Measuring Quality Change due to Technological Externality in Multi-Feature Service Bundles

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Abstract

Technological innovation, externalities and network effects keep shifting the preference parameters in cellular telecommunication service sector. The paper suggests a framework to model these changes.It notes two channels that affect the service prices (in possibly opposite ways). In each corresponding period, consumer with lower reservation prices are shopping for the services. But these reservation prices are going up due to complementarity/ network-effects. Under some reasonable assumptions on industry and cost structure, market data can be used to identify these changes.

A price index is suggested that decomposes service bundle price changes into the change in price for same-quality of service and change in quality of the service bundle. Some interesting properties of these indexes are also discussed.

1 Introduction

Service bundling is pervasive specially in high-tech sector. While explanations for this trend vary, there is no argument about its importance. Bundling can be a result of monopolist trying to price discriminate (Adams and Yellen, 1976 [1]) who wants to reduce the variance in buyers' valuations (Schmalensee, 1984 [12]) or it can be due to sector specific economic factors (Bakos and Brynjolfsson, 1999 [3]). There are papers talking about optimal bundling strategies i.e. whether complements or substitutes should be bundled (Venkatesh and Kamakura, 2003 [9]).

However, recognition of the fact that these service bundles represent useful *economic information* is missing from most of these literature or very less emphasis is put on importance of examining the composition of service bundles.

One important distinction with high-tech products and services is that most of the features bundled in the services are *complements* of each other. Then bundling becomes more of a requirement rather than a restriction from consumer's point of view. Imagine people having to buy caller-id, voicemail, call-waiting etc. separately and then consuming them. Consumers will have to bundle *all* of these anyways to enjoy *any* of these. I call them *technical bundles* or natural bundles compared to optional or forced bundles where a consumer may enjoy the contents of bundle separately as well (e.g. mobile internet browsing). So what do the composition of service bundles tell us? First it is indicative of the preference structure and technology of that sector. Any cellular service provider will not package music and games download portal without internet/ data plan (these are technical bundles). Similarly each bundle is targeted toward a particular section of consumers e.g. family package, student packages etc. This is because value of each feature in the service bundle is different for different customers. Thus looking at the available bundles should also inform us about the distribution of consumer preferences.

How about the prices? Apart from papers treating bundling in the context of monopoly pricing, there is a really rich branch of literature involving product differentiation or discrete choice approach. Products are considered a set of characteristics and consumers buy one of them depending on their taste and other parameters (Berry, Levinsohn and Pakes, 1995 [4]). One can derive implicit feature-prices which are reflective of consumer's valuation of each feature and cost structure of production process (Rosen, 1974 [11]).

But if these implicit prices represent what I call *inherent value* of a feature, then changes in these prices should be treated as **changes in preference parameters** (to some extent, because these prices could also change due to changes in supply side/ cost structure). This is a fact which not many are willing to accept and even fewer are trying to work on it.

This paper deals with this type of *inherent quality change*. Same set of features (i.e. same data plan) gives more utility in the corresponding period due to some externality (i.e. availability of Google Search for mobile), then optimal allocation will have consumer increase their consumption of data transfer. But this kind of externality and resulting substitution might happen *with-in* service itself (i.e. between features). For example availability of video and audio content makes consumer valuation of Sound and Video card go up. The bundle composition and price will change (in later periods) to reflect these changes.

The problem with current papers on hedonic regression is that quality is regarded mostly as *quantity of features*. I admit that the literature on 'exact' hedonic price indexes (Feenstra, 1995 [6]) discusses how to compare costs of attaining the 'same utility' in two periods. But it talks more about changes in characteristics' value due to bundle-composition changes. For example value of Data plan is higher for the corporate Blackberry users. That concept is more like what I call **Usage Profile**. But what about change in the *unit value of feature* itself (in all kind of bundles) i.e. the increase in utility for a particular feature due to technological innovation and other externalities? I admit that this line of thinking implies that preference parameters are changing over time and that is an area which involves many other issues. That is why the papers (on 'exact' hedonic price index) employ Random Utility model or involve dealing with distribution of preferences over characteristics and as a result end up being too complicated to solve without making many assumptions. But that should not deter us from finding easier ways to look at this issue. We can not ignore it altogether specially in high-tech sector where pace of innovation has been (and probably will be) is remarkable.

The above issue is also important in the context of productivity analysis. Papers suggest accounting for high-tech input good's characteristics (Triplett, 1996 [13]), but that is just the first step. Treating productivity of these features as constant is unrealistic assumption since the industry is innovating at very fast pace. As an example if we are studying productivity of computer as an input, then in consecutive periods software may be becoming more period compared to hardware due to increase in software quality or other technological factors. Hence, increase in productivity of few features (relative to others) and increase in overall productivity (that pertains to all the features) should be identified properly to account for increasing the measurement efficiency and crediting the proper sub-input (e.g. computer software)

In cost-of-living CPI, hedonic regression coefficients (or implicit feature prices) represent not only consumer's valuation but also the cost parameters. Disentangling this classical simultaneity problem requires strong assumption on industry and cost structure. But fortunately, services are different from goods. One can not create the services in advance and store them in inventories (Hill, 1999 [8]). Most of the production process is instantaneous. In high-tech service sector where production is just the capacity utilization (fixed cost), under some assumptions on the industry structure these regression coefficients along with service composition have a relationship that is useful for price statisticians.

The paper combines the ideas of normalization(Diewert, 2001 [5]) and hedonic imputation method to develop *projection approach* for creating equivalent-quality price index.

