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How to Measure the Outcome of Innovations: Application to Product Innovations

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Abstract

This paper provided a conceptual framework to quantify consumer gains from product innovations. Using an example of VCRs, we illustrate a model that is useful to measure consumer welfare, and describe what data are to be used for the analysis. We also make a selective survey of papers that measure the consumer welfare of product innovations and discuss advantages and limitations of the analytical framework.

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Section 1. Introduction: How to Consider the Value of Innovations

Innovations are at the heart of economic progress. Innovations improve the way we live and work and allow us to maintain our current quality of life more economically. Many scholars have been interested in measuring the magnitude of social gains created by innovations. One conventional index that is often employed in the literature is the aggregate measures of price level. The construction of "real" price indices or the "true" cost-of-living index is supposed to serve as a useful indication regarding the extent to which innovation outcomes contribute to improving our welfare being. The standard definition of the cost-of-living index is the ratio of the minimum expenditure of two periods required to maintain the same level of utility. However, translating this theoretical notion into the actual construction of price indices is an extremely difficult task. It is indeed difficult to know how much of the expenditure would be reduced at the same level of utility upon the introduction of entirely new innovations. To answer this question, we need to address a counterfactual question: If innovations were removed from our society, what would be the extent of the change we perceive the quality of our life? [1]

In an attempt to answer such a counterfactual question, we present a conceptual framework for measuring consumer gains from innovations in this paper. For the sake of brevity, this paper focuses solely on a particular type of innovations — product innovations — and quantifies their economic benefit on consumer well-being. [2] Thus, this paper leaves the other type of innovations — process innovation — to other studies in the literature.

The paper's focus on consumer gains from innovations is admittedly quite limited in terms of the scope of the analysis of innovations. Presumably, innovation activities encompass many stages, including applied scientific research, exploratory and basic research, the development of prototypes and new production techniques, and product development marketing, as reflected in the conference theme: the Global Innovation Ecosystem (GIES). Any one of the innovative activities is essential to link innovative ideas discovered in the upstream stage with commercially successful products

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1 Alternatively, we can ask the following question: what would have happened to our utility if innovations accessible to us today had been available before?

2 As we will discuss in Section 2, the distinction between product and process innovations is not as clear as it appears to be.

delivered to society in the downstream stage. A majority of the existing studies, for instance, in the field of bibliometrics, have intensively examined the summary statistics of the upstream indices, including scientific papers, patents, and their citations. These studies have indeed provided useful insights into our understanding of, say, the relationship between the amount of research and development expenditure and the number of patents existing in the upstream innovation activities. However, in view of our interest in quantifying social gains from innovations, these output indices examined in the existing studies should instead be considered as intermediate inputs to, not the output of, the downstream innovation activities. Hence, the number of scientific papers, patents, or citations may not be an appropriate measure for assessing the value of innovation outcomes beneficial to our society. In this paper, we instead concentrate on directly estimating social gains from commercially successful innovations generated as part of the downstream activities.[3]

In order to do so, this paper adopts a concept from welfare economics, and assumes that the magnitude of the benefit of innovation be defined by the effect on welfare in monetary terms. In other words, we assess the value of innovations in terms of the extent to which consumers perceive the worth of an innovation, namely, the extent to which consumer welfare is increased by the introduction of the innovation. An advantage in using the welfare measure as the magnitude of innovations is that it directly captures, at least in principle, the value of benefits that consumers perceived from these innovations. Thus, the welfare measure we propose in this paper would overcome the weakness of alternative measures, including the number of citations or the rate of changes in product characteristics. A number of criticisms have been placed on these conventional measures, in that the number of citations or the rate of changes in product characteristics are not necessarily linked with the benefits of innovations received by society.

