Measuring the Societal Benefits of Innovation

J. G. Tewksbury, M. S. Crandall, W. E. Crane

Although most people sense that technological innovation benefits society and is important for maintaining productivity in manufacturing, relatively little has been done to quantify its economic impact. For many years innovation proceeded apace and the productivity of manufacturing rose. Now, however, technological innovation is clearly lagging in the United States, as is productivity. Hence, the development of better economic tools for measuring the social benefit of innovation becomes more urgent, as does an effort to understand better the complex process of innovation.

One of the best attempts to quantify the benefits of specific technological innovations to society that we are aware of is the work of Mansfield *et al.* in 1975 (*1*). They developed a basic method for determining the social benefit of an innovation which parallels the way businesses financially evaluate commercial projects, and applied the method to 17 historical cases. The project described here, undertaken as an independent evaluation of Mansfield's results and method, consisted of 20 case studies.

Summary. Quantitative economic analysis of 20 commercial innovations shows that there is great benefit to society that is often not reflected in the rate of return to the innovator. The study also documents the importance of marketing strategy and proper consideration of risk.

The Sample

The sample was limited to technological innovations which had been in full-scale commercial operation for an extended period. Essentially all the data are based on actual commercial performance. The study was not limited to successful innovations; it included one which the innovator dropped after several years of commercial operation at a loss, and two others which would be judged to be commercial failures by any business standards. Nevertheless, the sample is probably somewhat biased toward commercially successful innovations, both because innovators are more likely to volunteer to provide data on achievements they are proud of and because one tends to be more aware of successful innovations than of unsuccessful ones.

A sample which was as representative as possible of the universe of technological innovations would have been desirable, and we would have preferred to follow a scientific sampling procedure. As a practical matter, however, even though information was sought on a confidential basis, it was so difficult to obtain that availability of data became dominant in the selection of cases. We solicited and researched many different industries and included in the sample the first 20 innovations on which we were able to obtain adequate data. Data for 11 of these were primarily confidential and voluntarily supplied by the innovating firms; data for the other nine were taken primarily from published sources.

In spite of the way the sample was determined, it turned out to be rather broadly representative, in that it took in different industries, different sizes of firms, different types and degrees of importance of innovations, and different degrees of patent protection. The 20 innovations include 12 industrial products, four consumer products, and four industrial processes. In impact on the country as a whole, eight of the innovations were very important, seven were important, and five were of minor importance. (An example of what constitutes a very important innovation—not included in this study, however—is synthetic polyester fiber.) About half had strong patent protection, which gave the innovator a virtual monopoly for many years; the rest had weak or negligible patent coverage. The environmental impact of most of the innovations was minor, but four were judged to have a favorable impact on the environment and two had a controversial and possibly very large negative impact. The innovating entities in the 20 cases range in size from some of the world's largest corporations to small companies with very limited resources. Twelve innovations were basically mechanical in nature, from four different industries; five were basically chemical in nature, from four different areas of the industry; two were based on a principle of advanced physics; and one was a formulated consumer product.

The Approach

A business firm evaluates projects largely in terms of dollars returned compared to dollars invested, with guidelines as to acceptable return based on risk and other factors. The primary concern of the business firm is dollars, and the dollar value of assets committed to a project constitutes the "resources" allocated to a project, with returns or profits also expressed as dollars.

On the other hand, the primary concern of society is optimizing allocation of its limited resources, that is, labor, land, and capital. The method developed by Mansfield *et al.* and used here parallels that of the firm in that projects are evaluated in terms of resources "returned," or saved, compared to resources "invested," or allocated, by the nation. Resource value is expressed in dollar terms, so that rate of return can be expressed in terms identical with those used by business firms and thus have much the same meaning. We can then compare a so-called private rate of return, which means the rate of return to the innovating firm or firms, with a so-called social rate of return, which is the rate of return to society on resources.

It should be emphasized that the societal benefit measured here was limited to what could be called economic benefit. Esthetic and other quality-of-life benefits were generally not included, these being difficult or impossible to measure in dollars. This does not mean that environmental or health and safety consid-

Dr. Tewksbury is a vice president and Dr. Crandall is a consultant of Foster Associates, Washington, D.C. 20036, and Mr. Crane is energy survey director at Data Technology Industries, Riverdale, Maryland 20840.

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erations were excluded, because most of the cost and benefit in those areas can be expressed in dollar terms (in two of the 20 cases studied safety benefits to society were substantial).