Another implication that comes out of this paper (which has been stressed many times) is the need to have more than one index to fully understand the changes in *cost-of-living* between periods. If we say that quality-adjusted price of a mobile service plan has gone down by 10% compared to 2 yrs ago, we are not telling that an average service plan now has four time as much SMS and we are also not telling that a same service plans give 15% more utility now because of proliferation of numerous mobile websites and applications.

2 Consumer Optimization

I use the setup that is typical in hedonics and bundling literature. There is a good X and service bundle S which comprises of (N+1) features $[F_0, F_1, F_2, ..., F_N]$. Consumer gets utility from consuming X and features $F_0, F_1, ..F_N$. Utility function follows usual assumptions.

There are M such service bundles with *service composition matrix* Q_S.

Preference for X does NOT change due to any externality or network effects. We could think of X as a composite good that represent items required for subsistence e.g. food etc. There is *Quality Neutral* Feature F_0 which is also immune from externalities.

Another addition compared to usual models is that one of the features is brand name. It represent prestige, product reliability perception, friendliness of support staff and other non-measurable features.

Consumer's problem can be written as -

$$max_{s,x}\, U(f, x) \;\; s.t. \;\; P.s + x \leq I \;; s.Q_S = f \tag{1}$$

In equation 1 above, P is the price vector for service bundles (in terms of good X) and f is the feature vector. We can rewrite the problem as that of choosing the features directly.

$$max_{f,x}\, U(f,x) \;\; s.t.\; P.(Q_S)^{-1}.f + x \leq I \tag{2}$$

The budget constraint above is obtained by [1] substituting s from second constraint in equation 1.

If we treat $P.(Q_S)^{-1}$ as *implicit price vector* β, then optimization problem in equation 2 becomes usual utility maximization.

First Order conditions imply that following should hold -

$$\frac{\frac{\delta U}{\delta f_0}}{\frac{\delta U}{\delta x}} = \beta_0 \tag{3a}$$

$$\frac{\frac{\delta U}{\delta f_i}}{\frac{\delta U}{\delta f_j}} = \frac{\beta_i}{\beta_j} \tag{3b}$$

Equations 3 denote the two wedges consumer uses to shifts his allocation.

1. **Inter-sector substitution** is shown in equation 3a. It has nothing new. A reduction in β_0 will result in consumer buying more of feature 0.

2. **Intra-sector substitution** is guided by equation 3b. This is the channel by which changes in utility due to externality end up being reflected as changes in the service composition. Suppose that due to some technical innovation, each unit of feature i consumed starts giving more utility (i.e. utility function shifts up in f_i). Then even in the absence of relative implicit price change (i.e. $\frac{\beta_i}{\beta_j}$ constant) consumer will want to increase his consumption of feature i (to achieve optimal allocation).

Continuing the scenario above, assume that consumer was buying some quantity of one of the service bundles whose feature composition exactly matched his optimal allocation (actually it just has to be in the same ratio). Now think what happens if there are some costs involved in changing the feature composition to its new optimal values. If producer can just change the prices such that increase in $\frac{\delta U}{\delta f_i}$ is offset by corresponding increase in β_i , then consumer's optimal allocation remain the same (or in same ratio) as in the bundle being offered.

[1] It is implicitly assumed that Q_S can be inverted

2.1 Preferred-Bundle Surfaces

Equation 3b imply that for each value of f_0 there is a vector $[f_1, f_2, ...f_N]$ that consumer would like to buy. It means that in N+1 dimension space there are surfaces (set of vectors) which represent consumer's optimal allocation or preferred bundles.

Till now, I have put no restrictions on which services (or how many of them) can consumer buy. As is typical in models of discrete choice/ product differentiation), I assume that consumer buys only one of the services and their is consumer heterogeneity.

This heterogeneity is along two lines. First is in their **brand affinity**. Second is in their **usage profile**. Brand affinity is that everything else being equal, consumer values one brand more than other. To be more concrete, assume that he gets some extra utility from consuming his favorite brand (and nothing extra if consuming bundle from someone else).[2] Consumer's usage profile is related to his preference for different features and the technology of the sector. e.g. for cellular service plan the consumer could be a student (gives more value to the SMS), a business person (more value to the emails/ data plan)or a family person (calls are more important).

Modeling of brand as a feature of product itself makes all introduces the product differentiation without the complexity of *vertical* and *horizontal* features. If brand feature have a low feature-price, then they are like horizontal feature. This is a different and more flexible approach than using a 'brand intensity' parameter (Perloff and Salop, 1985 [10]). For example if brand prices for HP and DELL are quite close for a consumer, these are horizontal features for him (i.e. brand intensity is low), but if for Apple he has strong liking meaning brand-price is higher then it is a vertical feature for him (i.e. brand intensity is high OR not easily substitutable).

The concept of *marginal value of a characteristic in a good* (Feenstra, 1995) is same as consumer heterogeneity between different usage profiles.

With this kind of setup, the feature space will have multiple 'preferred bundle-surfaces'. Producers offer services by bundling these features together, which is equivalent to positioning their products in the feature space.

2.2 Choosing among non-optimal bundles

Applying the spatial competition concept to features space (actually the multi-dimensional version) there is a literature on *address* models (Archibald,

[2]This will increase the dimension of feature space due to these dummy brand features. But since most of the high-tech service industry have only 3-4 players, I think this should not be an issue.

Eaton and Lipsey, 1982 [2]). Most of these either derive consumer demand by assuming that consumer chooses the product that is 'nearest' to his preferred choice or minimizes the *distance* (Fixler and Zieschang, 1992 [7]). This is obvious in one dimensional space, but in multi-dimensional it is not that straight-forward. Since consumer does not value each feature same, there is no reason why distance from his preferred location in each dimension should be treated the same.

