Section 1. Introduction: How to Consider Value of Innovations

Innovations are at the heart of economic progress. Innovations improve the way we live and work, and allow us to maintain the current quality of life at less expense. Many scholars have been interested in measuring the magnitude of the social gains created by innovations. One conventional index 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 are supposed to be served as a useful signal regarding the extent to which innovation outcomes contribute to improving our welfare-being. The standard definition of 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 tackle with a counter-factual question: how much would we perceive the quality of our life changed, if the innovations were removed from our society? 1

In an attempt to answer such a counter-factual question, we present in this paper a conceptual framework for measuring consumer gains from innovations. For the sake of saving space, the paper solely focuses on a particular type of innovations --- product innovations --- and quantifies their economic benefit on consumer well-being. 2 The paper thus leaves the other type of innovations --- process innovation --- to other papers in the literature.

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

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1 Alternatively, we can ask: what would have happened to our utility, if innovations accessible to us today had been available before?
2 As we discuss in Section 2, the distinction between product and process innovations is not as clear as it appears.
to the society in the downstream stage. A majority of the existing studies, in the area of bibliometrics for instance, has intensively examined summary statistics of the upstream indices, including scientific papers, patents and their citations. These studies have indeed provided useful insights to our understanding of, say, the relationship between the amount of research & development expenditure and the number of patents in the upstream innovation activities. In view of our interest in quantifying social gains from innovations, however, these output indices examined in the existing studies should rather 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 to assess the value of innovation outcomes benefited to our society. In this paper, we instead concentrate on directly estimating social gains from commercially successful innovation generated at the downstream activities.3

To do so, this paper adopts a concept from welfare economics, and assumes that the magnitude in the benefit of innovation be defined by effect on welfare in monetary terms. In other words, we assess the value of innovation in terms of the extent to which consumers perceive the innovation worth, namely how much 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 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 the 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 which allows us to assess the economic benefit of innovation. 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 innovation; the one is to focus on “similarity” of innovations to existing technologies, and the other is to emphasize on “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 laying down a theoretical model and discuss how to implement the framework described in the previous section. We illustrate the importance of analyzing the consumer behavior in the evaluation of the consumer gains from innovation, and introduce an analytical framework that investigates consumer behavior. The model

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3 Since Innovations that fail to be introduced in the market do not reach to our society, they are outside the scope of the paper. In this sense, our measure of social gains from innovations is conditional on the existence of commercially-successful innovation.
of consumer transaction behavior, called demand function, provides a convenient tool to construct consumer welfare, and enables us to quantify the economic benefit of consuming innovative outcomes. A number of studies in the area of industrial organization uses the consumer behavior model and calculate welfare gains. We make a selective survey of such literature, and discuss the advantage and disadvantage in using such models. We conclude the paper in Section 4.

Section 2. Welfare Gains from Innovations: Diagrammatic Approach

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

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 magnitudes of innovations occurring in different product, say video cassette recorders and computers. In the field of economics, innovation is usually considered as an increment to the stock of knowledge available to society. This additional knowledge makes it possible to improve the quality of existing goods and services available to the society at lower prices. Therefore, the measurement unit of innovations is presumably linked to “economic value” (namely, a shadow price in the economics term) of the additional knowledge to the society. It is however 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 of economics of innovations. For example, one approximates the economic benefit of innovations by using the counts of respective patents, citations, and scientific publications, related to the innovation under focus. Another approximates the benefit from innovations by simply measuring changes in characteristics available to products introduced by innovations. For example, if a new model of automobiles doubles the maximum horse power available to the existing models, the latter group considers the change in horse power as the social gain from innovations. Unfortunately, since innovations exhibit considerable variances in their economic and technological significances, none of these proxies would be sufficient as measurement unit in assessing the benefits of innovations. As we discussed in the previous section, the measures often used in bibliometrics are not directly linked to the outcome measure at the downstream innovation activities. By the same token, the changes in the product characteristics may not be a good measure for consumer gains: For example, doubling automobile horse power would not be appreciated by people in Tokyo where streets are often congested and strict speed limits are enforced.

In this paper, we take an alternative method adopted from welfare economics, and assume that the
magnitude in the benefit of innovation be defined by the effect on consumer welfare, or consumer surplus.\(^4\) The value of innovation is thus quantified as how much worth consumer perceives the innovation. An advantage in using consumer welfare as the measurement unit is that the welfare, in principle, directly captures the innovation benefits enjoyed by consumers. While this paper is interested in the consumer benefits, one can also estimate the producer welfare as well, by incorporating additional information on the cost side in the analysis.

