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Measuring Welfare Gains from Better Quality Infrastructure

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ABSTRACT

Projects and reforms targeting infrastructure services can affect consumer welfare through changes in the price, coverage, or quality of the services provided. The benefits of improved service quality – while significant – are often overlooked because they are difficult to quantify. This paper reviews methods of evaluating the welfare implications of changes in the quality of infrastructure services within the broader theoretical perspective of welfare measurement. The study outlines the theoretical assumptions and data requirements involved, illustrating each method with examples that highlight common methodological features and differences. The paper also presents the theoretical underpinnings and potential applications of a new approach to analyzing the effects of interruptions in the supply of infrastructure services on household welfare.

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1. Introduction

The provision of modern infrastructure services is an important element of poverty reduction strategies in many developing countries, but gaps in access to services persist. Of the poor households in low-income countries, only 41 percent have access to piped water, only 27 percent have access to improved sanitation, and a mere 10 percent have access to electricity. These statistics are not adjusted for quality of the service and include households that have access to services for only a few hours a day (World Bank 2006). Further, the burden of poor-quality infrastructure services falls disproportionately on women because they tend to be the ones collecting fuel wood and water during supply interruptions, and they experience greater exposure to indoor air pollution from stoves.

Additional and more effective investments are urgently needed to close these gaps in access to services.¹ Current levels of infrastructure spending need to be increased across the developing world in order to improve service delivery,² but the efficacy of future investments will depend on the ability to make service providers accountable to policymakers and client households (World Bank 2004a). Improvements in accountability, in turn, hinge upon better impact evaluation and data regarding developing-country infrastructure services, including the accessibility, quality, and affordability of such services. As Bourguignon (2006, p.9) points out, “without systematic initiatives to expand our capacity to monitor infrastructure availability (and deficiencies), along with efforts to improve performance measurement and evaluation, there is little likelihood that the ambitious infrastructure agenda can move forward.”

Importantly, access to modern infrastructure services doesn't guarantee adequate service supply. Recent evidence from countries for which demand-side indicators on service quality are available suggests that nearly half the households with access to water

¹ Thus, the Millennium Development Goals (MDGs) include a target of halving the proportion of people without sustainable access to safe drinking water and sanitation by 2015. While the MDGs do not include a target for energy, access to modern and sustainable energy services is recognized as a necessary condition for attaining MDGs in other areas (Modi et. al. 2006).

² According to recent estimates, investment in new roads, railroads, telecommunications, electricity, water, and sanitation need to increase to around \$465 billion per year by 2010—or from the current level of approximately 4 percent of GDP in developing countries to 5.5 percent—in order to meet the growing demand and investment in rehabilitation and maintain existing infrastructure at current service levels (Fay and Yepes 2003).

supply and modern energy services experience supply interruptions.³ The macro statistics frequently used to evaluate improvements in infrastructure service quality can offer insights into aggregate-level welfare gains of projects or reforms, but they provide no information on the heterogeneity of impacts at the household level.

Accurate cost–benefit analyses are a vital tool for maximizing and prioritizing scarce public investments in developing countries. Projects and reforms targeting infrastructure services can affect consumer welfare through changes in the price, coverage, or quality of the services, but the benefits of improved service quality—while significant—are often overlooked because they are difficult to quantify. This is common, for example, when increased competition among service providers is expected to lower the price of the service, and associated changes in the quality of the service are omitted, leading to erroneous policy conclusions. Although several techniques for evaluating the welfare impact of quality changes have been proposed in welfare economics, in practice they are rarely used in assessing the gains from improvements in quality of infrastructure services (McKenzie and Mookherjee 2003; Briceño-Garmendia et. al. 2004). There are two main reasons for this. First, adequate data for such evaluations are rarely available, and, second, the practical applications of certain, potentially useful, methods for project analysis have yet to be fully explored. Policymakers are only now beginning to focus their attention on infrastructure service quality.

The objective of this paper is to provide a synthesis of methods that can be used to evaluate changes in infrastructure service quality and to demonstrate how these methods can be applied to assess the impacts of infrastructure reform on household welfare.

2. Theoretical Framework

From a theoretical standpoint, the benefits of improved service quality can be interpreted as a change in an individual’s or a household’s utility. These changes can be measured by compensating variation (CV), which is the (positive or negative) monetary payment

³ A review of household surveys in 60 developing countries reveals that information about the continuity of access to electricity and piped water is available for only 10 countries in Europe and Central Asia and two countries in other regions. The data reveal that, on average, only 55 percent of households in these countries have access to uninterrupted piped water supply, with little difference between urban and rural areas, while 58 percent of urban households and 36 percent of rural households have access to continuous electricity supply (Briceño-Garmendia and Klychnikova 2006).

necessary to bring a consumer back to her initial level of well-being after a price and quality change occurs. Formally, CV can be defined in terms of the indirect utility function as

$$V(p^1, q^1, y - CV) = V(p^0, q^0, y),$$

where p^0 and q^0 represent the initial price and quality combination, p^1 and q^1 represent the price and quality combination after the change, and y is income. The change in welfare could also be measured by the equivalent variation (EV), which is defined as the (positive or negative) monetary payment to a consumer that would maintain his or her well-being at the same level as it would have been had the price/quality change not occurred. In terms of the indirect utility function, EV is defined as