A more appropriate concept will have the utility maximized among the available non-optimal choices. That is to have the utility as close to optimal-bundle utility as possible.

If we assume that U(f,x) is separable in u(f) and u(x). Then using first order Taylor series approximation for u(f) around optimal bundle f*, we get -

$$u(f) = u(f^*) + \frac{\delta u(f^*)}{\delta f}.(f - f^*) \tag{4}$$

This can be rewritten using the first order conditions as -

$$u(f) - u(f^*) = (\frac{\frac{\delta u}{\delta f_0}}{\beta_0}).[\beta.(f - f^*)] \tag{5}$$

Equation 5 is the loss function that consumer tries to minimize when choosing among non-optimal bundles. Now if we define $\tilde{\beta} = [1, \frac{\beta_1}{\beta_0}, \frac{\beta_2}{\beta_0}, ..., \frac{\beta_N}{\beta_0}]$, then above can be re-written as -

$$u(f) - u(f^*) = (\frac{\delta u}{\delta f_0}).[\tilde{\beta}.(f - f^*)] \tag{6}$$

This objective function 6 shows the two substitution wedges we discussed earlier.

Consumer optimizes in two ways. First is between other good and bundled service (appears as term $\frac{\delta u}{\delta f_0}$). Once given that (i.e. deciding how much to spent on bundled service compared to other good), he chooses a bundled based on relative implicit prices (or relative valuations, if we think producer is a monopolist charging the value of each feature).

This is one of the main point this paper makes. Income share spent on a particular service bundle tells how consumer values that service compared to other goods. But service bundles offered in the market tell us about the relative value he puts on each of the feature with-in the service bundle (using prices and feature composition data).

Why do we need to treat two substitutions differently (one between good and service and second one between features within the service). There are two main reasons. I have already discussed one of them which is the pace of innovation in high-tech service sector and externalities effecting the utility each period. Because of this the market data does not only represent the substitution due to price changes, but also reflects the changes in **inherent value** of single unit of various features due to innovation. The other reason has to do with our ability to extract any meaningful information from market data. In reality we do not observe consumer's valuations for each feature. So unless we make some strict assumption on cost and industry structure, it is hard to claim that hedonic regression coefficients (or implicit prices) represent these valuations. But the way high-tech service production works (in most of the cases anyways), we can deduce these valuations with realistic-enough assumptions.

3 Production Side

There are M producers. Each has a *capacity* vector K_m, representing the maximum amount of each feature it can serve in each period.[3] I assume that these producers have plenty of capacity, so that congestion and load balancing issues don't appear in the decision making process.

Each producer offers a service bundle for each *usage-profile*. In each usage-profile each producer has some brand reach(i.e. there are consumers with positive valuation for its brand). Preferences are identical with-in a usage profile, but differ between them.

For each of the bundle producer offers, there is fixed cost C, which can be thought of as sticker or menu change cost (e.g. advertising, billing software changes etc.). For each unit of bundle it sells the producer incurs a constant cost, c. This c is like account setup and maintenance costs.

As mentioned earlier, the price vector P for all these services within each usage profile can be represented as -

$$P = \beta . Q_S \tag{7}$$

In equation 7 above, Q_S is the feature composition of all the bundles available in the usage-profile.

I want to mention again that since consumers are heterogeneous in their valuation for different features, the hedonic regressions coefficients β should be treated as representing the valuation (or reservation price) only if it is run *within the usage-profile*.

[3]The capacity can be in different unit for different features. e.g. maximum number of calls a cell phone provider's network can support at given time.

The β above is same as the one obtained in equation 2 by combining his two constraints.

The discussion below is in the context of a usage profile.

Producer's problem can be written as -

$$max_{q_s}\ (p-c).D(q_s)\ \ s.t.\ \ D(q_s).q_s \leq K_m\ \ ;\ p = \beta.q_s \tag{8}$$

where $D(q_s)$ is demand for producer's service bundle q_s. The assumption here is that a producer can not unilaterally change β.

This kind of cost structure is common in high-tech industry. Once wireless internet infrastructure is setup, it does not cost anything extra (assuming no congestion) if people use 1MB of it or 1GB. OR once the mobile game and music download website is setup, it does not matter if the person downloads only 1 song or 10 songs.

3.1 Demand Determination

How is demand $D(q_s)$ determined? In general, within each usage profile there is a distribution of valuations or **reservation prices** of consumers for each feature which is indicative of consumers characteristics, specially his income.[4] There is also a distribution of consumer reservation prices along *brand feature* dimensions, with each consumer having a positive reservation price for only one of the brands (rest are zero) and there are few consumers for each brand.

If the producer offers a service bundle that is in-line with consumer's optimal allocation he buys it. Since we have not put the usual restriction that he can buy only 1 quantity, only the proportional composition matters. I am assuming that he can buy any quantity ≥ 1 of the service plan. It makes more sense to think that these bundles are bought in positive numbers, but theoretically they don't have to be. This can raise objections like people can not use 1.5 cellular service plans. That is true, but this is the fact that many cellular service provider are realizing and offering flexible plans. So that one can in fact consume 1.5 times number of minutes in the original plan, 1.5 times number of MMS etc.[5] But that is besides the point. The idea here is to identify the **participation decision** without making too restrictive distribution assumptions. I am ignoring the non-participating consumers that might decide to reduce their consumptions of other goods, so that they

[4] Other characteristics could be how much does he travel or even how concerned he is with the studies linking brain-tumor to cellular use.