First the private rate of return was determined for each case. This is basically the return to an individual innovator. It is a guide to his performance and is a standard measure of success of industrial projects. The essential parts of this calculation (*2*) were as follows:

1) Determine all direct investment and direct profits for the innovation annually for the life of the innovation. Investment starts with the first basic research on the innovation, and continues through full-scale commercial plant investment. It also includes advertising and other promotional costs. It does not include use of otherwise idle facilities or space without alternative value.

2) Reduce direct profits from the innovation by the profit lost from displaced products, if any.

3) Assign an appropriate share of the cost of uncommercialized R & D, if any, to the innovation.

4) Designating investment as negative and profits as positive, determine a single net figure for each year.

5) Adjust all net figures to a real (constant dollar) basis, in this project with the Bureau of Labor Statistics Consumer Price Index in constant 1967 dollars.

6) Calculate an internal discounted cash flow (DCF) rate of return. This is in essence the real interest rate which makes the "present value" of all the net real investment and profit equal to zero; this is one standard method for determining rate of return. "Present value" is a widely used concept which accounts for the fact that a dollar earned today is worth more than one earned in the future.

The next step was calculating the social rate of return. This follows the same basic principles as for private return, expanded to cover the entire nation:

1) Add investments and profits of firms which imitate the innovation, if any, to the net private returns as determined in paragraph 4 above.

2) Reduce profits by profit lost from displaced products of other firms than the innovator.

3) Reduce profits by assigning an appropriate share of the cost of uncommercialized R & D of other firms than the innovator.

4) Add the savings to consumers that result from the innovation. This is often the largest component of social benefit. Economists may call this figure the "change in consumers' surplus." It typically includes a somewhat controversial savings component, what consumers would be willing to pay for the goods or services affected compared to what they actually pay as a result of the innovation. This portion is usually only a fraction of the total savings from an innovation.

5) Add or subtract any other benefits or costs to the nation from the effect on the environment, health and safety, and so forth.

6) Calculate the internal DCF social rate of return on a real basis, by the same procedure as for the private return.

In both private and social return calculations, investment was generally small during the basic R & D stage and rose sharply when full-scale commercial facilities were built. Then there were typically several more years of losses as market volumes built up.

Table 1. Discounted cash flow rates of return on innovations.

Innovation	Rate of return (%)	
	Social	Private
	Industrial products	
A	62	31
B	Negative	Negative
C	116	55
D	23	0
E	37	9
F	161	40
G	123	24
H	104	Negative
I	113	12
J	95	40
K	472	127
L	Negative	13
	Consumer products	
M	28	23
N	62	41
O	178	148
P	144	29
	Industrial processes	
R	103	55
S	29	25
T	198	69
U	20	20
Median	99	27

Results

The internal DCF rates of return of the 20 innovations, calculated by the original Mansfield method, are shown in Table 1. The social rates of return are seen to be very high, the median being 99 percent.

A second major finding of the study, also shown in Table 1, is that a number of innovations with substantial social rates of return had unacceptable private rates of return: innovations D, E, and H had social returns of 23, 37, and 104 percent and private returns of 0, 9, and less than 0 percent. Clearly, if the innovators had anticipated these low rates of return, they would not have commercialized these innovations and the social benefits would have been lost. This poses an interesting question which was not addressed in the study: Are there characteristics of innovations which would lead innovators to anticipate low private rates of return, or are low rates of return a random phenomenon in high-risk enterprises? The answer to this question has important implications for determining whether incentives to innovate are adequate and, if they are inadequate, for determining what government action might be taken.

A third finding of the study was that private return was typically much less than social benefit. This poses the question, which also was not addressed, whether the ratio of private to social benefit is optimal for the nation. On the one hand, a smaller proportion of benefit accruing to the innovator might not reduce commercialization much but might be preferable because the consumer would receive more. On the other hand, a larger proportion of benefit accruing to the innovator might result in more commercialization and therefore greater overall social benefit.

Our findings confirm those of Mansfield *et al.* (*1*) and were subsequently confirmed by others (*3*). In addition, the study uncovered a number of interesting aspects of the analysis of the innovative process:

Marketing strategy often had an important effect on private rate of return, which in turn strongly affected social benefit. Passing on substantial savings to the customer, determined in part by pricing policy, often substantially increased private return by increasing rate or depth of penetration of the market. Also, marketing strategies that result in lower capital investment for the purchaser of the new product or process also often increased private return.