This paper is concerned with the welfare measurement of product innovations. The literature on this topic has recently been developed with the advance in demand estimation techniques. Among them, the discrete-choice model proposed by McFadden (1982) provides significant contributions to the field. In contrast to product innovations, the alternative type of innovation is called process innovation, the innovation type on which the past literature has predominantly concentrated its research effort. Process innovation is often regarded as easier to tackle with, because this innovation can be assessed by shifts in production or cost functions, the estimation techniques of which 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 are not as clear as it sounds for many innovations. To take an example, when people think that computers are a revolutionary invention not available in the past, computers would no doubt be classified as product innovation. However, when people view that computers are a cheaper version of a combination of calculator, typewriter, and day planner, computers are more likely to be categorized as process innovation. The analytical method appropriate to quantify consumer gains from the innovation differs upon whether researchers view innovation as process innovations or product innovations. In the rest of the section, using an example from video cassette recorders (i.e., VCRs), we describe intuitively how the method of measuring the consumer gains differs by the type of innovation. The discussion provided below is similar to that made in Bresnahan and Gordon (1990), and 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 the 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 as being equipped with two main functions; (1) watching pre-recorded tapes, such as movies, and (2) time shifting. The first function (1) may be considered to make the VCRs as process innovation, because the VCRs are thought of reducing the hourly cost of watching

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\(^4\) We use the terms, “welfare” and “surplus,” interchangeable.

\(^5\) This paper focuses on tabletop VCRs, which sit close to a television and are not designed to be moved around. In addition, there were three other types of VCRs more or less connected with 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 worldwide VCR markets. Ohashi (2002) discusses the V-2000 format, popular in Europe.
movies. On the other hand, the second function (2) could make VCRs as product innovation, because there had been no other devices that had allowed us to “shift time” of watching TV programs.

Let us first take a view that VCRs are categorized as process innovation, and describe how to quantify consumer welfare from such invention. Figure 1 presents how the advent of VCRs generates the consumer welfare. It is reasonable to assume that consumer’s demand for pre-recorded tapes (mostly movies) is unchanged if we consider that the introduction of VCRs remained consumer’s tastes for movies unaltered. Thus, the invention is represented by a downward shift in the supply curve, which reflects the cost of providing movies for consumers. The introduction of VCRs presumably makes the delivery cost of movies much cheaper for movie distributors. The downward shift of the supply curve lowers the equilibrium price of watching movies as shown in Figure 2, from \( P_0 \) to \( P_1 \). Consumer welfare prior to the invention is denoted by the horizontally shaded area. Consumer gains from the advent of VCRs are thus presented by the vertically shaded trapezoid area.

Of course, the magnitude of shift in the supply curve relies on the number of rental video shops within easy reach to consumers. If the rental shops are far fewer in number than the movie theaters, the entertainment supply curve would not shift that much in Figure 1. It is often the case that the inventions produce useful services when combined with other inputs complement to the inventions. 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 the figure, it is implicitly taken into account in the assessment of consumer gains from the innovation.

We now turn to consider the case where VCRs are categorized as product innovation. When the VCRs were first rolled out in 1975, the main use of VCRs was regarded as recording TV programs on air, and replaying them when they were at convenient time for users. This time-shifting function can be considered as a revolutionary innovation that no other previous technology 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 substitution to existing technologies. The notion of product substitutability can be translated into the slope of consumer demand curve for a particular invention. If a good is a perfect substitute to the existing technology, its demand curve is nearly flat, so that suppliers of such good should not be able to exercise market power. As the invention

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7 Perfect competition is assumed in Figure 1, the assumption which is trivial to our discussion here.
8 This is the reason why Universal Studios and Walt Disney Productions brought the 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 changes selling Sony VCRs were at fault, since they produced and sold the equipment that was used to violate the studio’s copyright by taping movies and other material.” (cited from Ohashi, 2003).
becomes poorly substitutable to existing goods because of its innovativeness, the demand curve for such 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 stresses the similarity of the VCRs to the existing goods, while that in Figure 2 stresses the differences between them. In the former view, we must quantify the extent of the fall in prices, represented by the downward shift of supply curves from $S_0$ to $S_1$. This task is not trivial, as it requires evaluating the role of other technologies complement to VCRs. In the latter view of product innovation, we can think of the introduction of VCRs as the new item in the utility function, as VCRs are considered to be unique. In principle, if we can correctly identify both the shift in 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 of 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 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 improvement in the characteristics of existing products. Thus, the model presented in this section should be able to describe explicitly what choice set the consumer faces 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 way to model a product as a bundle of characteristics that enter directly in the utility function of consumers. In the rest of this section, following Ohashi (2003, b), we briefly describe the model and discuss how the characteristics approach helps us identify the consumer gains from innovations. We also present a selective survey of the literature that employs this approach to estimate the consumer gains from innovation, and discuss limitations of the approach.