The rest of the paper is organized as follows. The next two sections describe a conceptual framework taken from the field of welfare economics, and describe the method that allows us to assess the economic benefit of innovations. We begin with Section 2 by illustrating our approach at an intuitive level using diagrammatic exhibition. The section proposes two approaches by which we can quantify the magnitude of innovations: the one involves focusing on the "similarity" of innovations to existing technologies, and the other is to emphasize the "differences" between innovations under focus and existing goods. The first approach is often used in the assessment of process innovation, and the second is used for product innovation. In Section 3, we turn to proposing a theoretical model and discussing how to implement the framework described in the previous section. We illustrate the importance of analyzing consumer behavior in the evaluation of consumer gains from innovations, and introduce an analytical framework that investigates consumer behavior.

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[3] Since innovations that fail to be introduced in the market do not reach our society, they are outside the scope of this paper. In this sense, our measure of social gains from innovations is conditional on the existence of commercially successful innovations.

The model of consumer transaction behavior, called the demand function, provides a convenient tool to analyze consumer welfare; moreover, it enables us to quantify the economic benefit of consuming innovative outcomes. A number of studies in the field of industrial organization use the consumer behavior model and calculate welfare gains. We conduct a selective survey of such literature and discuss the advantage and disadvantage of using such models. We conclude the paper in Section 4.

Section 2. Welfare Gains from Innovations: Diagrammatic Approach

In this section and the next, we describe the method used to estimate consumer gains from innovations in terms of economic welfare. This section illustrates how to quantify the magnitude of innovations at an intuitive level. In the subsequent section, we then turn to describing the implementation of the method in a more rigorous manner.

When we attempt to quantify "downstream" gains from innovations, it is imperative to have a unit of measurement. Otherwise, we would have difficulties in comparing the magnitude of innovations occurring in the case of different products, for example, video cassette recorders and computers. In the field of economics, innovation is usually considered as an increment in the stock of knowledge available to society. This additional knowledge makes it possible to improve the quality of existing goods and services available to society at lower prices. Therefore, the measurement unit for innovations is presumably linked to the "economic value" (namely, a shadow price in economic terms) of the additional knowledge to society. However, it is not easy to assess the economic value of such incremental knowledge, primarily because knowledge itself is inherently unobservable to researchers. Thus, a number of proxy variables have been proposed in the literature on the economics of innovations. For example, some researchers suggest that the economic benefit of innovations be approximated by use of the counts of the respective patents, citations, and scientific publications related to the innovation under focus. Other researchers propose to approximate the benefit from innovations by simply measuring changes in the characteristics of products introduced by innovations. For example, if a new model of automobiles doubles the maximum horsepower of an existing model, the latter group considers the increase in horsepower as a social gain from an innovation. Unfortunately, since innovations exhibit considerable variances in their economic and technological significance, none of these proxies would be sufficient as measurement unit for assessing the benefits of these innovations. As discussed in the previous section, the measures often used in bibliometrics are not directly linked to the outcome measure of the downstream innovation activities. Similarly, the changes in product characteristics may not be a good measure for consumer gains. For example, doubling automobile horsepower would not be appreciated by people in Tokyo where streets are often congested and strict speed limits are enforced.

In this paper, we employ an alternative method adopted from welfare economics, and assume that

the magnitude of the benefit from innovation be defined by the effect on consumer welfare or consumer surplus.[4] The value of innovation is thus quantified in terms of how much worth consumers perceive in that innovation. An advantage of using consumer welfare as the measurement unit is that in principle, welfare directly captures the innovation benefits enjoyed by consumers. While this paper is interested in consumer benefits, producer welfare can also be estimated by incorporating additional information on the cost side of the analysis.

This paper is concerned with the welfare measurement of product innovations. The literature on this topic was recently developed with the advancement in demand estimation techniques. Among them, the discrete choice model proposed by McFadden (1982) provides significant contributions to this field. In contrast to product innovation, an alternative type of innovation is called process innovation — the innovation type on which past literature has predominantly concentrated. Process innovation is often regarded as being easier to deal with, because it can be assessed by the shifts in production or cost functions. Further the estimation techniques for process innovation are already well established in economics (for a recent study, see Nakamura and Ohashi, forthcoming).