[5] How about 1.5 times the cellular phone no? Well he can have two phone numbers. Have call-forwarding enabled in one of them. Give 50% of his contacts the other second phone number.

can just buy one unit of the service bundle. This is based on availability of outside options available to these non-participating consumers which provide same benefits (e.g. non-bundled cellular services, use internet at home for sending-receiving text messages).

Now let us consider the industry and producers in Game theoretical setup. Some interesting economic forces play a role in restricting producers choice and making the analysis easy.

Consider a strategy profile where in each period all producers agree on the **cut-off reservation price matrix** i.e. they decide on β (except brand prices). So consumers below this cut-off will not buy any service bundle (because their optimal allocation demands less than 1 of the bundle which is not available). Notice that each producer will have some of the consumers buying their service bundles if they charge brand price of zero. Each will also have some of their *brand consumers* not buying any service bundle.

Suppose a producer increases the price of his bundle. Since brand-name is considered one of the features by consumers, what happens is that instead of changing the whole β it is perceived as just an increase in brand price for that producer. There will be **cross brand movements** when its consumers try to minimize their loss function and they will end up buying from someone else (who is charging zero brand price).

If distribution of brand reservation prices is flat (i.e. most of the brands are identical), the gains from increased prices will be much smaller than loss due to reduction in demand. Hence none of the producers changes its price.

$$\Pi(p) \leq \Pi(p = \beta.q_s) \tag{9}$$

Note that the result is being driven by the fact that costs do not depend on service composition q_s (which is not too restrictive an assumption in high-tech service industry e.g. telecommunication) and from the fact that consumers are not tied to their preferred location (each direction is worth maximum up-to its reservation price).

A decrease in price by single producer will not induce any cross brand movement toward itself from the buying consumers because other brands' consumers are already at their optimal allocations. It will however have some of the non-buying consumers to start buying. But this increase will not be large, because these are low-valuation consumers and the value for brand feature is small compared to other features for which they are paying more than their reservation prices.

How about service composition? If every producer offers the bundles which have feature composition *proportional* to consumer's optimal allocation (for that usage profile) F*, then each will get demand from their brand-consumers (i.e. consumers with positive reservation price for their brands).

To determine whether this is a feasible strategy profile, let's consider a deviation from it. Suppose one of the producer starts offering some more quantity of one of the features at the same price. It will be perceived as *brand discount* without affecting the β. It would have increased its demand inducing *cross brand movements* if not for the fact that its service bundle is not proportional to optimal allocation anymore. Moreover, its own brand-consumers will no longer find this service bundle optimal and will compare their utility differences between this and other brand bundles which are still optimal except for the brand feature.

The actual movement is hard to predict without assumptions on distribution of reservation prices in the features space. But if consumers have low valuations for the brands (and free to move between bundles), fear of losing its own brand customer will act as a deterrent to locate its service bundle away from preferred surface.

$$D(q_s) = \begin{cases} +ve; \ if \ q_s \propto F^* \\ 0; \ \ otherwise \end{cases}$$

For this logic to work, there is an implicit assumption. Distribution is such that the cost of offering a NEW additional bundle is not recovered by the residual demand for that NEW bundle.

The basic idea is that if the same producer is going to get the revenue from sale of any of the features, he has no incentive to induce any *intra-service* substitution. Service composition does not matter to the producer. If he can offer only one bundle it is best for him to offer what his consumers want (or most of them want).

Another economic force at work here is **market saturation**. Producer's gains in demand from price reduction (directly or by changing service composition) generate additional demand from low valuation consumer. But the same objective he can achieve by using his second leverage in conjunction with other producers by lowering cut-off reservation price. So if there are enough consumers left (market saturation is low) and their capacities are fixed; then producers have no incentive to compete. Hence in place of fighting for the same consumers they can all have new consumers up to their capacity.

3.2 Proportional Changes

The hedonic equation for a usage profile is depicted in equation 10. As long as features offered remain proportional to optimal allocation there is no cross brand movement.

$$\begin{cases} P_1 = \beta_0.f_0^1 + \beta_1.f_1^1 + ... + \beta_N.f_N^1 \\ .... \\ P_k = \beta_0.f_0^k + \beta_1.f_1^k + ... + \beta_N.f_N^k \\ .... \\ P_M = \beta_0.f_0^M + \beta_1.f_1^M + ... + \beta_N.f_N^M \end{cases} \tag{10}$$

Note that even though feature composition of each service is proportional to the optimal allocation F*, the prices need not be proportional. Because producers can charge different price for their brand feature. This can be re-written as -

$$\begin{cases} P_1 = \beta_0.(f_0^1 + \frac{\beta_1}{\beta_0}.f_1^1 + ... + \frac{\beta_N}{\beta_0}.f_N^1) \\ .... \\ P_k = \beta_0.(f_0^k + \frac{\beta_1}{\beta_0}.f_1^k + ... + \frac{\beta_N}{\beta_0}.f_N^k) \\ .... \\ P_M = \beta_0.(f_0^M + \frac{\beta_1}{\beta_0}.f_1^M + ... + \frac{\beta_N}{\beta_0}.f_N^M) \end{cases} \tag{11}$$

This equation is analogous to 6 and is same as -

$$P = \beta_0 * \tilde{\beta}.Q_S \tag{12}$$

If a producer changes the features' composition by increasing or decreasing the amount of all the features in same ratio α (so that its service bundle is still optimal), but keeps his price fixed.

$$P_k = \frac{\beta_0}{\alpha}(\alpha.f_0^k + \alpha.\frac{\beta_1}{\beta_0}.f_1^k + ... + \alpha.\frac{\beta_N}{\beta_0}.f_N^k) \tag{13}$$

Since consumers can still reach their optimal allocation by buying different quantities of this service bundle, the producer does not lose any demand. It induces cross brand movements toward itself because other brand-consumers can achieve their optimal allocation (except brand feature) at a much lower price.

