision-making as possible."
  - "Provide job security consistent with the employee's job performance."
- Twenty-five factors likely to cause R&D counter-productivity including
  - "Ineffective reward systems which inadequately correlate individual productivity and compensation."

Ransley, Derek L. and Jay L. Rogers (1994), "A Consensus on Best R&D Practices," *Research Technology Management*, (Mar-Apr), 19-26.

Summaries reports from ADL, SRI, Meritus, and Pugh-Roberts. Useful table summarizing the four reports. Draws "consensus" on what all four say.

- "strong alignment of technology strategy with the corporate and business strategy"
- program selection's "goal is to link technology programs to business needs"
- "importance of identifying, nurturing, and exploiting core technologies"
- effectiveness is best measured based on business objectives
- technology transfer and communication are important

Support for the role of Tier 2 as matching technology to core competency and for the role of Tier 3 to solving business problems.

Some mixed advice on whether Tiers 1 and 2 should be centralized.

Reed, Lawrence W. (1992), "The Trust and Share Plan: A Prescription for Success," *Journal of Labor Research*, 13, 3, (Summer), 317-320.

Shows that one can tie pay to performance.

"Trust and Share Productivity Plan" at Merillat Industries in Michigan. (Makes kitchen and bath cabinets.) "Employees and the company split 50/50 of the amount equal to the calculated labor/fringe portion (30%) of the increased production volume." -- as much as $5,000 per year, $7M in incentive pay to 2,800 employees = $2,500 average.

Lower absenteeism and higher morale reported.

Reinganum, Jennifer F. (1983), "Uncertain Innovation and the Persistence of Monopoly," *American Economic Review*, 73, 741-48.

The author models a Nash-Cournot game in which an incumbent and a challenger decide how much to spend on innovation. She models innovation as a random process with a hazard rate defining the probability density function for the time until the innovation. She argues that the incumbent will spend less because, at the margin, the challenger gains all the benefits of the innovation, but the incumbent gains only the net benefits (the incumbent can keep selling the old product until the innovation occurs).

This article demonstrates that the assumption of a stochastic process is critical. It reverses the result obtained with a deterministic process.

Reynolds, William B. (1965), "Research Evaluation," *Research Management*, (March), 117-125.

This article was published in 1965 by a Chief Technical Officer of General Mills. There is much that is constant between his views and those that were found in the recent interviews described in

Zettelmeyer and Hauser (1995).

"In our laboratory we have an Assistant Director in charge of reading all articles that tell us how to run our business -- and writing letters to Management explaining why most of them do not apply."

"A discussion of research evaluation must be concerned with project selection as well as termination and post evaluation since new projects compete for dollars with the old ones."

Indicates that project rating systems are "intended primarily for projects in applied research." "weighted check list approach will lead to relatively sure but highly conventional results."

For applied research

1. Is project within corporate objectives?
2. Growth potential.
3. Competitive environment.
4. Do we have the skills.
5. Will we develop new and protectable technology?
6. Can program be undertaken without hurting long-term exploratory?

60/40 applied/exploratory mix. Corporate funds exploratory "kept as free as possible of short-term operating considerations even though much or it is of great potential interest to the divisions."

"As a rough guide we expect every research man to spend at least 15% of his time on scouting experiments."

"I might add that we make liberal use of check lists, market and financial data in our research project reviews, but we basically guide the programs on the basis of qualitative judgments."

CEO gives strategy then "we keep our exploratory programs in these areas but within these areas we have no inhibitions whatever in permitting a creative research man to follow his own scientific urges."

Argues against micro-management -- top management just can not do it. Instead should ask:

1. new product and process to keep us competitive in established lines,
2. new product and process to keep us in new lines,
3. real breakthroughs and willingness to work on fringe,
4. accomplish 1-3 with efficiency.

Roberts, Edward. B. (1990), "Evolving Toward Product and Market-Orientation: The Early Years of Technology-Based Firms," *Journal of Product Innovation Management*, 7, 274-287.

Study of 114 MIT spin-offs. The study of new innovation is clearly related to the study of R&D.