As Bresnahan and Gordon (1990, Chapter 1) note, the distinction between product and process innovations is not as simple as it sounds in the case of many innovations. For example, when people consider computers to be a revolutionary invention that was unavailable in the past, computers would no doubt be classified as a product innovation. However, when people realize that computers are a cheaper version of the combination of a calculator, typewriter, and day planner, they are more likely to be categorized as a process innovation. The analytical method appropriate to quantify consumer gains from an innovation based on whether researchers consider the innovation as a process innovation or a product innovation. In the rest of this section, using the example of video cassette recorders (i.e., VCRs), we intuitively describe how the method for measuring consumer gains differs depending on the type of innovation. The discussion provided below is similar to that in Bresnahan and Gordon (1990); moreover technical details and data are available in Ohashi (2003, a, b).

Today's VCRs were invented by Japanese firms, whose basic technology came from the United States. [5] The Japanese succeeded in applying this foreign technology to home use in the 1960s. There were two different and incompatible formats: Betamax (invented by Sony) and VHS (by JVC).[6] VCRs are considered to perform two main functions: (1) watching prerecorded tapes, such as movies, and (2) time shifting. The first function may result in VCRs being regarded as a process

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4 We use the terms "welfare" and "surplus" interchangeably.

5 This paper focuses on tabletop VCRs, which are placed close to a television and are not designed to be moved around. In addition, there were three other types of VCRs that are more or less connected to video photography, portable-type VCRs, dockable or convertible VCRs, and camcorders (short for "cameras-cum-recorders").

6 Betamax and VHS were not the only formats in the worldwide VCR markets. Ohashi (2002) discusses the V-2000 format, which was popular in Europe.

innovation, because VCRs are thought to reduce the hourly cost of watching movies. Conversely, the second function could result in VCRs being classified as a product innovation, because there were no other devices that allowed people to "shift time" for watching TV programs.

Let us first consider VCRs as a process innovation, and describe how to quantify consumer welfare from such inventions. Figure 1 shows how the advent of VCRs generated consumer welfare. It is reasonable to assume that the consumers' demand for prerecorded tapes (mostly movies) is unchanged if we hold that with the introduction of VCRs consumers' tastes in movies remained unaltered. Thus, the invention is represented by a downward shift in the supply curve, which reflects the cost of providing movies to consumers. The introduction of VCRs presumably lowers the delivery cost of movies for movie distributors. The downward shift of the supply curve lowers the equilibrium price of watching movies from P_0 to P_1, as shown in Figure 2. [7] Consumer welfare prior to the invention is denoted by the horizontally shaded area. Thus, consumer gains from after the advent of VCRs are represented by the vertically shaded trapezoid area.

Undoubtedly, the magnitude of shift in the supply curve relies on the number of rental video shops within easy reach of consumers. If the rental shops are far fewer in number than the movie theaters, the entertainment supply curve would not shift to such an extent in Figure 1. It is often the case that inventions provide useful services when combined with other inputs complementary to them. Bresnahan and Gordon (1990) list three types of complementary technology that help diffuse the inventions: market-supplied complements, social infrastructure, and changes in people's practices. Although the availability of these complementary technologies is not explicitly considered in this figure, it is implicitly taken into account in the assessment of consumer gains from the innovations.

We now turn to consider the case where VCRs are categorized as a product innovation. When the VCRs were introduced in 1975, their main use was regarded as recording TV programs that were on air and replaying them at a more convenient time for users. [8] This time-shifting function can be considered as a revolutionary innovation that no other previous technology could matched.

How can we formulate this aspect of product innovations? It is important to notice that a revolutionary invention is unique in that it lacks any substitute in existing technologies. The notion of product substitutability can be translated into the slope of a consumer demand curve for a particular invention. If a product is a perfect substitute for an existing technology, its demand curve is nearly flat, so that suppliers of such a product are unable to exercise market power. As an

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[7] Perfect competition is assumed in Figure 1, an assumption that is trivial to our discussion here.