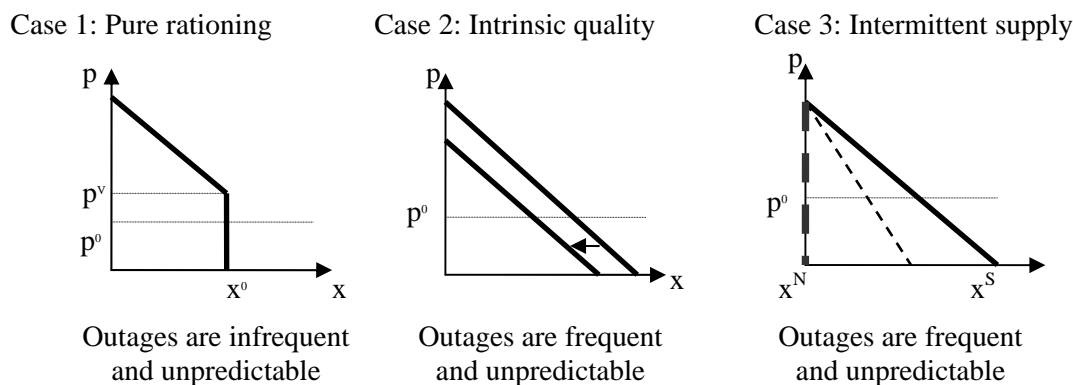
$$V(p^0, q^0, y + EV) = V(p^1, q^1, y).$$

These two measures are equal when the changes in utility are small enough not to alter the marginal utility of income.⁴

Infrastructure services have a variety of attributes that fall into two categories: service reliability and intrinsic service quality. Examples of intrinsic service quality are voltage fluctuations for electricity services, pressure for network gas, temperature for heating, or the level of contaminants in a water supply. Service reliability for utilities is reflected in the frequency of outages and the predictability of their timing. Several modeling approaches can be used to assess the welfare effect of a change in the reliability and intrinsic qualities of infrastructure services. The choice of an approach depends on the implications of an outage occurrence for household behavior. Figure 1 depicts three outage situations, where the quantity of an infrastructure service is shown on the horizontal axis, and the price is shown on the vertical axis.

⁴ Willingness to pay and willingness to accept are alternative definitions of the same theoretical measures of welfare. For an improvement in circumstances, CV is equal to the maximum willingness to pay to obtain better quality, and EV is the minimum willingness to accept to forgo the improved service quality. For degradation in service quality, CV is the minimum willingness to accept to agree to new circumstances, and EV is the maximum willingness to pay to avoid the new conditions (Haab and McConnell 2002).

Figure 1. Theoretical frameworks for analyzing infrastructure service outages



Under pure rationing, when service reliability is poor, household consumption levels are lower than they would be at the prevailing price but with perfect reliability; hence, the consumption of an unreliable service by these households is rationed (Figure 1, Case 1). Households make no adjustments in their consumption patterns; they simply do without the service on the rare occasion that service is interrupted. In rationed markets, prices do not reflect the marginal utility of consumption, and the observed consumption expenditure cannot be used in welfare analysis of reliability changes (Deaton 1981; Pudney 1989; Hentschel and Lanjouw 2000). Several methods have been proposed to account for the discrepancy between the observed consumption and the true quantity demanded.⁵ Pure rationing mainly occurs in developed countries, where service reliability is high; hence, this is not dealt with in this paper.⁶

When outages are frequent but their timing cannot be predicted, households may adjust by investing in appliances that use alternative sources of energy or water when outages occur (Figure 1, Case 2). These outages can be modeled in the same way as a

⁵ Sometimes an unbiased measure of consumer surplus, or CV, can be obtained by imputing the unobserved quantity that would be consumed if the rationing constraint was not binding (Deaton 1981; Pudney 1989). Alternatively, it may be possible to impute a virtual price, which is a price that corresponds to the observed consumption if this were the actual quantity demanded. Virtual prices can be obtained from markets with very similar conditions but no rationing (Hentschel and Lanjouw 2000).

⁶ The pure rationing approach has been used to estimate the cost of electricity outages. Caves et al. (1990) describe the consumer surplus approach to estimating outage costs. Their method relies on an assumption of advance warning of an outage. The shorter the warning time, the less consumers are able to adjust; thus, the steeper the demand curve and the greater the welfare losses from an outage (Sanghvi 1983). With no advance warning, this method is equivalent to the rationing model.

change in the intrinsic quality of an infrastructure service. Such adjustments allow households to reduce their losses from outages, but they may also cause additional costs associated with mitigating actions. Households may permanently shift away from an unreliable energy or water source in favor of a more reliable substitute. If such adjustments result in permanent changes, an inward shift of the demand curve for the original service results.

Instead of a permanent shift away from an unreliable infrastructure service, households may continue using the service when it is available and rely on substitutes during outages (Figure 1, Case 3). Thus, part of the time, the demand curve for the service is unconstrained (shown by a solid line), and part of the time it is inapplicable because supply is zero. The vertical dashed line represents demand during outages. The degree to which observed consumption is lower than it would be in the absence of an outage depends on duration of the outage. An average consumption level that includes periods of reliable supply and outages is represented by a thin dashed line. This case cannot be formulated using conventional frameworks of rationing or a change in intrinsic quality, as is made clear in the next section of this paper; therefore, this study proposes a new approach to modeling this case within the framework of the intermittent supply model.

Other outage situations are also possible. Sometimes outages are frequent, but their timing is predictable—for example, when outages occur at the same time of day. In these cases, households may be forced to use services during predictable periods of availability. The cost of the resulting inconvenience lowers demand for the unreliable infrastructure service. This situation cannot be adequately modeled using one of the three approaches described above; it may require a model of intra-household allocation and time use, which is beyond the scope of this paper.