"evolution over the first several years after founding toward more product-oriented businesses and away from consulting and R&D contracting, and increased orientation of the founders to sales and marketing, with lessened emphasis on engineering."

Rosenau, Jr., Milton (1994), "Rewards for New Product Development Teams," *Journal of Product Innovation Management*, 11, 253-258.

Honeywell Space System Group had a cash bonus for timely chip design.

"While corporations stress multifunctional teamwork, they continue to primarily reward individual behavior."

Only 7.4% of 189 responding companies tie compensation plans to successful performance of new products.

Rotemberg, Julio J. and Garth Saloner (1995), "Overt Interfunctional Conflict (and its Reduction Through Business Strategy)," *Rand Journal of Economics*, 26, 4, (Winter), 630-653.

While this article is focused on conflicts between marketing and manufacturing, it obviously applies more generally to conflicts between R&D and other functions.

The basic argument is this. If the firm invests more in one function, say R&D, then R&D gains some expertise that makes it more effective in the future. The key idea is that, with this expertise, one of today's employees is worth more than a new (inexperienced) employee. Thus, if the firm invests in R&D, then R&D employees gain more experience and can command higher wages. This, in turn, encourages them to seek information that favors investment in R&D. If the firm can either invest in R&D or something else, then this might encourage R&D to attempt to challenge information that favors the "something else" department. Thus, the system becomes one of an adversarial presentation, much like the US legal system.

The authors analyze the dynamics of the situation to determine when it is optimal for one or the other function to seek information -- this leads to costs and benefits to the firm. The benefit is that the information may change the firm's decisions for the better. The cost is the cost of the information. Under some conditions the benefits can exceed the costs.

Under other conditions the costs might exceed the benefits and the firm might consider strategies to reduce unnecessary conflict. (For example, if information is difficult to obtain and the benefit of changing the firm's strategy is small.) The firm has the option of favoring one department over the other. For example, it can be R&D driven or market driven. (In the paper this is "differentiation" -- favoring marketing, or "low cost" favoring manufacturing.) In this case, the department with the greater core competence has a greater chance (or a sure chance) of winning, thus there is less of a need to seek information.

Rust, Roland T., Anthony J. Zahorik, and Timothy L. Keiningham (1994), "Return of Quality (ROQ): Making Service Quality Financially Accountable," Technical Working Paper, Marketing Science Institute, Cambridge, MA 02138. (April).

Provides a methodology to calculate the return on quality (ROQ).

Satisfaction with attributes → process satisfaction → overall satisfaction → retention (repurchase intent).

Models retention with a simple Markov process give market share. Share then is used to calculate net present value and then ROQ. An ADBUDG-like model is used to map spending to attribute satisfaction.

Reports two applications.

Schainblatt, Alfred H. (1982), "How Companies Measure the Productivity of Engineers and Scientists, *Research Management*, 25, 5, (May).

This article provides a perspective on how hard the problem was perceived to be in 1982. He called 34 firms and found that only 20% of the R&D managers routinely collected some type of productivity measure. None were collected at 20 of the 34 firms.

"There are no currently used systems for measuring the productivity of scientific and engineering groups without substantial flaws."

"attempts to quantify benefits of R&D have led to monstrosities that caused more harm than good."

An official was very negative even about discussions of the topic because "he had convinced his top management that it wasn't necessary."

Engineers and scientists "question the meaningfulness of the output measures, which are basically counts of things. Also, as technical and professional employees, they resent and resist being measured in this way."

The author lists a number of very "bean-counting" types of systems like publications, citations (with hard to find references like working papers and government reports), hours per quantfiable output, etc. Review of literature suggests that a large portion devoted to publications or citations.

One company used science panels for quality, value ratings which include probability of a discovery, and the potential value of the discovery. Another used commercialization measures.

"'vintage charts' which depict sales in a given year of products developed in previous years."

One algorithm for "program value" multiplies the following four factors:

- potential annual benefit
- probability of commercialization
- competitive technical status
- comprehensiveness of the R&D program.