But if one producer does that, each producer has an incentive to do the same to retain their consumer. They will have to incur the fixed cost C for offering the new bundle. So as long as it does not make their operation unprofitable, they will also increase each feature by ratio α.

Effectively what it ends up doing is setting up a new $\beta^1 = \frac{\beta}{\alpha}$. This just means that the cut-off reservation price vector has gone down. So some new consumers start buying service bundles.

Above discussion might seem too restrictive. But relaxing some of the assumptions should not change the basic intuition. Just like on consumption side, there are two wedges. One is to have consumers buy more or less of the service bundle ($s \uparrow\downarrow$) i.e. substitution between other good and service. The other is substitution between features (Q_S changing). This second wedge is becomes less important (vanishes) if the producer can not increase his demand by positioning his service bundle at some other location.

There is another reason which might enforce this kind of behavior in high-tech service sector. It is the presence of *outside option*. If consumers can get 'customized bundle' (may be at a higher price), then service bundle producers have even more incentives to locate their feature composition at consumer's optimal.

4 Externalities and Price Changes

One mechanism of price change is already discussed above. If producers decide to reduce the cut-off reservation price β, then prices for existing bundles go down. Producers might want to do that to make better use of their capacity which was under-utilized in last period. OR they might have increased their capacity so now they can afford to serve more quantities of bundles.

The price reduction (i.e. lowering the cut-off reservation price) comes at a cost of losing revenue from high-value customers. This is the reason why most of the cellular companies insists on **service contracts**. This way they can lock in higher valuation consumers at their reservation price and then in next period increase their utilization by offering service bundles to lower valuation consumers.

More important mechanism of the price change in high-tech sector is due to externalities and network effects from technology innovation. This changes the inherent utility of (unit value of) some features to go up. This is what most of the hedonic regression literature does not deal with.

Using the consumer optimization equation 3b, we see that if technological innovation moves the utility function up along feature i (i.e. $\frac{\delta U}{\delta f_i}$ shifts up for all values) the previous allocation no longer remain optimal. This is equivalent to saying the reservation price for feature i has gone up for all consumers. So if producers know this and want their bundle to remain optimal (so that they can sell those without having to create new bundles which requires bundling cost), they will just change prices such that β_i goes up by the exact amount such that equation 3b holds.

This second channel (due to technical innovation) does not have any effect on β_0, hence optimization equation 3a also holds.

It means that in each period we have to look for two types of information in the service bundle prices data. They represent substitution between good-and-service and between features with-in a service.

$$\begin{cases} \tilde{\beta}_i \uparrow\downarrow; \; if \; MU_i \uparrow\downarrow uniformly \\ \beta_0 \uparrow\downarrow; \;\; otherwise \end{cases}$$

In reality, we do not see all the service bundles being exactly identical (even within a usage-profile). There may be several reasons for it. The most obvious is that consumer preferences are not evenly distributed along the feature space. This fact combined with the fact that few producers develop 'specialization' in few features (or have higher brand price for some usage profile) will have the effect of many different kind of service bundles in the market. Also if some of the producers can not afford to offer a separate bundle for each usage-profile, they might end up offering something in between. But most of them should offer quite similar bundles.

Another trend that is visible in the service market is having **flexible bundles** which we discussed while talking about consumer demanding non-integer quantity of the bundle. There are some features that are offered in fixed ratios, but for other features consumer can buy extra. This has to do with extracting more surplus, while allowing consumer to move toward his *preferred location* and proper capacity utilization without offering a new service bundle or changing the existing one. This kind of flexibility also enhances the corporation among the producers.

It is easy to find an example illustrating the difference between *inherent quality change* and the marginal value of feature in the good as used in exact hedonic price index literature. Cellular service bundles offer family plan, corporate plan and student plan by packaging number of minutes, text-messaging and internet/ data transfer. The marginal value of per KB of data (or internet access) is different in each plan, with it being maximum for corporate plan users and minimum for family plan users. These are *usage profiles* I talked about. So what is technological innovation then? It will be something like the increase in applications and websites for mobile (e.g. yahoo messenger, google maps). As a result value of per KB of data in ALL the plans goes up. And this is not because their compositions have changed, but because quality of per KB of internet access in cellular service plan has increased.

Basically, the result that production model implies is that service bundle offered are in-line with consumers' optimal allocations. To increase their profits producers lower the cut-off price to include more consumers. We can get these results by just assuming a monopoly in each brand, and consumer buying only if bundle is in-sync with his allocation otherwise he choses outside option. But I want it to be more realistic and that is why I have low reservation price along the brand feature axis kind of setup.

5 Service COL Indexes - Price and Quality

Building on the concepts discussed earlier, I try to identify economic information from the price and quantity data along with the feature composition of service bundles. In particular, how much does the Quality (that is the value-per-unit) changes and how much does the constant-quality-price changes.