3. Empirical Methods of Measuring the Welfare Impact of Changes in Service Quality

The welfare impact of changes in the quality of infrastructure services represented in Cases 2 and 3 of Figure 1 can be measured with revealed or stated preference data using one of four methods reviewed in this paper:

1. the exact welfare impact can be measured with the direct demand estimation method,
2. welfare can be approximated using the averting behavior model,
3. exact welfare can be measured using the intermittent supply model, and
4. expected welfare impact can be measured using conjoint analysis.

The revealed preference approach comprises methods that use data indicating expenditure on market goods associated with the service in question. These data permit the estimation of an implicit value of welfare improvements due to a change in the quality of a particular service. Revealed preference methods include direct demand estimation, averting behavior, travel cost models based on the random utility modeling, and hedonic pricing. With the exception of the random utility method, revealed preference methods of measuring the impact of changes in services quality are based on the household production function approach (Becker 1965; Lancaster 1966; Gorman 1980). In this theoretical framework, households use infrastructure services as inputs in the production of household services. For example, electricity combined with household appliances produces lighting, heat, energy for cooking, and entertainment provided by radio and television. Network gas can be used to produce heating or cooking services. Water can be consumed for drinking or for bathing and cleaning (which could be considered as health services). At the same time, water contaminated with harmful bacteria provides a disservice through an increase in the risk of illness. This framework applies to the direct demand estimation method, the averting behavior approach, and the intermittent supply model.

The term “stated preferences” refers to survey-based methods that rely on information about households’ willingness to pay for an improvement in service quality, or about their choices and behavioral changes in hypothetical scenarios involving a quality change (Freeman 2003). Stated preference methods include contingent behavior, whereby respondents answer survey questions about their behavior under a hypothetical situation; conjoint analysis, whereby the respondent is given a choice of projects or commodities with specific quality and price attributes; and contingent valuation, whereby respondents report their willingness to pay for a change in quality of a service. Revealed preference data and stated preference data from contingent behavior or conjoint choice

surveys can be utilized for most of the approaches discussed in this paper. The theory, applicability, and data requirements for each of these methods are presented in subsequent sections, along with illustrative examples.

3.1 Direct demand estimation method

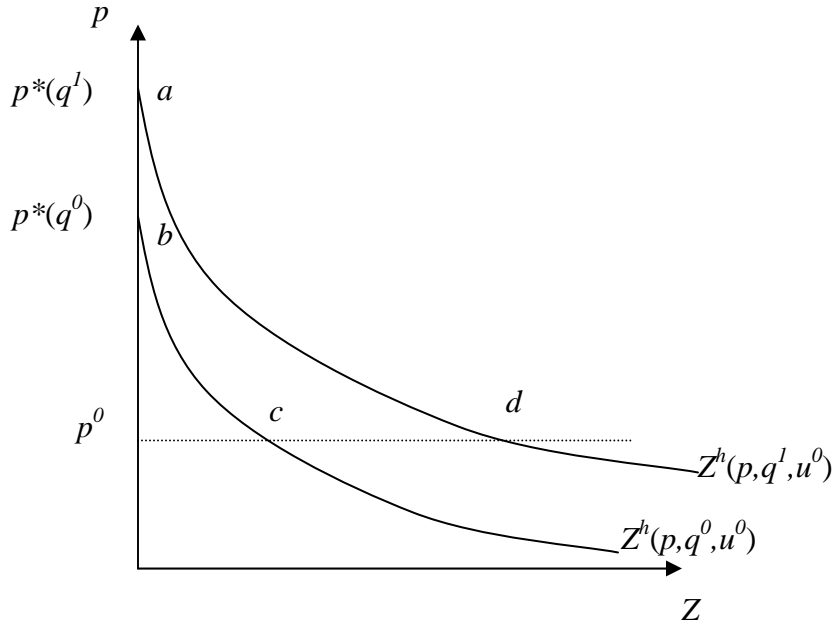
The most straightforward way to estimate the welfare effect of a change in service quality is to measure the area between the demand curves of the original and improved quality levels and above the price line. This is the essence of the direct demand estimation method, which relies on two assumptions. First, the assumption of weak complementarity requires that the consumer's welfare is unaffected by changes in the quality of a service he or she does not consume (Mäler 1974). For example, the welfare level of a household that consumes no electricity is assumed to be unaffected by a change in the quality of electricity supply. Second, the assumption of non-essentiality implies that it is possible to compensate an individual for a complete loss of the service. This assumption would not be satisfied for vitally important goods or services; however, for the provision of water or heat, the non-essentiality assumption can be relaxed. Water and heat, while essential, can be satisfied by a variety of inputs. Drinking water, for example, can be obtained from bottled water or the public supply, and heating can be generated by gas, electricity, or wood. In that sense, neither service is essential, the only requirement being that at least one is available. Thus, the non-essentiality condition is satisfied in household production models with complete substitutability of any particular input used in the production of a service.

Assumptions of weak complementarity and non-essentiality are required by most methods (direct demand estimation, averting behavior, and conjoint analysis), and they may or may not be appropriate for a specific application. Nevertheless, the direct demand estimation method relaxes non-essentiality conditions for household services such as cooking and heating for the reason discussed above—the fuels used as inputs in the production of these services are individually non-essential.

When the weak complementarity and non-essentiality assumptions are satisfied, the area between two compensated (Hicksian) demand curves is finite (the curves cross the vertical axes). That area can be interpreted as an exact measure of the welfare effect

of a change in service quality (Train 2003; Just et al. 2004). Graphically, the CV of a change in quality is represented by the area $abcd$ (Figure 2), where Z^h denotes the Hicksian demand for the service, q^0 and q^1 are quality levels before and after the change, respectively, u^0 is the initial level of utility, p^0 is the price of service, and $p^*(q^1)$ and $p^*(q^0)$ are the so-called choke prices at the initial and final quality levels. The choke price is the lowest price at which the demand for the service is zero. The choke price is defined for non-essential goods only because the demand curve would otherwise have no intersection with the vertical axis.