The actual scales are given on p. 16.

This article provides one practical way to incorporate the ideas of core competency and strategic advantage into a metrics system.

Reviews other work. From Ruch (9) -- five categories of obstacles:

- difficulty of defining output of a knowledge worker

- tendency to measure activities not output
- matching outputs in different time frames from inputs
- lack of a quality dimension
- need both effectiveness and efficiency.

Schmitt, Roland W. (1987), "R&D in a Competitive Era," *Research Management*, (Jan-Feb), 15-19.

Schmitt was the Chief Technical Officer of General Electric and was with the National Science Foundation. He is a member of the National Academy of Engineering. He provides suggestions on the way to manage R&D.

"Select the right area of science and technology in which to work"

> "You have got to stick your neck out into new areas of science and technology before it becomes obvious to everyone that you should be there."
>
> "We put more effort into AVLSI than would be justified by aerospace opportunities alone."
>
> "How do you sit down and target high leverage programs, based on forefront technology, with a business that does not have a clear idea of where its technology priorities are?"

"Choose the right application targets for that science and technology"

"Execute right"

> "The answer is not, 'Stay away from marketers,' but rather, 'Don't let them out of your sight.'"

"Recruit and keep excellent people."

> "If you put too much pressure on the payoff, you'll scare away the best technical people."
>
> "get the best person you can, not just the person who can best do the task that's immediately at hand."

Datum In General Electric, the corporate lab costs twice as much per staff member as operations.

> Interesting concept on why you don't want R&D to do customer-responsive jobs that could be done in operations. Relates to research vs. customer driven.

Schuster, Jay R. (1985), "Compensation Plan Design," *Management Review*, 21-25.

Surveyed "24 companies that designed their compensation plans to communicate important performance priorities in the organization and 42 companies that did not." The article does not indicate whether this classification was a priori or a posteriori. Subject to that caveat, the 24 companies outperformed the 42 companies. The article claims that this performance was due to the compensation system. "the differentiating factor was the establishment of a series of performance priorities by the chief executive officer that are supported by managers throughout the organization." ... "Compensation programs are designed specifically to communicate and reinforce these priories throughout the organization."

Group incentives in best performing companies; individual incentives in the others.

In the best performers: "Financial rewards are distributed according to how accurately employees hit their performance priority targets."

It appears to be important that

- financial incentives communicate priorities
- performance period matches the period that makes sense for the group
- use a few performance categories.

Sen, Falguni and Albert H. Rubenstein (1989), "External Technology and In-House R&D's Facilitative Role," *Journal of Product Innovation Management*, 6, 2, 123-138.

This article covers 31 case studies in the US and India in which R&D was involved in the acquisition of technology. R&D was most involved in focus (generating potential targets and information on those targets), evaluation, receiving (choose personnel, generate improvements), and then implementation (construct, improve, retool, redesign). While less involved in identifying needs, they were somewhat effective in doing so. See Table 4 of involvement vs. effectiveness in each stage (including satisfaction with solutions, overall, decision information, and ability to predict problems).

Shapria, Reuven and Shlomo Globerson (1983), "An Incentive Plan for R&D Workers," *Research Management*, (Sept-Oct), 17-20.

Provides an example of a subjective evaluation of R&D employees (weights in parentheses):

- discipline at work (15)
- professional knowledge relevant to the last period's projects (30)
- human relations (15)
- production and quality of performance (20)
- dedication at work and responsibility (20)

A score is calculated for each employee and bonuses are distributed in proportion to the score (adjusted by the load that the employee carries). The system is similar for managers but includes additional criteria.

Slater, Stanley F. and John C. Narver (1994), "Does Competitive Environment Moderate the Market-Orientation-Performance Relationship?" *Journal of Marketing*, 58, (January), 46-55.

In a study of 81 business units at a forest products company and 26 business units at a manufacturing company the authors collect data on market orientation, market performance (manager's assessments), and various descriptors of competitive situations such as market turbulence, technological turbulence, competitive hostility, market growth, buyer power, and firm concentration. The effect of the moderators is not found to be strong.