[8] This is the reason why Universal Studios and Walt Disney Productions filed a lawsuit against Sony in 1976. The studios charged that any taping and replaying of TV programs was a form of copyright infringement, and contended that "Sony, Sony's advertisement agencies, and several retail chains selling Sony VCRs were at fault, since they produced and sold the equipment that was used to violate the studios' copyright by taping movies and other material" (cited from Ohashi, 2003).

invention becomes a poor substitute for existing goods because of its innovativeness, the demand curve for such an invention becomes steeper, and consumer gains emerge at a given level of price, P_2, as is indicated by the shaded area in Figure 2.

Intuitively, the view presented in Figure 1 emphasizes the similarity of the VCR to existing goods, while that in Figure 2 emphasizes the differences between them. In the former view, we must quantify the extent of the fall in prices, represented by the downward shift of the supply curves from S_0 to S_1. This task is not trivial as it requires the evaluation of the role of other technologies that are complementary to VCRs. In the latter view of product innovation, we can consider the introduction of VCRs as a new item in the utility function, because VCRs are considered to be unique. In principle, if we can correctly identify both the shift of the supply curves in Figure 1 and the slope of the demand curve in Figure 2, consumer welfare calculated by the above two approaches must produce the same result. In the next section, we concentrate on the second approach for evaluating product innovations, and describe analytical methodology to quantify consumer welfare.

Section 3. Methodology to Quantify Product Innovations

In this section, we present the methodology to quantify consumer gains from product innovation, which is illustrated in Figure 2. We employ the model of consumer behavior in the product characteristics space. Product innovation can be considered as a new addition to the existing choice set of products, or an improvement in the characteristics of existing products. Thus, the model presented in this section should be able to explicitly describe what choice set the consumer is faced with and how the consumer perceives product characteristics. The characteristics approach, originally proposed by Lancaster (1966) and developed by Trajtenberg (1990) and Berry (1994), provides a means to model a product as a group of characteristics that directly enter into the utility function of consumers. In the reminder of this section, following Ohashi (2003, b), we briefly describe the model and discuss how the characteristics approach helps us identify consumer gains from innovations. We also present a selective survey of the literature that employs this approach to estimate consumer gains from innovations, and discuss the limitations of this approach.

Section 3.1 The Analytical Framework

In order to evaluate the extent of consumer welfare gained from innovations, we need to model the consumer purchasing behavior of a particular invention, and model a mechanism through which product characteristics contribute to consumer welfare. Considering the example of VCRs from the previous section, we follow Ohashi (2003, b) and describe consumer purchasing behavior in the case of VCRs. Suppose that the consumer is the purchasing entity, and consumer i is assumed to

maximize utility by choosing brand j from among M alternative VCR brands at time t. When the consumer purchases brand j, the consumer obtains utility from a vector of product characteristics, $s_{j,t}$. This vector is composed of price, $p_{j,t}$, and brand j's attributes, $x_{j,t}$. That is, $s_{j,t} \equiv (p_{j,t}, x_{j,t})$. Ohashi (2003, b) uses five attributes in x_j: the number of programs times preset in a VCR: the number of days in advance a VCR model could memorize preset program times, the availability of remote controls, and the indicators of audio and sound quality. In the characteristics approach, a consumer is assumed to maximize its utility by choosing a bundle of characteristics from among $S_t \equiv (s_{1,t}, s_{2,t}, \ldots, s_{M,t})$.

In the above analytical setup, product innovation that occurred at time t can be considered as changes in the characteristics space from S_{t-1} to S_t. This change in the characteristics space may be caused by the introduction of a new invention (i.e., an expansion in the dimension of the characteristics space) or the improvement of the existing characteristics. In any event, consumer gains from the product innovation, denoted by ΔW_t, can be represented as follows:

$$\Delta W_t \equiv W(S_t) - W(S_{t-1}) \qquad (1)$$

Thus, once we know the property of W, we should be able to quantify consumer welfare gains from product innovation. For example, using the argument of Trajtenberg (1990), when we suppose that marginal utility from consuming the characteristic, $x_{j,t}$, is β_j, ΔW_t is given by

$$\Delta W_t = \Sigma_j \beta_j [x_{j,t} - x_{j,t-1}] \qquad (2)$$

Hence, according to equation (2), all we need to know is the marginal utility coefficients, β_j, where j=1, …, M, and the data on $x_{j,t}$, and $x_{j,t-1}$ reveal the value of ΔW_t. The coefficients, β_j, can be estimated using two methods: one method is based on stated preference and the other on revealed preference (For a survey, see Louviere et. al., 2003).