Figure 2. Compensating variation of a quality change



Formally, the area $abcd$ between the Hicksian demand curves at the initial and final quality levels and above the price line can be expressed as

$$\int_{p^0}^{p^*(q^1)} Z^h(p, q^1, u^0) dp - \int_{p^0}^{p^*(q^0)} Z^h(p, q^0, u^0) dp. \quad (1)$$

Using Shepherd's Lemma evaluation of these integrals at the limits of integration obtains area

$$abcd = e(p^*(q^1), q^1, u^0) - e(p^0, q^1, u^0) - e(p^*(q^0), q^0, u^0) + e(p^0, q^0, u^0), \quad (2)$$

where the sum of the first and the third terms is equal to zero if the weak complementarity assumption is satisfied (Freeman 2003). CV is then the difference between the expenditure necessary to attain the same level of utility after a change in service quality as before the change,

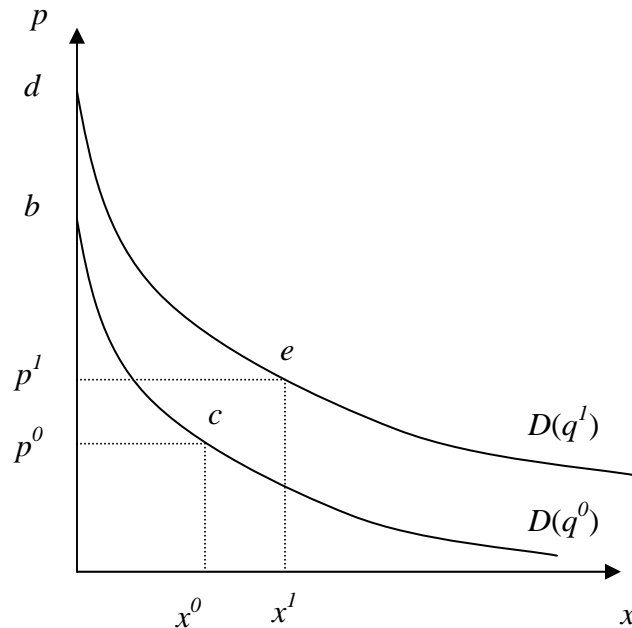
$$CV = e(p^0, q^0, u^0) - e(p^0, q^1, u^0). \quad (3)$$

The sum of the second and fourth terms is equal to the compensating variation of the quality change from q^0 to q^1 . The EV can be found similarly by replacing u^0 by u^1 .

In practice, the compensated (Hicksian) demand is not directly observable because it depends on unobservable utility. Alternatively, many studies measure the welfare implications of quality changes by using the uncompensated or ordinary (Marshallian) demand, which is directly observable. Calculations similar to those in equations (1) through (3) with ordinary demand functions measure the change in consumer surplus, which approximates the welfare change (CV or EV) when certain conditions are satisfied.⁷ The welfare effect of a price and quality change is represented by a change in consumer surplus (Figure 3). Ordinary demand curves for service x are represented by $D(q^0)$ at the initial quality level and $D(q^1)$ at the improved quality level. The change in consumer surplus associated with a simultaneous change in price from p^0 to p^1 and in quality from q^0 to q^1 is the difference between the initial consumer surplus (area p^1de) and the final consumer surplus (area p^0bc).

⁷ Unlike the observable Marshallian demand curves, which are income-constant, Hicksian demand curves are utility-constant and not directly observable. Willig (1976) shows under which conditions the consumer surplus (CS) measure (the area under the Marshallian demand) provides a close approximation to the area under Hicksian demand, which is the true measure of welfare change. If these conditions are satisfied, i.e., if the expenditures on the good in question represent a small share of the household budget, and the income elasticities are low, then the change in CS associated with a price change falls within tight bounds between the CV and EV measures. If Marshallian demand is used to approximate the welfare impact of a change in quality rather than price, then an additional restriction is necessary to establish these bounds (Bockstael and McConnell 1993; Palmquist 2005).

Figure 3. Consumer surplus change associated with a quality and price change



Hause (1975) and Hausman (1981) show how Hicksian demand estimates can be inferred from ordinary demand estimates. Just et al. (2004) describe the application of this approach to welfare measurement for a variety of flexible functional forms. The exact welfare measures of price changes (CV or EV) can be calculated based on estimates of ordinary demand functions derived from those indirect utility forms.

The direct demand estimation method has traditionally been used to assess the welfare impact of changes in reliability of residential electricity provision. In this approach, the demand for electricity is modeled as an ad hoc function of some reliability measure. For example, the welfare costs of electricity outages are estimated using data on consumption of electricity at different reliability and price levels. Having estimated demand functions for different reliability levels, a researcher can calculate the change in welfare resulting from improved reliability (e.g., Dias-Bandarnaike and Munasinghe 1983; Westley 1984). When electricity supply becomes unreliable, households reduce their reliance on electricity, substituting other sources of energy or increasing their consumption of non-energy goods. An improvement in reliability has the opposite effect, causing an increase in electricity consumption. The electricity demand curve shifts outward from $D(q_0)$ to $D(q_1)$, and this shift represents an increase in a consumer's willingness to pay for all units of electricity delivered with higher reliability (Figure 3).