This article suggests that the competitive environment might modify strategy, but does not find strong statistical support for the hypothesis.

Souder, William E. and T. Mandakovic (1986), "R&D Project Selection Models: The Dawn of a New Era," *Research Management*, (July-Aug.), 36-41.

This article argues against the blind application of R&D portfolio selection models. "Can it be that the literally thousands of models that now exist have proven to be of little real value to R&D managers?"

They point out that portfolio selection is more complex. "Some low priority projects may be funded in order to establish a beachhead. Some high-priority projects may not be funded because critical skills are needed elsewhere." Classical OR methods can not handle this dynamic decision making. They provide other criticisms as well. "few real situations are linear, and forcing them into a linear programming model may result in meaningless solutions."

Instead they suggest that portfolio models be use to clarify a project potential and to <u>aid</u> the decision maker. Behavioral methods (Q-sort) and communication methods (decentralized hierarchical modeling) are cited as critical to helping managers use this information. "In the past, naive attempts were made to find *answers* to *R&D questions*. Today, there is a growing recognition that project selection models should be used to *ask questions* of the *entire organization*."

Stahl, Michael J. and Joseph Steger (1977), "Measuring Innovation and Productivity -- A Peer Rating System," *Research Management*, (January)

This is a classic *Research Management* article cited by many subsequent authors. This article develops scales for innovation and productivity and then has US Air Force scientists and engineers rate their peers. The two scales are inter-correlated (.735) The scales are fairly reliable (.66-.72) and have some validity (more productive and more innovative researchers have more publications).

Staudt, Erich, Jurgen Bock, Peter Muhlemeyer, and Bernd Kriegesmann (1991), "Incentive Systems as an Instrument of Company Innovation Management: Results of an Empirical Investigation in the R&D Sector," *International Journal of Technology Management*, 6, 3/4, 395-413.

Study of 522 inventor employees drawn from the German patent office. Shows that material incentives are <u>perceived</u> as important.

- more than 70% classified material incentives as important
- just under 40% consider material incentives satisfactory
- desire for "justice" -- "relationship between profit for the company and the inventor's own monetary profit"
- social status partially important (promotion 37.5%, acknowledgement 12.3%)
- staff development incentives 60%
- flexibility "only one third"
- "91.1% of the combinations contain at least one material incentive component"

Steele, Lowell W. (1987), "Selling Technology to Your Chief Executive," *Research Management*, 30, 1, (Jan-Feb).

Steele was 30 years at General Electric. He argues that R&D managers should focus on those things that are important to the CEO.

Two kinds of credibility:

- "Safety credibility -- a belief that this person's values, beliefs, and priorities are enough like my own that I can trust him; I can trust him to act in such a way that I can accept the consequences."
- "Technical credibility -- a belief that this person knows what he is talking about."

Suggests Chief Technical Officer should be aware of the entire business equation.

Meeting schedules and budgets is a signal of safety credibility.

"A dispassionate explication of probabilities and uncertainties will help the CEO understand the full implications ..." convert uncertainty into risk -- For example, one might give a better probability density function with a tighter variance.

Chief Technical Officer should have technical vision, breadth of view (not just new product, but cost reduction, etc.).

Need to aggregate -- that is, the whole program, a broad scope, and a balanced picture.

Steele, Lowell W. (1988), "What We've Learned: Selecting R&D Programs and Objectives," *Research Technology Management*, (March-April), 1-36.

This article reviews 50 years of R&D program selection and objectives and assesses the state of the art. It begins with a history of changes from the 1930s to the 1960s to the 1980s -- this is an interesting historical perspective. He then reviews current methods and comments on a variety of managerial phenomena. Talks highly of MIT research including work by Edward Roberts, Thomas Allen, and James Utterback.

"The techniques and processes now in use tend to externalize and make explicit what the great leaders of the 1930s did largely intuitively."