The stated preference method involves asking respondents the weights they perceive on β_j. This method is often used in the field of pharmaceutical medicine through the use of questionnaires. On the other hand, the revealed preference method uses market data, such as that of prices and quantities sold, which are generated by the actual behavior of consumers and producers. Both methods possess advantages and disadvantages. The former method allows researchers to flexibly accommodate the content of questions, in that they directly, even qualitatively, ask the consumers their perception of a particular invention. However, the answers from the respondents are subjective and may be vulnerable to how the questionnaire is constructed. Although the revealed preference method is free from the criticisms of the former approach, it requires us to impose modeling assumptions to retrieve information on consumer welfare from the market data.

Section 3.2 A Selective Literature Survey

The estimation of demand and welfare functions from the revealed preference data is an active area of economics. In particular, the discrete-choice model, developed by McFadden (1981), allows researchers to incorporate the characteristics approach in demand estimation. The discrete-choice model escapes the "dimensionality problem" and curbs the number of estimated parameters even with an increase in the number of brands available to consumers in the choice set. The model also allows us to deal more appropriately with the "endogeneity problem" in the price coefficient; lacking appropriate controls for endogeneity in prices, we tend to overestimate the slope of the demand curve. In the extreme case, as is reported in the study of CT scanners by Trajtenberg (1990), we observe an upward sloping demand, if this problem is not controlled for. For the sake of brevity, we leave the development of a theoretical foundation and estimation methods for the discrete-choice model to others. For survey, see, for example, Anderson, et. al (1992) and Train (2003).

Using estimates from demand models, many of which are based on the discrete-choice model, many recent papers quantify consumer welfare from innovations. To name a few, consumer gains from the introduction of satellite TVs are assessed to be 2.5 billion USD per year (Goolsbee and Petrin, 2004); the advent of mobile phones generated an annual consumer welfare amounting to 24 to 49 billion USD (Hausman, 1999); Further, the invention of the minivan generated 2.9 billion USD worth of consumer welfare (Petrin, 2003).

A limitation of this approach, highlighted by the above papers, is that by concentrating attention on the evaluation of changes in S_t from that of the previous period, we cannot incorporate the spillover effects. Indeed, in the case of VCRs, as the use of this invention became increasingly common among consumers, it should have benefited manufacturers of video cassettes and the movie industry. It may have also affected the sales of other entertainment goods, such as books, because households who used their VCRs frequently must have reduced the time they could use to entertain themselves. Although it is very difficult to obtain information on the spillover effects, we need to recognize such shortcomings of the approach when we assess consumer gains from innovations based on this method.

Section 4 Conclusion

This paper provided a conceptual framework to quantify consumer gains from product innovations. Using the example of VCRs, we presented an overview of the diagrammatic and analytical methods that are useful to measure consumer welfare, and describe what data is to be used for the analysis. We also made a selective survey of the papers that measure the consumer welfare of product

innovations and discussed the advantages and limitations of the conceptual framework.

Due to the technical difficulty and uncertainty with regard to the robustness of obtained estimates, the method introduced in this paper has not been well recognized. Therefore, the use of this method has not been widespread among researchers who study innovation policy. In the meantime, the policy needs to quantify the mounting outcome of innovations across nations. Although we are unable to assess the benefits to the academic and policy circles accrued by the adopting of the method for quantifying consumer welfare, there is no doubt that the method presented in this paper casts a new light on our discussions on innovation policy.