An evaluation of the welfare impact of changes in reliability of electricity supply in Costa Rica illustrates this method. Dias-Bandarnaike and Munasinghe (1983) use county-level time-series data on residential electricity consumption to estimate demand at very low, low, and medium reliability levels via three demand equations. When supply reliability improved from very low to medium, the estimated consumer surplus increased by about 50 percent over pre-reform levels. In practice, applications of the direct demand estimation approach are limited by the availability of data. The prices of infrastructure services tend to be regulated and set either nationally or regionally, and price variations across regions are usually insufficient for use in estimating a demand function. Moreover, when supply interruptions constrain consumption, the observed consumption by some households may be below true demand. Therefore, these data cannot be used to estimate a demand function unless discrepancies between true demand and observed consumption are accounted for.

The applicability of the direct demand approach could be extended by imposing an assumption of perfect substitutability between the publicly supplied infrastructure service and its market substitutes. Two examples of an evaluation of the welfare effect of improved municipal water supply and electricity service provision illustrate this approach. The Panamanian government sought to encourage private-sector service delivery in the water supply and sewerage sector in its recently launched Public Enterprise Reform Program. The cost-benefit analysis of the sector's reforms focused on the behavior of unmetered consumers who cope with intermittent water supply (Barreix et al. 2003). Before the project, these consumers paid a fixed monthly fee, receiving water at a zero marginal price, and used overhead water tanks during water supply interruptions. The implicit price of water when overhead tanks are used is the marginal cost of operating a tank. After the project, households received service 24 hours a day, but they were forced to pay a new tariff based on their water consumption, rather than a zero marginal price. Assuming that water from overhead tanks is a perfect substitute for water from the public supply, the price-quantity combinations of these two sources are sufficient to estimate a linear demand function for water and to calculate a change in consumer surplus. The welfare impact of the project can then be approximated as the sum of two components: the first component is a reduction in consumer surplus resulting from

reduced consumption at a higher marginal tariff due to the introduction of consumption-based volumetric charges; the second component is an increase in consumer surplus due to the savings in electricity, maintenance, and other expenses associated with the operation of overhead tanks.

The drawback of this analysis is that it fails to account for changes in behavior of households with intermittent supply. It assumes that households always rely on the overhead tanks, even when water is available from the public supply system. In fact, before the reform, some of the time the formerly unmetered households relied on water from the public supply, which they received at a zero marginal price. These households were charged for water from the public supply after the change. Another problem with this approach is the assumption of perfect substitution between water from overhead tanks and water from the public supply. The analysis assumes that households do not benefit from consuming water from the public supply system compared with the overhead tanks. These assumptions could lead to a bias in estimating the benefits of improvements in service quality.

The assumption of perfect substitutability requires careful consideration when employed for the analysis of household energy use. The direct demand estimation approach has been used to approximate welfare gains of electrification in the Philippines, where electricity is primarily used for lighting (Choynowski 2002; World Bank 2002). If kerosene and electricity are assumed to be perfect substitutes in producing light, the data on kerosene consumption by non-electrified households and electricity consumption by electrified households give two points on the demand curve for lumens. This information is sufficient to calculate consumer surplus of electrification under an assumption of linear demand function for electricity. However, the assumption of perfect substitutability is not always plausible. While it could be reasonable to assume that public water and water from overhead tanks are perfect substitutes, this assumption is more questionable for the use of electricity versus kerosene for lighting, or electricity versus fuel wood for heating. In the Philippines, for example, the majority of non-electrified households that use kerosene for lighting recognize that indoor air pollution can cause health problems, so they place a higher value on a lumen from electricity than on a lumen from a kerosene lamp (World Bank 2002). Consumer surplus calculated under the assumption of perfect

substitutability can be interpreted as the lower bound on the true welfare gains. So in the Philippines, the estimated consumer surplus of switching from kerosene to electricity is the lower bound on the welfare gains from electrification, as long as lumens from electricity are cheaper than lumens from kerosene.

The direct demand estimation method imposes rather innocuous assumptions of weak complementarity and non-essentiality on the household's preference structure. If necessary data are available, the method permits the welfare impact of changes in service quality to be measured accurately with CV (EV). However, variations in price and service quality are rarely sufficient to enable demand functions for infrastructure services to be estimated reliably. Even when such data exist, if the anticipated quality and price changes fall outside the range of observable data, the estimated welfare measures may not be statistically accurate. Experimental data from contingent behavior surveys are particularly useful in this case because they can supplement observed data and provide useful observations outside the range of variation in observed sample data. As demonstrated by Azevedo et al. (2003), combining data in this way is an advantageous approach because it imbeds stated preference data in observed behavior. To the best of our knowledge, the direct demand estimation method has never been used in combination with revealed preference data and data from contingent behavior surveys to evaluate the welfare impact of quality changes in infrastructure services. This method, the intermittent supply method recently developed by one of the authors of this paper, is discussed in the next section.

3.2 A new model of intermittent supply

The intermittent supply method explicitly incorporates the supply constraints of infrastructure services into a model of household behavior. Consequently, observations on constrained service consumption levels can still be used to estimate demand and hence the welfare effects of a change in the frequency and duration of supply interruptions. In addition, the intermittent supply model permits welfare impact analysis even when the price variation is insufficient to enable demand to be estimated at different levels of service quality. The method uses variations in hours of infrastructure service supply per month to identify the necessary price parameters for welfare measurement.

The model of intermittent supply assumes that a household can use different fuel sources for heating, cooking, and lighting based on the availability of those sources. The model further assumes that the different fuel sources are perfect substitutes for each other. If the share of time that households have access to a specific source of fuel is known, it is possible to model household behavior in each regime of energy availability and to estimate expected total demand for substitute fuels. The CV or EV of a change in prices and availability of energy (as a share of time) can then be calculated.