In more than half the cases the amount of money risked was different from the amount actually invested, even substantially different. In some of these cases, the money risked far exceeded the amount actually invested, and in others the money risked was far less than the amount invested. For example, if equipment purchased has substantial salvage value, the amount risked is less than the amount invested. Conversely, if there is a substantial cost for cleanup if the innovation fails, then amount risked is greater than the amount invested. This can be important in determining the acceptability of the rate of return. For example, the rate of return based only on money invested might appear acceptable, but if the amount of money that would be lost if the innovation failed is double that invested, then that same rate of return may not be acceptable. In this study only the amount actually invested was included in the calculations. It would generally be possible, however, to quantify the amount risked, with the cooperation of the innovator, because the amount risked was typically very important to the innovator.

There was no obvious correlation between strong patent coverage and high private and social rate of return, nor between strong patent coverage and the difference between social and private return. In our view this means not that patent coverage was not important but that there were other more important influences on rates of return.

Allocation of benefits between an innovation studied and innovations which preceded it was often important and presented special problems.

In some cases customers rewarded a successful innovation by purchasing other essentially unrelated products from the innovator. Thus, a company might have shown a loss on the innovation itself in its records but, because of other sales increases, have realized a net benefit from the innovation.

Government influence was quite important in a number of cases, even though many of the innovations studied were commercialized before the government's influence had become as pervasive as it has in the last few years. In the study this influence included patents, approval for use in certain markets, air pollution regulations, and import policy.

One innovation (L) was of itself not particularly financially attractive for the innovator and had a negative social rate of return, but led to another innovation (G) which was more profitable and had a good social rate of return. This illustrates the possible hazard of analyzing an innovation independently of other innovations.

Illustrative Cases

Three of the 20 cases illustrate both the approach and some of the more interesting features of the innovations we studied. To protect confidentiality, some information not critical to calculation of rate of return has been altered.

Product innovation L had a fairly low private rate of return and a negative social rate of return, so would of itself appear to have been unprofitable to both the innovator and the nation. However, it led to another innovation, G, which was profitable for both the innovator and the nation. L is an example of substantial and reasonably quantifiable safety benefits, and of benefits from sales of products unrelated to the innovation itself.

L is a functional component of a widely used machine. It performs the same basic function as an earlier product, Y, but it improved safety and had esthetic advantages. Although L was more expensive than Y, its superior performance resulted in penetration of Y's market.

Not long after the innovator developed L, the same innovator made a major modification of L which sharply reduced its cost without diminishing performance. This is product innovation G, which quickly replaced all of L and then displaced the rest of Y. (The apparent sequence reversal in the lettering of innovations G and L resulted because data for inclusion of L were not obtained until late in the study, after G had already been completed.)

The calculation of the private return for L is summarized in Table 2. Indirect profit is the profit from unrelated products that is attributed to L. The innovator reported that the company's continuing existence was directly attributable to continuing innovation and that part of the profits realized on its other, established products should be credited to innovations. Therefore, we credited a portion of profits on unrelated products to several innovations made in the period considered, and prorated this portion of profits to each innovation according to its relative importance.

The social benefits attributed to L, which are negative, are also set out in Table 2. Imitators quickly copied this innovation; their investments and returns were included in the social benefit, and we estimated their initial capital expenditures. L replaced Y on a one-for-one basis, and we assumed that they yielded the same profit. Therefore it was not necessary to estimate the imitators' returns because they are offset by the displaced profits on Y. L was more expensive than Y, hence the negative consumers' surplus.

Improved safety from use of L resulted in substantial savings for society. From published data, the total cost of safety attributable to the widely used machine of which L is a part was estimated and then the proportion attributable to L was estimated. The calculated real social rate of return for L was negative. However, a less conservative (higher) estimate of safety benefits could well have resulted in the finding of a positive social benefit. Also, the negative return could be considered as a trade-off for the unquantifiable value of reducing human suffering.

The basic information used for analysis of L and G was obtained from the innovator, annual financial reports, government and other published statistics, and a government safety expert.

Product innovation G showed a good social rate of return. However, the risk in the commercialization of this innovation substantially exceeded the capital expenditures and R & D cost because the firm had a major sales contract for G before it was perfected. If the innovation had failed, the cost to the company would have far exceeded the capital expenditure and R & D cost entailed. Like L, this innovation benefited from sales of products unrelated to it and from the substantial safety benefits it afforded.

The calculation of returns for G is summarized in Table 3. Imitators also quickly copied this innovation. The basis for estimating imitators' investments and returns was the same as for L.