History. In the 1930s research laboratories were smaller and more tightly connected to the enterprise. They were often co-located with the production facility and interacted on a day-to-day basis. Firms were managed by a relatively small number of executives, hence communication was easier. The CTO was often involved in all projects and, at least, was aware of all projects.

"Directors of research and members of the staff, then as now, attempted to identify the intersection of technical opportunity and business need or opportunity that would have greatest leverage. Directors in particular worried about the balance between short term and long term and between focused and exploratory work."

After World War II "industrial R&D embarked on a two-decades-long expansion of unprecedented magnitude." This led to dramatic growth, but problems developed because the "inherent difficulties and complexities of technological innovation were underestimated and oversimplified ..." In addition, the "softening of the criteria for measuring performance" led R&D managers to advocate a doctrine that R&D was unique, should be managed differently, and should be left alone.

In the 1960s corporate managers started asking for returns on the R&D investment. "R&D managers came to recognize that they were playing a very circumscribed role in the enterprise and that this constraint was severely inhibiting the contribution that technology could make to corporate success."

In the 1980s the demands on performance increased further and "corporate executives are looking to R&D to provide technological solutions to productivity." "Selectivity, with an attendant increase in risk, becomes mandatory in program planning."

Current methods (1988). Many analytical approaches which "express (the) return as a function of the benefit the R&D generates, the probability of its occurring, and the cost of achieving it." however, "managers usually perceive program selection techniques as requiring an inordinate amount of managerial effort." Scoring methods -- combine a variety of weighted criteria. Net present value methods. Linear or dynamic programming methods.

"Present value calculations have much appeal." "Perhaps a more serious charge is that discounting techniques tend to favor near-term, incremental contributions to the business over longer-term, but presumably bigger, advances."

"Despite the methodological power of linear programming, it has virtually no use in industry." "Dynamic programming attempts to address some of the deficiencies of linear programming."

"One report in the literature indicated 90% agreement between less demanding scoring techniques and much more sophisticated, but costly approaches."

Important to take into consideration the track record of the program proposer."

Treat R&D as a portfolio. Program planning requires inputs from external as well as internal sources. Gatekeepers are important. "However, program planning must include market inputs."

"In general, corporate goals will translate into strategic guidelines for divisions, that, in turn, will help shape the direction of effort and the allocation of resources among programs." Strategic planning represents a "doorway for R&D management to become more involved in the basic policy deliberations of senior management." "Unfortunately, not every enterprise recognizes this yet." However, not all programs need be consistent; some should be "contrarian" to provide insurance options.

Not every firm must be a technology leader in all areas. In some they should lead, in some they should be parity, and in some they should follow. It depends on the other firms.

Stigler, George (1961), "The Economics of Information," *Journal of Political Economy*, 60, (June), 213-225.

R&D can be thought of as a search for information. This article is a classic reference for the cost of searching for information (on price). It models outcomes as a maximum (minimum) of n draws from a normal distribution. Also illustrates other classic properties of order statistics.

Sykes, Hollister B. (1992), "Incentive Compensation for Corporate Venture Personnel," *Journal of Business Venturing*, 253-265.

This is a series of eight case studies of compensation plans.

A key theoretical construct is equity vs. equality.

Arguments for equality

- other (non-R&D) employees contribute to a venture's success. They may undermine effort.
- the internal entrepreneur does not bear much risk
- uniform compensation facilitates transfers of employees
- want to focus on overall corporate profits not just the ventures

Arguments for equity

- keep and recruit talent
- venture career risk is greater
- hours are longer and more stressful

Discusses the issue of career risk. Even if there is no monetary payout, and even if failure carries no stigma, careers are put on hold while working on failed ventures.

Includes examples of how the corporation reneged on promised long-term pay-outs. (I.e., why personnel should be more short-term oriented.)

Szakonyi, Robert (1990), "101 tips for Managing R&D More Effectively - I," *Research Technology Management*, (July-Aug), 31-36.

Szakonyi, Robert (1990), "101 tips for Managing R&D More Effectively - II," *Research Technology Management*, (Nov-Dec), 41-46.

101 recommendations from 115 companies interviewed -- Szakonyi is a technology manager at IIT. Here are some example recommendations.