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Figure 1
Measuring Value of Innovation:
Repackaging Existing Product Attributes

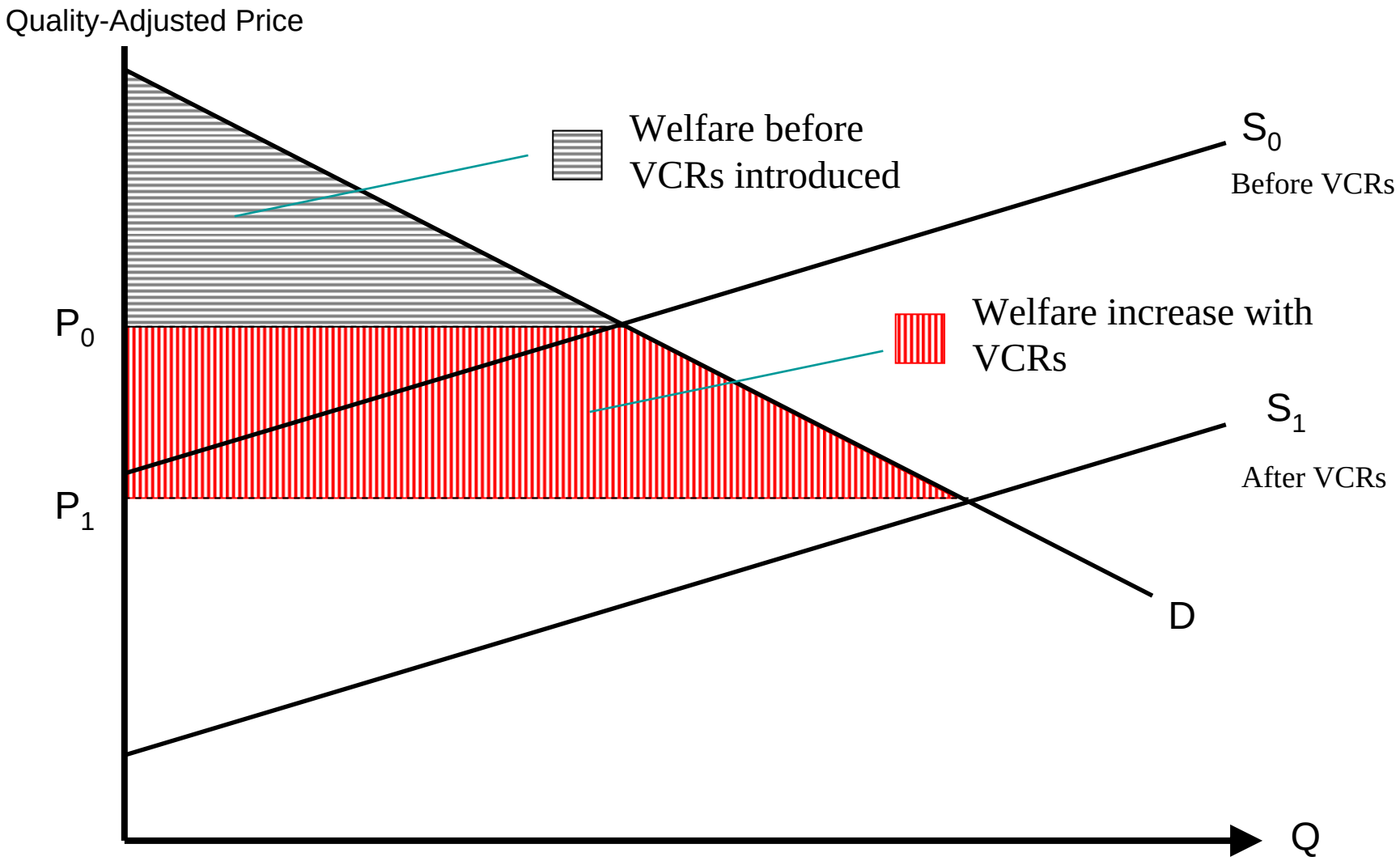

Figure 2
Measuring Value of Innovation:
Introducing Fundamentally New Attributes