Suppose a household's utility is a function of a numeraire good and the level of consumption for heating, cooking, and lighting. These services can be produced using various network energy sources and market fuels at a cost that depends on the fuel price and conversion efficiency. A household maximizes its utility subject to production functions of energy services and the budget constraint. Different regimes are defined based on fuel availability at each point in time. For example, the first regime might denote the availability of all fuels (network gas, electricity, wood, and kerosene), while the second might represent a situation where all fuels except network gas are available, and the third regime might indicate that households only have access to wood and kerosene. Under any regime, households select the least expensive fuel based on energy conversion coefficients of existing appliances. If network gas is less expensive than other fuels, it will always be chosen for heating and cooking as long as gas is supplied; if gas is not available, electricity is the next preferred option; and if neither gas nor electricity are available, a household would choose the only remaining options—wood for heating and cooking, and kerosene for lighting. Therefore, the optimal solution of a household utility maximization problem depends on the availability of fuel sources.

Since households choose different fuels for cooking, heating, and lighting, different prices enter the indirect utility function in each regime. The indirect utility function associated with the first regime, whereby network gas is used for cooking and heating, and electricity is used for lighting, can be expressed as:

$$V(P_G / z_{HG}, P_G / z_{CG}, P_E / z_{LE}, Y), \quad (4)$$

where P_G and P_E are the prices of gas and electricity, respectively; Y is income; and z_{HG} , z_{CG} , and z_{LE} are conversion coefficients of gas for heating, gas for cooking, and electricity for lighting, respectively. The indirect utility function for the remaining two regimes is

obtained in a similar way. This modeling approach circumvents the problem of missing prices of fuels that are not used, since these prices do not enter the indirect utility function.

Over time, households consume multiple fuels for the same purpose. Assuming that fuel substitution occurs because of changes in fuel availability, the household utility maximization is formulated as a problem of intertemporal aggregation. An aggregate expected indirect utility function can be expressed as a weighted average of the regime-specific indirect utility functions. The weights are the shares of time fuels are available. Thus, if both electricity and gas are available 50 percent of the time, households are in the first regime of fuel availability half of the time and in the second and/or third regimes the rest of the time. Then the aggregate expected indirect utility function takes the following form:

$$E(V) = s_1 V\left(\frac{P_G}{z_{HG}}, \frac{P_G}{z_{CG}}, \frac{P_E}{z_{LE}}\right) + s_2 V\left(\frac{P_E}{z_{HE}}, \frac{P_E}{z_{CE}}, \frac{P_E}{z_{LE}}\right) + s_3 V\left(\frac{P_W}{z_{HW}}, \frac{P_W}{z_{CW}}, \frac{P_K}{z_{LK}}, Y\right), \quad (5)$$

where z_{ij} represents the efficiency of converting energy source j into energy service i ; i equals heating, cooking, and lighting; j equals gas, electricity, wood, and kerosene; P_j is the price of energy source j ; Y is total household income; and s_1 , s_2 , and s_3 are the expected shares of time a household operates under regimes 1, 2, and 3, with $s_1 + s_2 + s_3 = 1$.

To derive a system of expected fuel demand, Klytchnikova (2006) uses a flexible functional form for the indirect utility function (4).⁸ This demand system is expressed in terms of household budget shares, obtained by multiplying household consumption of each fuel by its price and dividing by total household income (expenditure). The econometric model that corresponds to this system of budget shares is given by the following equations:

$$w_{jn} = s_{1n}(\alpha_i + \sum_j \beta_{ij} \log p_{j3n}) + s_{2n}(\alpha_i + \sum_j \beta_{ij} \log p_{j2n}) + s_{3n}(\alpha_i + \sum_j \beta_{ij} \log p_{j3n}) + \varepsilon_{jn}, \quad (6)$$

⁸ A version of the model shown here utilizes a homothetic translog functional form. More flexible forms that don't impose homotheticity can also be assumed, but they make the estimation substantially more complicated.

where p_{j1n} , p_{j2n} , and p_{j3n} denote the price of fuel for heating, cooking, and lighting under each of the three regimes; β is the vector of unknown parameters to be estimated; w_{jn} is the vector of budget shares for gas, electricity, wood, and kerosene for each household n , where n equals $1, \dots, N$; and ε_{jn} is the vector of error terms. The equation for the budget share of all other goods is omitted to satisfy the additivity restriction in this system of equations.

This demand system can be estimated by the method of maximum likelihood, directly imposing cross-equation restrictions on the structural parameters that constitute the estimated coefficients β 's. The structural parameters of the demand system (6) could be recovered from the estimated parameters and used to obtain exact measures of welfare changes following changes in the frequency of service interruptions of gas and electricity and their price changes.⁹

The model of intermittent supply has several limitations. First, it can only estimate short-run responses to price and quality changes, since decisions to purchase appliances are not explicitly modeled. The method is applicable to situations where households have already adjusted to frequent supply interruptions by purchasing new appliances. Second, this modeling approach is only appropriate when households cannot predict outages, so that cooking and other activities that use electricity or network gas as an input cannot be timed.

The method of intermittent supply raises additional possibilities for welfare analysis. For example, it is possible to test whether relative prices are the sole driving factor underlying the choice of fuel, or whether households also demonstrate preferences for cleaner and more convenient modern fuels. Preferences for a type of fuel can be evaluated by adding estimated preference parameters to the energy conversion coefficient. The main advantage of this modeling approach, however, is that it permits the welfare effect of changes in supply quality to be estimated even when lack of price variations preclude the use of the direct demand estimation approach.