2. Corporate R&D should have the greatest voice in selecting long-term research and a lesser voice in responding to new product requests.
3. Should not apply a uniform hurdle rate for all R&D projects.
12. "R&D proposals that address broad company needs are at a disadvantage in the selection process."
20. "Cost-sharing arrangements between corporate R&D and a business unit are another way of

stretching limited budgets."

33. "Because the uncertainties involved in R&D are greater, the controls on R&D projects should be looser."
35. "Managing R&D means, first and foremost, managing people."
36. "Some R&D managers should not be managers."
38. "Regardless of how good the performance evaluation system is, its integrity will be undermined greatly if R&D people are not compensated in accordance with their own evaluation."
44. "Sending R&D people to profession conferences helps them keep abreast of new technical developments and also lessens their preoccupation with the operating manager's short-term demands."
48. "Another way to encourage creativity is to have more than one or two sources of funds for the pursuit of technical ideas."
51. "R&D people with the ability to improve existing products do not necessarily have the ability to carry out a research project to advanced development."
54. "Another likely skills gap has to do with the field development skills directed toward finding new market opportunities."
75. "R&D projects are uncertain creatures."
96. "Being a senior R&D manager is very different from being a junior or middle-level R&D manager." ... " The higher one goes, the more abstract the responsibilities."
97. Senior manager's responsibilities: 1. everything as before, 2. defining the role of technology at the company.

Szakonyi, Robert (1994), "Measuring R&D Effectiveness - I," *Research Technology Management*, (Mar-Apr), 27-32.

Szakonyi, Robert (1994), "Measuring R&D Effectiveness - II," *Research Technology Management*, (May-June), 44-55.

The first article reviews the literature and provides citations; the second article proposes a qualitative system and gives examples. An editorial side-bar criticizes the article as incomplete.

The qualitative system rates 10 things on a 6-point scale. They are:

"1. selecting R&D,
2. planning and managing projects,
3. generating new product ideas,
4. maintaining process,
5. motivating people,
6. cross functional teams,
7. R&D-marketing coordination,
8. technology transfer,
9. R&D-finance coordination, and
10. linking R&D to business planning."

Tauss, Kurt H. (1975), "A Pragmatic Approach to Evaluating R&D Programs," *Research Management*, (September), 13-15.

Uses constant sum paired comparisons to rank project criteria.

Taylor, Curtis (1995), "Digging for Golden Carrots: An Analysis of Research Tournaments," *American Economic Review*, 85, 4, (September), 872-890.

Formal model. The idea is that the firm announces a research tournament in which the winner gets a prize. Each researcher pays an entry fee and, at a pre-determined time, T, the firm trades the prize for the best innovation. The reason for the tournament is to get around the problem that both the research costs and the research outcomes are difficult to observe.

The author models R&D as a search problem. In each period, the researcher draws a value from a probability density function. The optimal solution for each firm is to continue drawing until the value exceeds some cutoff (dynamic programming). In the author's model, the draws are independent over time and over firms.

The key insight is that the firm sponsoring the tournament would want to limit the number of contestants so that they have incentives to carry out the research. The firm can not implement the first-best, except in a one-period tournament. The idea is that the first-best uses a global cutoff -- as soon as any firm exceeds the cutoff, stop. However, for the tournament, each firm implements its own cutoff rule. The author shows that the researchers' cutoff values are less than the global cutoff value.

This article reinforces the need to model the active decisions by R&D. R&D managers and researchers will optimize against any reward system; that optimization will affect the expected value of the research outcomes. This article implicitly indicates why it might be easier to manage R&D if one were to develop metrics that provided an observable value for R&D outcomes.

Teece, David (1980), "Economies of Scope of the Enterprise," *Journal of Economic Behavior and Organization*, 223-247.

Argues that Panzar and Willig's (1981) results (actually an earlier working paper) might be too strong. Uses Williamson's transaction cost analysis. Basically, the concept is that transactional difficulties make economies of scope difficult to capture relative to the common input.