Section 3.1 The Analytical Framework

In order for us to evaluate the extent of the consumer welfare gained from innovation, we need to model the consumer purchasing behavior of a particular invention, and model a mechanism through which product characteristics contribute to the consumer welfare. Taking from the example of VCRs from the previous section, we follow Ohashi (2003, b) and describe the consumer purchasing behavior of VCRs. Suppose that the consumer is the purchasing entity, and consumer $i$ is assumed to
maximize its utility by choosing brand $j$ among $M$ alternative VCR brands at time $t$. The consumer utility function, when the consumer purchase brand $j$, consists of 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, $s_{j,t} = (p_{j,t}, x_{j,t})$. Ohashi (2003, b) uses five attributes in $x_{j}$: the number of programs times preset in a VCR; the number of days ahead a VCR model could memorize preset program times; availability of remote controls; and indicators of audio and sound qualities. In the characteristics approach, a consumer is assumed to maximize its utility by choosing a bundle of characteristics among $S_t \equiv (s_{1,t}, s_{2,t}, \ldots, s_{M,t})$.

In the above analytical setup, product innovation occurred in 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, the consumer gains from the product innovation, denoted by $\Delta W_t$, can be written as:

$$\Delta W_t = W(S_t) - W(S_{t-1}) \quad (1)$$

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 $\beta_j$, $\Delta W_t$ is given by:

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

Hence, according to equation (2), all we need to know is the marginal utility coefficients, $\beta_j$, where $j=1, \ldots, M$, and the data on $x_{j,t}$ and $x_{j,t-1}$ tell us the value of $\Delta W_t$. The coefficients, $\beta_j$’s, can be estimated by two methods; one method is based on stated preference, and the other based on revealed preference (See for survey Louviere, et. al., 2003).

The stated preference method is to ask respondents what weights they perceive on $\beta_j$’s. This method is often used in the area of pharmaceutical medicine, through the use of questionnaire. On the other hand, the revealed preference method is to use the market data, such as those of prices and quantities sold, which are generated by the actual behaviors of consumers and producers. Both methods possess advantages and disadvantages. The former method allows researchers to flexibly accommodate the content of questions such that they directly ask, even qualitatively, the consumer perception on a particular invention, while the answers from the respondents are subjective and may be vulnerable to how the questionnaire is constructed. Although though the revealed preference method is free from such criticisms on the former approach, it requires us to impose modeling assumptions to retrieve the information on consumer welfare from the market data.
Section 3.2 A Selective Literature Survey

Estimation of demand and welfare functions from the revealed preference data is an active area of economics. In particular, discrete-choice model, originated by McFadden (1981), allows researchers to incorporate the characteristics approach in the demand estimation. The discrete-choice model escapes the “dimensionality problem,” and curbs the number of estimated parameters even with the increase in the number of brands that consumers face in the choice set. The model also allows us to deal with more appropriately 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 his study of CT scanners in Trajtenberg (1990), we observe an “upward” sloping demand, if not controlling for this problem. To save space, we leave to other work a theoretical foundation and estimation methods of the discrete-choice model. See, for example, Anderson, et. al (1992) and Train (2003), for survey.

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

A limitation of the approach illuminated from the above papers is that, by concentrating attentions on the evaluation of changes in $S_t$ from the previous period, we cannot incorporate the spillover effects. Indeed, in the case of VCRs, as the invention diffused across consumers, the VCRs should have been benefited to manufacturers of video cassettes and the movie industry. It may have also cost the sales of other entertainment goods, such as books, because households who spent more time on VCRs must have reduced the time to entertain themselves. Though it is very difficult to obtain information on the effects of spillovers, we need to recognize such shortcomings of the approach when we assess the consumer gains from innovation based on this method.

Section 4 Conclusion

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

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

References
Figure 1
Measuring Value of Innovation:
Repackaging Existing Product Attributes

Quality-Adjusted Price

Welfare before VCRs introduced
Welfare increase with VCRs

Before VCRs
After VCRs
Figure 2
Measuring Value of Innovation: Introducing Fundamentally New Attributes

Quality-Adjusted Price

Welfare with VCRs

Demand for invention that perfectly substitutes to existing goods

Demand for invention that poorly substitutes to existing goods