⁹ The joint estimation of equation (4) allows parameters to be identified that could not otherwise be identified from the gas and electricity budget shares without the shares for fuel wood and kerosene. Estimating the budget share equations separately will still produce an unbiased estimation for the parameters of this system of equations; however, identifying parameters in the electricity and gas equations cannot be achieved without a price variation for these energy sources.

The intermittent supply approach has been used to evaluate the welfare impact of expected electricity sector reforms—greater service reliability and higher prices—in Azerbaijan (Klytchnikova 2006). The estimates of the own price elasticity of electricity range from -0.30 to -0.83 depending on whether electricity was used for heating, cooking, or lighting. The calculation of the effects of alternative reform scenarios reveals substantial potential for welfare gains through improved reliability, especially for the poor. On average, households experience welfare losses of less than 1 percent of the total household income under the scenario of a 50 percent increase in the price of electricity. Another scenario for moving toward perfect service reliability indicates gains for different categories of households ranging from 0.5 to over 2.5 percent of total income. An important finding of this analysis is the scope for welfare gains through these reforms even when improved service reliability is combined with a price increase. Nevertheless, the direction of the welfare impact is reversed at a 100 percent price increase and a 50 percent improvement in reliability, so some households stand to lose from the reforms.

An earlier ex ante evaluation of the same reforms by the World Bank (2004b) concludes that poor households are particularly vulnerable to the adverse impact of pricing reforms. Hence, the World Bank advised the Government of Azerbaijan to design a well-targeted social assistance scheme to mitigate these adverse effects. Welfare gains from improved supply reliability were deemed to be important for Azeri households, but they were not quantified. Including the positive welfare impact of these gains using the intermittent supply model presented in this paper reveals that the poor are more likely to benefit from the reform, even if the greater service reliability is accompanied by a moderate price increase. Adversely affected households are more likely to be non-poor. Thus, directing policy and investments toward improving service reliability can more than compensate vulnerable households for the losses brought about by a moderate price increase, and social assistance may not be needed as long as substantial quality improvements take place. The results of these policy simulations demonstrate the need to take the welfare impact of improved service quality into account in analyzing the costs and benefits of infrastructure reforms structured to increase the price and reliability of infrastructure services.

3.3 Averting behavior model

Given that both the direct demand estimation approach and the intermittent supply model are demanding in terms of data requirements, and the assumptions underlying the intermittent supply model are implausible in some settings, an alternative approach to estimating the welfare impact of infrastructure service quality changes is the model of averting behavior.¹⁰ This model estimates the bounds on CV using information on expenditures associated with deteriorating service quality. The model assumes that a consumer can mitigate deteriorating service quality by using certain purchased commodities—i.e., that service quality and the purchased commodity are substitutable. Under this assumption, a change in averting expenditures triggered by a change in service quality represents bounds on the welfare effect.

Consider, for example, a household that purchases bottled water to avoid exposure to contamination in the public water supply. Suppose a household maximizes a utility function $U(q, z(x, b))$ subject to a budget constraint, where q is a composite bundle of purchased commodities, x is purchased bottled water, b is the quality of public drinking water supply, and z is the level of health services a household obtains from drinking water.¹¹ The utility function is increasing in q and z , and z is increasing in x and b . Also suppose that public water is supplied at no charge. This household utility maximization problem can be represented as a dual problem of expenditure minimization.

The expenditure function, $e(p, r, b, U)$, represents the minimal expenditure necessary to reach the level of utility U , where p is the price of the consumption bundle q , and r is the price of bottled water. The expenditure function is decreasing in b and increasing in the other arguments. The expenditure minimization problem can be written as follows:

$$\min_{q, x} e(p, r, b, U) = pq + C(z, r, b) + \mu(U - U(q, z(x, b))), \quad (7)$$

¹⁰ This approach is often referenced in the literature as defensive expenditures, mitigating behavior, or coping cost models (Freeman 2003).

¹¹ This presentation of the model borrows from Bockstael and McConnell (1999). See also Ribaudo and Hellerstein (1992) and Freeman (2003).

where $C(z, r, b)$ is the cost function for the production of health services from drinking water. Compensating variation resulting from a change in quality of public water supply can be expressed as

$$CV = e(b^0, U^0) - e(b^1, U^0), \quad (8)$$

where U^0 is the utility level before the change, and b^0 and b^1 denote the quality of the public water supply before and after the change, respectively. The change in the cost of producing the original level of health services is given by the averting expenditure

$$AE = C(z^0, b^0, r^0) - C(z^0, b^1, r^0), \quad (9)$$

where z^0 is the original level of health services from drinking water. It can also be shown that

$$e(b^0, U^0) - e(b^1, U^0; z^0) = C(z^0, b^0, r^0) - C(z^0, b^1, r^0) \quad (10)$$

(Bockstael and McConnell 1999). Then Equation (8) can be rewritten as

$$CV = e(b^0, U^0) - e(b^1, U^0; z^0) + e(b^1, U^0; z^0) - e(b^1, U^0). \quad (11)$$

The third term in Equation (11) is a restricted expenditure function and is necessarily greater than the fourth term, which is an unrestricted expenditure function (Bockstael and McConnell 1999). In other words, compensating variation is equal to averting expenditures plus a term that is positive. This is a well-known bounding result based on Bartik (1988), who showed that averting expenditures both underestimate the benefits associated with an improvement in service quality and overestimate the losses stemming from a deterioration in service quality.