The cost savings of G resulted in a substantial consumers' surplus, all of which derived from savings to those consumers who would have bought L if G had not been available. Those consumers who would have bought Y if G had not been available did not realize a saving because, over the life of the widely used machine of which they were a component, Y cost the same as G; they did, however, receive a safety benefit.

The real social rate of return was 123 percent. Without the safety benefits, the return would have been 114 percent. This indicates that accuracy of the estimate of safety benefits was not critical in calculation of the social rate of return.

Product innovation C demonstrates the importance of patent coverage to private rate of return. Profit dropped when another firm infringed upon the patent, then rose when infringement was stopped by litigation, and was projected to drop again because of new alleged infringement. Since the degree of alleged infringement possible in this instance relates strongly to federal patent policy, this case is one illustration of the importance of government influence.

C is an industrial product which substantially reduces the cost of manufacturing a consumer product. Savings result primarily from increasing the output of an existing facility. Use of C does not alter the consumer product, which was already established in the marketplace before C was introduced. C was first conceived in 1955, and testing began in

Table 2. Calculation of private (innovator's) and social returns from innovation L, in millions of dollars. Parentheses indicate costs or losses.

Year*	Innovator's return					Social return				
	R & D	Capital expenditures	Return on sales: Direct	Return on sales: Indirect	Total	Imitator's return	Consumers' surplus	Displaced profits	Safety benefits†	Total‡
1	(1)	(2)			(3)					(3)
2	(1)	(3)	(2)		(6)	(2)	(6)		0	(14)
3		(2)	(1)		(3)	(3)	(8)		1	(13)
4			0		0	(2)	(16)		1	(17)
5			1	0.5	1.5		(30)	(1.5)	2	(28)
6			2	1	3		(33)	(3)	4	(29)
7		(5)	3	1	(1)		(33)	1	6	(27)
8			4	1	5		(33)	(5)	8	(25)
9			6	1	7		(33)	(7)	12	(21)
10			8	1	9		(33)	(9)	14	(19)
11		(5)	10	0	5		(33)	(5)	14	(19)
12			7	1	8		(33)	(8)	18	(15)
13			4	2	6		(33)	(6)	23	(10)

*Shown as year from start in order to preserve confidentiality. †Could be considered as part of consumers' surplus. ‡Includes innovator's total return. Given only in current dollars in order to preserve confidentiality.

Table 3. Calculation of private (innovator's) and social returns from innovation G, in millions of dollars. Parentheses indicate costs or losses.

Year*	Innovator's return					Social return				
	R & D	Capital expenditures	Return on sales: Direct	Return on sales: Indirect	Total	Imitator's return	Consumers' surplus	Displaced profits	Safety benefits†	Total‡
1	(1)				(1)					(1)
2	(1)	(1)			(2)					(2)
3	(1)	(2)	(2)		(5)	(1)				(6)
4		(2)	(1)		(3)	(2)	21			16
5		(2)	1		(1)	(2)	30	(1.0)	2	28
6		(17)	5	0.5	(11.5)	(17)	33	(5.5)	4	3
7			10	1	11		33	(11)	10	43
8		(3)	15	1	13		33	(13)	23	56
9			20	1	21		33	(21)	38	71
10		(5)	25		20		33	(20)	47	80
11		(10)	19	2	11		33	(11)	61	94
12		(2)	13	6	17		33	(17)	85	118

*Shown as year from start in order to preserve confidentiality. †Could be considered as part of consumers' surplus. ‡Includes innovator's total return. Given only in current dollars in order to preserve confidentiality.

Table 4. Calculation of private (innovator's) and social returns from innovation C, in millions of dollars. Parentheses indicate costs or losses.

Year	Innovator's return				Social return*				
	Innovation costs	Gross profits	Total: Current dollars	Total: Constant dollars	Imitators' return	Consumers' surplus	Unsuccessful R & D	Total: Current dollars	Total: Constant dollars
1960	(0.1)		(0.1)	(0.1)			(0.1)	(0.2)	(0.2)
1961	(0.1)		(0.1)	(0.1)			(0.1)	(0.2)	(0.2)
1962	(0.1)		(0.1)	(0.1)			(0.1)	(0.2)	(0.2)
1963	(0.4)		(0.4)	(0.4)			(0.4)	(0.8)	(0.9)
1964	(0.8)		(0.8)	(0.9)			(0.8)	(1.6)	(1.7)
1965	(0.8)		(0.8)	(0.8)		9	(0.8)	7.4	7.8
1966		2.2	2.2	2.3		14		16.2	16.7
1967		3.4	3.4	3.4		18		21.4	21.4
1968		4.1	4.1	3.9	1.0	22		27.1	26.0
1969		4.9	4.9	4.5	2.1	27		34.0	31.0
1970		4.0	4.0	3.4	2.7	39		45.7	39.3
1971		1.9	1.9	1.6	1.9	38		41.8	34.5
1972		1.1	1.1	0.9	1.6	23		25.7	20.5
1973		0.5	0.5	0.4	0.8	33		34.3	25.8
1974		0.5	0.5	0.3	0.8	45		46.3	31.3
1975		1.0	1.0	0.6	0.4	51		52.4	32.5
1976		2.0	2.0	1.2	0.9	78		80.9	47.4
1977		3.2	3.2	1.8	1.4	97		101.6	55.7
1978		7.0	7.0	3.6	3.0	78		88.0	45.1
1979		(0.2)	(0.2)	(0.1)	(0.1)	78		77.7	37.2