The logic is simple. If features do not have any marginal costs, then the effect of industry wide cost shocks or structural changes will be even (i.e. it will not make one of the feature relatively costly or cheaper to provide). Hence all the implicit prices should be effected in similar way (otherwise producer has to change its service bundle which is costly). Basically a producer (in corporation with all the other producers) has two leverages to use. One is to change the implicit price of some features (disproportional change), but this will end up him incurring loss due to bundles becoming non-optimal unless this implicit price change keeps current bundle as optimal. That means producers will change implicit prices disproportionally only when there is an increase in the reservation price (i.e. utility shift) of few features. The other lever is to change implicit prices proportionately. This way they can manipulate how many of their *potential* consumers they want to sell in this period depending on their capacity.

If that is the case, then market data should enable us to identify and separate these two. What is the need to decompose these changes? Of course, the more we know the better. But apart from satisfying academic curiosity, this information is useful both in estimating the effect of technological innovation from consumer's perspective (beyond the usual per-unit-feature price reduction) and also in calculating cost-of-living indexes more accurately.

In each period we observe service bundle prices P, service bundle composition Q_S and quantities sold for each bundle S.

The first step is to identify the *usage profiles*. For example in mobile phone services consumers can be office users, family users, weekend users, messaging users etc.

For each usage profile the preferences are similar and hence the above results could be used. Once we know how to extract information from data for one usage profile, it is just a matter of repeating the same exercise and then doing the aggregation (using weights).

Within each usage profile, we run following hedonic regression for each period (because potentially reservation prices might change due to innovation).

$$P = \hat{R}.Q_S + \epsilon \tag{14}$$

To match this with discussion in previous sections, $\hat{R}$ above is estimated value of β.

The crucial and new step is to construct an **Equivalent Quality value** for each service. This is the amount of quality neutral feature (f_0) that is equivalent to the service bundle. In a sense this is a combination of both normalization and imputation.

$$n_0 = q_0 + \frac{\hat{R}_1}{\hat{R}_0}.q_1 + ... + \frac{\hat{R}_N}{\hat{R}_0}.q_N \tag{15}$$

Basically what I am doing is projecting the utility (reservation prices) from all the other features on the f_0 axis. This will enable us to compare like with the likes. The scenario I am trying to address is same one unit of feature f_i giving more utility in next period. Then how do you compare services in these two periods (which one gives more utility). It is by comparing this equivalent quality value of feature f_0. Since f_0 is quality neutral, comparing it in two periods does not pose any problem.

Rewriting 15 for all the services in the usage profile for that period, we get -

$$N_0 = \frac{\hat{R}.Q_S}{\hat{R}_0} \tag{16}$$

$$P = \hat{R}_0.N_0 + \epsilon \tag{17}$$

Equation 17 has a very simple interpretation. It is a set of M equations. It tells that service sold during this period were equivalent to N_0 of quality neutral feature and the price for that feature in the period was $\hat{R}_0$. I will use this equation to derive some interesting results.

This gives us a unique price $\hat{R}_0$ which is easily comparable across the periods. $\hat{R}_0$ combined with total equivalent quantity of quality-neutral feature $N_0.S$ (using quantity vector S for base or current periods as weights) can be used to construct **Equivalent Quality** Laspeyres, Paasche or Fisher price indexes in the service sector.

$$P_L^{EQ} = \frac{\hat{R}_0^1(N_0^1.S^0)}{\hat{R}_0^0(N_0^0.S^0)} \tag{18}$$

$$P_P^{EQ} = \frac{\hat{R}_0^1(N_0^1.S^1)}{\hat{R}_0^0(N_0^0.S^1)} \tag{19}$$

$$P_F^{EQ} = (P_L^{EQ}.P_P^{EQ})^{\frac{1}{2}} \tag{20}$$

The terms in brackets (N.S terms) represent the corresponding *service quality index*. These EQ indexes will give us estimates of price change very close to the conventional Laspeyres, Paasche or Fisher price indexes when there is no externality or technology innovation. In case of shift in preferences these indexes will be a better measure of **constant utility** price changes, because conventional price indexes just ignore this shift.

We can even get more information using this **projection approach**. Suppose feature compositions of different service bundles are not exactly the same (say for some reasons few features are available only with certain provider e.g. iPhone is locked and available only with AT&T), then using quantities of bundles sold as weights we can calculate average **Service Quality** for each period using the equivalent quality value for each service.

$$n_s^{avg.} = \frac{(n_1.s_1 + ... + n_M.s_M)}{(s_1 + .. + s_M)} \tag{21}$$

Service Quality defined by 21 can be reduced to following expression if we use the set of equations represented by equation 17.

$$n_s^{avg.} = \frac{\frac{(P_1.s_1+...+P_M.s_M)+\mu}{\hat{R}_0}}{(s_1 + .. + s_M)} \tag{22}$$

$$n_s^{avg.} = \frac{P_s^{avg.}}{\hat{R}_0} + \nu \tag{23}$$

Here μ and ν are functions of error term ϵ.

Equation 23 is another intuitive relation. It tells that average Service Quality is equal to average price of the Service divided by the price of the quality-neutral feature (the unit of measurement of the quality) plus some estimation error.

5.1 Properties

The idea of this kind of decomposition can be made clear using an example. Suppose cellular phone service bundles consist of minutes of call, number of MMS and KB of Data. Assume that utility from a single minute of call remains same (i.e. technology is already quite developed). To compare various different bundles in consecutive periods, one way is to find the 'matched sample'. Projection approach removes the need to find matched sample. It converts each cellular service bundle into **equivalent** of total minutes by converting the other innovation sensitive features MMS and Data into value-equivalent of minutes. Thus for each service bundle we can have a number (i.e. equivalent of total minutes) which can be compared across the periods since the effect of innovation is negligible in this feature. This combined with the estimated unit price of one minute of call will enable us to estimate various indexes we might be interested in.