"The basic conclusion is that economies of scope do not provide a sufficient raison d'etre for multiproduct firms. There are likely to be numerous instances where economies of scope can be captured by an economy of specialized firms contracting in the marketplace for the supply of common inputs. Nevertheless, there are importance instances where multiproduct firms will be needed to capture scope economies. Two circumstances were examined in some detail: (1) where the production of two or more products depends upon the same proprietary know-how base and recurrent exchange is called for, and (2) when a specialized indivisible asset is a common input into the production of two or more products. Under circumstances (1) and (2), integration (that is, multiproduct organization) is likely to be an efficient mode of organization."

Tenner, Arthur R. (1991), "Quality Management Beyond Manufacturing," *Research Technology Management*, (Sept-Oct), 27-32.

Describes how Total Quality Management helps the R&D process. Reviews ideas from Total Quality Management and gives examples of a better Help Desk and better distribution of R&D reports.

Notes that "measurements inside the work process are used routinely by scientists and engineers to perform their tasks."

"'High counts' may correlate with valuable R&D results, but they are not direct measures of it."

Quotes Chief Technical Officer (John Cadogan) of British Petroleum.

"The value of R&D is calculated by dividing the financial benefit attributed to research for a given year by the research budget."

"British Petroleum's measure of R&D outcome is based on the judgment of its business center managers. They are asked to quantify how much of their annual profits are attributable to research."

Tipping, James W. (1993), "Doing a Lot More with a Lot Less," *Research Technology Management*, (Sept-Oct), 13-14.

Tipping was the Director of Research and Technology for ICI Americas, Inc.
Describes an Industrial Research Institute study that (at the time of the article) will be done. See Wolff (1994).

Suggests that there is a common thread of a lack of suitable measures of R&D productivity.

"There is a movement away from corporate laboratories with US firms"

Datum: R&D expenditure is roughly the same amount as the dividend in many companies. The author claims that R&D spending is being a convenient target to increase dividends.

Tipping, James W., Eugene Zeffren, and Alan R. Fusfeld (1995), "Assessing the Value of Your Technology," *Research Technology Management*, 22-39.

The authors propose a Technology Value Pyramid:

Outcomes:	Value Creation
Strategy:	Portfolio Assessment
	Integration with Business
Foundations:	Asset Value of Technology
	Practice of R&D Processes to Support Innovation

They provide a menu of 33 metrics, from which the stakeholders can choose, for each level in the pyramid. They stress that the various stakeholders will have different values and time scales.

They surveyed 213 participants (R&D Directors or Chief Technical Officers) at an Industrial Research Institute workshop. These participants suggested that their top 10 metrics were

- Financial return
- Strategic alignment
- Projected value of R&D pipeline
- Sales or Gross Profits from new product
- Accomplishment of project milestones
- Portfolio distribution of R&D projects
- Customer Satisfaction surveys
- Market Share
- Development Cycle time
- Product Quality and Reliability
- Gross Profit Margin

General beliefs of the authors

- R&D must defend and enhance the value of the corporation
- linkage of R&D and strategic aims
- R&D must sustain its capability to produce useful output over the long term

Turner, W. J. (1979), "Stimulating and Rewarding Invention: How the IBM Awards Program Works," *Research Management*, (July), 24-27.

Describes IBM's award program and gives examples. There are awards for technical achievement and awards for business achievement.

Gives a small amount of money ($600) for a patent.

Strives for visibility, i.e., social context.

- Partnership between marketing and R&D
- Link performance indicators to strategy
- Spectrum of performance indicators
- Interpret and adjust continuously
- Learn from and act upon performance indicators
- Combine calendar-driven and event-driven reviews

Data: Hewlett-Packard gets 60% of sales from new product in last 3 years
3M -- 30% in 4 years
Baxter -- 34% in five years
Emerson Electric -- 20% in five years

Suggests that one should measure the quality of discarded ideas

Distinguishes incremental R&D vs. fundamental R&D. Different levels in organization use different measures.

Hold people accountable for performance measures they can influence.