*Includes innovator's total return.

1961. Government figures indicate that significant quantities were used in 1965, but according to the innovator large-scale commercial marketing first began in 1966, after R & D and testing costs of $2.3 million had been accumulated. Costs of R & D were insignificant through about 1959, were small through 1962, became large in 1963, and continued large in 1964 and 1965. The product began turning a substantial profit in the year it was introduced on a large scale.

The product is patented, and litigation related to patent coverage began soon after the product was introduced. First, there was litigation against a competitor from 1966 to 1970, which was decided in favor of the innovator in 1974. This competitor dropped out of the market at that time. In 1976 litigation began against several other competitors. The patent is quite important to profitable manufacture. The cost of the litigation has been substantial, totaling about $0.5 million through the period studied.

Table 4 sets out the profits of the innovator. The innovator provided a short-term profit forecast through 1979, which is included in the calculation. The profit pattern is unusual, not only because profits were generated early but also because they declined rapidly when the first competitor entered the market. Profits rose again sharply in the mid-1970's, in spite of other competitors' activities, because there was a temporary shortage of the product, but were expected to decline again in 1979, probably becoming negative in that year. After 1979, unless the second litigation is won, additional profits from the product are not expected.

Capital investment for manufacture of the product was negligible. It was manufactured in existing low-cost facilities which had several alternative uses. There was no uncommercialized R & D in areas related to this product. There were also no displaced profits, because the product was totally new.

The social rate of return of C is also shown in Table 4. Consumers' surplus was the same as the savings resulting from the innovation, because the innovation did not increase the market for the consumer product in question. According to the innovator, no one else would have discovered the same innovation. To account for the fact that another, less effective, product would have been used if C had not been available, net savings from the use of C were reduced by one-third. Also, although the innovator was not specifically aware of others working in the general area at the time C was introduced, the conservative assumption was nonetheless made that others spent the same amount at the same time on R & D as did the innovator.

Savings from use of C were primarily the result of lower manufacturing costs per unit of output of the consumer product in question. Use of C, according to government sources, does have some unfavorable environmental impact. However, the product displaced was considerably worse, so there is a net environmental benefit.

Future Directions

This and other studies (*1, 3*) clearly establish that social benefits from innovation can be very large, and that private benefits from some innovations with substantial social benefit are too low. The latter finding leads one to ask whether there are characteristics of some innovations which would lead innovators to anticipate these low returns and therefore reduce or eliminate commercialization of similar innovations in the future. This appears to be a fruitful subject for additional study.

Another question for possible future study is whether the ratio of private to social benefit is optimal for the nation. Such a study might also shed light on how the government might act to improve this ratio.

There appears to be widespread agreement that the ever more pervasive influence of government is a major cause of lagging innovation. The method used in this study may be useful as a framework for assessing the factors that determine the magnitude of benefits from an innovation, which in turn would permit assessing the influence of government actions on these factors. An example of how the method might be used for this purpose is calculation of the effect of, say, a 3-year delay in commercializing an innovation resulting from an excessively long federal permit process. However, appreciable progress on minimizing adverse effects of government may have to wait until economic tools designed expressly for the purpose of isolating and assessing the many facets of government influence are available.

References and Notes

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2. For a more detailed description of the method in economic terms, see J. G. Tewksbury, M. S. Crandall, W. E. Crane, *A Survey on Net Rates of Return on Innovations* (report to the National Science Foundation, May 1978), vol. 2, p. 13, or (*1*).
3. Robert R. Nathan Associates, *Net Rates of Return on Innovations* (report to the National Science Foundation, October 1978), vols. 1 and 2.

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