I now discuss some of the properties of these indexes.

P1: These Equivalent Quality price indexes defined above are close to conventional indexes.

Proof:

$P_L = \frac{P^1.S^0}{P^0.S^0} = \frac{(\hat{R}_0^1.N_0^1+\epsilon^1).S^0}{(\hat{R}_0^0.N_0^1+\epsilon^0).S^0} = P_L^{EQ}$, if ϵ's $= 0$.

The nearer ϵ's are to zero, the closer these indexes will be to conventional indexes.

P2: These EQ price indexes are independent of choice of quality-neutral feature.

Proof:

We can use n_i in equation 15 and use it along with $\hat{R}_i$ to define the price indexes.

$\overline{P_L^{EQ}} = \frac{\hat{R}_i^1(N_i^0.S^0)}{\hat{R}_i^0(N_i^0.S^0)} = \frac{(P^1-\epsilon^1).S^0}{(P^0-\epsilon^0).S^0} = P_L^{EQ}$

P3: Total value of service bundles purchased in each period is equal (almost) to price of quality-neutral feature times service quality in terms of that feature times total number of service bundles i.e

[Value = (Constant-Quality-Price * Quality) * Quantity] holds in each period.

Proof:

This is straight-forward result of equation 17.

$V = P.S = (\hat{R}_0.N_0 + \epsilon).S = (\hat{R}_0.N_0.S) + \psi$

P4: Price changes in the service bundles can be decomposed into changes due to quality-price movements and changes due to movements in service quality.

Proof:

This just follows from equation 17, taking derivative w.r.t. time, we get -

$\frac{\delta P}{\delta t} = R_0(t).\frac{\delta N_0}{\delta t} + N_0(t).\frac{\delta R_0}{\delta t}$

P4: Implicit EQ Quantity indexes are similar to usual quantity indexes, but using QUALITY as weights rather than prices.

Proof:

By definition we have -

$$Q_L^{EQ} = \frac{\frac{P^1.S^1}{P^0.S^0}}{P_L^{EQ}} = \frac{\frac{(\hat{R_0^1}.N_0^1+\epsilon^1).S^1}{(\hat{R_0^0}.N_0^0+\epsilon^0).S^0}}{\frac{\hat{R_0^1}(N_0^1.S^0)}{\hat{R_0^0}(N_0^0.S^0)}}$$

$$\Rightarrow Q_L^{EQ} \approx \frac{N_0^1.S^1}{N_0^1.S^0}$$

This has the exact formulation as $Q_L = \frac{P^1.Q^1}{P^1.Q^0}$ with Qualities N of service bundles as weights rather than their prices P.

5.2 Technological Innovation

Consider the case when due to technological innovation, utility of feature i goes up. If producers corporate on increasing the $\tilde{\beta_i}$, then none of the service bundle changes and only difference will be the price increase (i.e. $P^1 > P^0$).

Now none of the conventional indexes will reflect this fact. Moreover, Laspeyres index will show it as a price increase ($P_L > 1$), which means that price of service bundle went up. It seems counter-intuitive that innovation lead to an increase in price.

If we calculate P_L^{EQ} this will also show that the price has increased. But since we have the two separate values $\hat{R_0}$ and N_0 identified in the process, we could tell exactly what is going on.

Since $\hat{R_0^1} = \hat{R_0^0}$ and $N_0^1 > N_0^0$, it means that there was no change in the 'constant quality price', but innovation increased the 'service quality' itself went up. That is why the price of service went up.

If we consider the usual definition of quality (which is the amount of features a bundle has), nothing has changed. It still has the same amount of each feature including feature f_i. What has increased is the **inherent value** or quality of per unit of feature i. This is the distinction I want to emphasize.

This simple example shows that the EQ indexes are better than conventional indexes in explaining price changes when there is a shift in preferences due to some externality or network effects, which is quite common in high-tech service sector.

The importance of this approach becomes more apparent if we consider another example. Suppose that along with $\tilde{\beta_i}$ going up as above, producers also decide to use their other leverage by reducing the average/ cut-off reservation price (may be the technological innovation also helped them to serve more customers within the existing capacity).

If increase in β_i is large enough (compared to the agreed overall reduction α) then the prices of service bundles might go up.

$P^1 = (1-\alpha).P^0 + (\beta_i^1 - \beta_i^0).Q_i \quad > P^0$

Since service bundles are the same in two periods, using conventional indexes will give us the result that prices have increased and hence the welfare has gone down. But this will be quite opposite to what has actually happened.

Now if we calculate the *constant-quality prices* we can clearly see that $\frac{\hat{R}_0^1}{\hat{R}_0^0} = (1 - \alpha)$

So the constant-quality prices have in fact gone down. The prices have gone up because the *service quality* has gone up by a larger amount, so the net effect is that total price for the service bundle goes up.

In first example, conventional indexes failed to identify the quality-improvements. But in second example, they predicted the price movement in the opposite direction (quality improvements were quite large in this case).

So even if we are not interested in the fine details of decomposing the price movements in service bundles to its components, ignoring it altogether or thinking that it is not large enough to matter can be costly.