Vest, Charles M. (1995), "Drift Toward Mediocrity in Science," *The MIT Report*, (Sept-Oct), 23, 7, 3-4

One important aspect of R&D is the spillovers to other business units within the firm, to other firms in the industry, and to society as a whole. This article argues that Congress in not considering these spillovers.

Vest is President of MIT. "we are in danger of disinvesting in the future." Congress plans to reduce the budget for civilian R&D by more than one-third. The return on research investment (for society?) is 25-50%.

Ward, Michael and David Dranove (1995), "The Vertical Chain of R&D in the Pharmaceutical Industry," *Economic Inquiry*, 33, (January), 1-18.

This article examines the relationship in the pharmaceutical industry between basic research, mostly funded by the government, and applied research, mostly funded by industry. It is a careful econometric study with generalized least squares estimates of seemingly unrelated regressions. There is a very complete discussion of the industry and a careful selection of proxy variables.

There are definitely spillovers from the government to industry. "A 1% increase in research funding by the national Institute of Health leads to an estimated 2.5% increase in R&D expenditures by (industry)." This results from a 0.76% increase in the same category and a 1.71% increase in related categories (over seven years).

Also, the objectives between government funded research and industry funded research are not perfectly aligned. The government favors research on severe conditions while industry on conditions that are more prevalent.

Weisbrod, Burton A. (1992), "Productivity and Incentives in the Medical Care Sector," *Scandinavian. J. of Economics*, 94, Supplement, 131-145.

Measures of productivity in health care are proposed -- "quality adjusted life year" and "patient satisfaction."

Whelen, J. M. (1976), "Project Profile Reports Measure R&D Effectiveness," *Research Management*, (September)

Whelen was a research associate at Union Carbide. Develops a questionnaire (given in article) to rate R&D.

- to maintain continuity across time, categorize the funding source by small enough units so that the units remain intact after the inevitable reorganizations

- defensive vs. offensive (D/O) index to distinguish work on new businesses vs. support for existing businesses

Discusses the tendency to focus on existing businesses. Gives and example of this tendency for the chemicals and plastics business unit at Union Carbide. This "prompted immediate management action (by budget increase) to bolster the longer-range effort."

Wolff, Michael F. (1994), "Meet Your Competition: Data from the IRI R&D Survey," *Research Technology Management*, (Jan-Feb), 18-24.

Gives some results of the Industrial Research Institute's (IRI) Return-On-Research (ROR) study. Among the tables that are given are:

1. R&D $/Sales $ by industry
2. Source of R&D -- Corporate vs. business units by industry
3. Basic/Applied/new product/Process/Service breakdown
4.&6. Basic vs. Applied by industry
5. Allocation 5 to service by Industry
7. Ph.D's and M.D.'s by industry (% of employees)
8. R&D expenditure per employee by industry
9. Sales from new product by industry

Zettelmeyer, Florian and John R. Hauser (1995), "Metrics to Evaluate R&D Groups: Phase I, Qualitative Interviews," Working Paper #125-95, International Center for Research on the Management of Technology, MIT, Cambridge, MA, 02142. Revised March.

The authors "describe the results of in-depth qualitative interviews with Chief Executive Officers, Chief Technical Officers, and researchers at ten large research-intensive organizations. In these interviews (they) explored how these organizations measure success in the R&D mission and how the organizations provide incentives to managers and researchers in R&D."

This paper describes the three "tiers" of R&D -- "exploring the tools of the future, creating the tools, and pioneering the use of the tools." Other words to describe the tiers might be basic research, matching research capabilities to core technological competence, and applied research. The authors indicate how the interviewed firms use these tiers to organize and evaluate R&D. This tier structure is important to the understanding of R&D metrics because the appropriate metrics vary by tier. Those metrics that apply to basic research are not necessarily the best metrics for applied research, and vise versa.

The authors then describe how the tiers differ and indicate which metrics and incentives are now being used by the ten firms. The paper closes with suggestions for research based on the needs expressed in the qualitative interviews. See Hauser and Zettelmeyer (1996).