5.3 Aggregation

We can calculate **Constant-quality price Laspeyres index** and **Service-quality Laspeyres index** using $\hat{R}_0$ and N_0 for each period as prices and quantities of service bundle sold S as weights. Note that $\hat{R}_0$ will be same for each of the services in the usage profile, but will differ across profiles. I am using the symbol $\bar{R}_0$ to denote the vector of these $\hat{R}_0$.[6]

$$P_L^R = \frac{\bar{R}_0^1.N^0.S^0}{\bar{R}_0^0.N^0.S^0} \tag{24}$$

$$P_L^N = \frac{\bar{N}_0^1.S^0}{\bar{N}_0^0.S^0} \tag{25}$$

The constant-quality price index P_L^R uses total equivalent quantity of feature 0 (i.e. $N.S$) as weights.

If we use two-stage aggregation and calculate EQ price indexes. These in general will not be equal to the product of constant-quality-price index and service-quality index.

$(P_L^{EQ})^{Two-Stage} \neq P_L^R.P_L^N$

[6]This $\bar{R}_0$ is created first by dividing P and Q_S data by profiles and then running hedonic regression in each profile.

6 Illustrations

Utility function is $U(F,x) = f_0^{\alpha_0} * f_1^{\alpha_1} * .. * f_N^{\alpha_N} * x^{\alpha_x}$. The optimality conditions are -

$$q_0 = \frac{\alpha_0 * I}{\beta_0} \tag{26}$$

$$\frac{q_j}{q_i} = \frac{\alpha_j}{\alpha_i} * \frac{\beta_i}{\beta_j} \tag{27}$$

These equations are two wedges I discussed. Producer uses first one to increase his demand to utilize his capacity. The second one is used to keep current service bundle optimal (and hence save the bundling-cost) in response to changes in preference parameters due to some technological externality. In figures below, I draw graphical representation of these.

In figure 1, consumers' preferred planes are drawn in two feature space (Number of minutes, q_j and Data transfer q_i). I have shown two lines each representing a usage profile. Family users value voice calls more than data transfer, while for business users it is opposite. Figure 2 shows two mechanism of price changes. Once producers have decided to have their relative implicit prices such that their service bundles are optimal planes given by equation 27, they can adjust their total demand by changing the value of β_0. This is equivalent of deciding up to what minimum income consumer they wish to sell given equation 26. Again, I am abstracting from the process that might take place if consumer decides to consumer less of X, so that he can purchase one unit of service bundle.

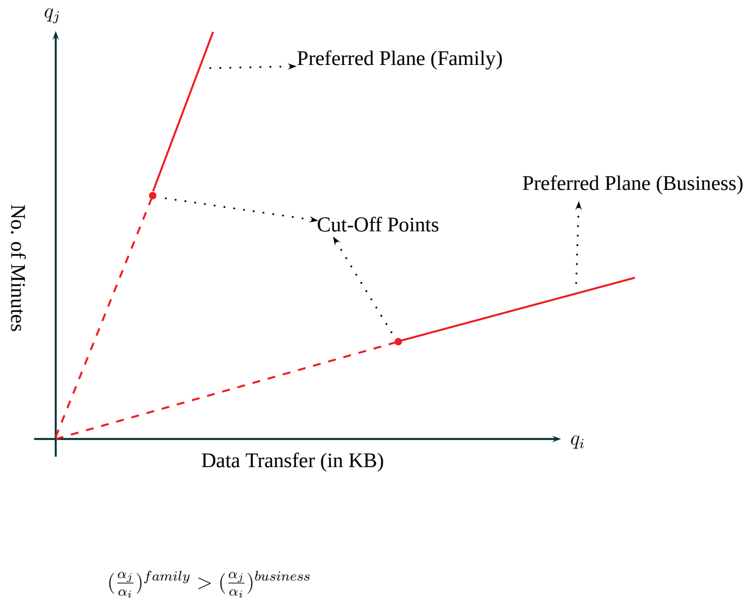
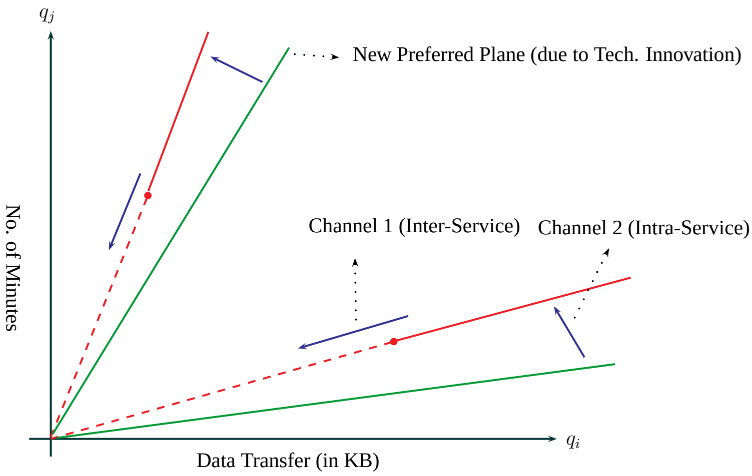


Figure 1: Preferred Planes and Cut-Off Points in Feature Space



Externality $\Rightarrow \frac{\alpha_i}{\alpha_j} \uparrow \Rightarrow$ New Optimal Planes

if Producers $\frac{\beta_i}{\beta_j} \uparrow \Rightarrow$ Same bundle still Optimal.

Figure 2: Price change mechanisms

7 Conclusions

The issue of utility gains due to externalities and technological innovation which is in addition to the most often talked about quality improvements (per-unit-feature-price reduction) is important for welfare analysis and price statisticians. In few sectors (like high-tech services), due to their production technology it becomes much easier to extract meaningful economic information from hedonic regression coefficients. For price changes in service bundles it makes more sense to explain that change by decomposing into 'constant-quality price change' and 'quality change.

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