A crucial assumption underlying this result is that the losses from the service deterioration are completely mitigated by a purchased substitute good. Averting expenditures give an exact measure of the welfare impact of a change in service quality if the purchased good (e.g., bottled water) and service quality (e.g., the quality of public water supply) are perfect substitutes in the production of good z (health services). Under these conditions, the perfect substitutability relationship is likely to hold. But this is not usually a plausible assumption, so the averting expenditures result in a lower bound estimate of CV (EV) rather than an exact measure of the welfare change.

It is important to note that households respond to the change in service quality by adjusting their consumption of z . For example, they may demand a lower level of health

services, z , after the water quality from the public supply b deteriorates. Bartik's lower bound is given by the averting expenditures necessary to hold the level of health services constant after the quality of the water changes. This is sometimes overlooked in practice, when the observed change in expenditures on health or energy services is used as the lower bound on CV (EV) (Ribaudo and Hellerstein 1992).

Most studies of drinking-water quality use averting expenditures as a lower bound on welfare gains from improved service quality (Table 1). Some studies estimate averting expenditures associated with a specific contamination incident (e.g., Harrington 1989; Abdalla et al. 1992; and Collins and Steinbeck 1993), while others analyze household behavior on the basis of perceived rather than measured contamination levels (e.g., Larson and Gnedenko 1999; McConnell and Rosado 2000; Um et al. 2002).

Table 1. Applications of the averting behavior model

Problem description and reference	Averting expenditures used in the study
Organic chemical contamination by a microorganism <i>Giardia lamblia</i> of water supply in Pennsylvania, United States (Harrington et al. 1989)	Cost of public drinking water supply substitutes and value of time
Bacterial, mineral, or organic chemical contamination in West Virginia, United States (Collins and Steinbeck 1993)	Expenditures for cleaning and repairing water systems, and hauling and treating water by households that rely on individual wells in West Virginia, United States
Organic chemical contamination of ground water with trichloroethylene in two communities in Pennsylvania, United States (Abdalla, Roach, and Epp 1992)	Increased expenditure on and new purchases of bottled water, and expenditures related to home water treatment systems and hauling and boiling water
Low perceived quality of drinking water in France (Carpentier and Vermersch 1997)	Household purchases of soft drinks and bottled water to avoid drinking tap water
Low perceived quality of drinking water in Moscow, Russia (Larson and Gnedenko 1999)	Prevalence of household activities to reduce potential health risks by boiling, settling, and filtering water and buying bottled water
Drinking water contamination in Brazil (McConnell and Rosado 2000)	Increases in expenditures on installing filtration systems, boiling water, and buying bottled water
Perceived contamination of the drinking water supply in Korea (Um, Kwak, and Kim 2002)	Increased expenditures on installing filtration systems, boiling water, buying bottled water, and drawing spring and ground water

This second group of studies suggests that individuals act on the basis of the perceived risk of contamination rather than objective contamination levels. Hence, perceived

measures of contamination have been used as the basis for empirical analysis and incorporated into the averting behavior model (Um et al. 2002).¹²

A classical example of the averting behavior method is the study of the welfare effect of drinking water contamination in Pennsylvania (Abdalla et al. 1992). Following the detection of contamination with Trichloroethylene (TCE) in a Pennsylvania community, the Environmental Protection Agency issued a warning to notify customers of the incident. Questionnaires were mailed to households in this community to collect information about increases in averting expenditures to avoid exposure to the contaminant. These expenditures included both cash outlays and the costs of time taken to effect averting behavior. In attributing averting expenditures to the contamination incident, Abdalla et al. (1992) were careful to satisfy the assumptions necessary for the bounding result to hold (Bartik 1988). First, the averting expenditures had to exhibit no jointness in production. This means, for example, that the purchase of bottled water has no additional benefits apart from mitigating the health risk of exposure to TCE. On the other hand, if households purchased water for reasons unrelated to the contamination incident, such as taste, expenditures on bottled water cannot be considered as averting expenditures. Second, the averting expenditures should not involve sunk costs in the purchase of durable goods. For example, the benefits of home water treatment systems extend beyond the contamination incident, so the cost of such systems can only be partially included in the estimate of averting expenditures.

Applications of the averting behavior model are limited to cases where households respond to the deterioration in the quality of infrastructure services by making expenditures of time or money. The averting behavior model has been used to analyze the welfare implications of changes in air and drinking-water quality, although the range of its potential applications is much broader (McConnell and Bockstael 2005).

¹² While the function of uncertainty, perception, and expectation of service quality changes are not emphasized in this paper, they are important aspects of welfare analysis. Households adjust their behavior in response to perceived health risks or the anticipated future supply reliability of infrastructure services (Foster and Just 1989; Um et al. 2002). The role of perceptions can be more readily explored with stated preference rather than revealed preference methods.

3.4 Conjoint analysis approach

In some cases, households have the choice of a range of service providers or alternative energy or water sources. Conjoint analysis relies on actual data from revealed household behavior or experimental data provided by conjoint choice or contingent behavior surveys. The household decision problem can be modeled conveniently in the framework of the random utility model (McFadden 1974). This model postulates that households that have a choice of services and providers, choose the option that yields the highest utility. This problem lends itself to econometric estimation with discrete choice models (Hanemann 1984; Train 2003). In this framework, the welfare impact of changes in service quality can be measured with modest assumptions about the form of the indirect utility function and the distribution of the error term. The indirect utility function is usually assumed to be linear in household characteristics, infrastructure service quality, and other service attributes. Writing the indirect utility function in terms of these characteristics and attributes results in an expression for the expected willingness to pay for service quality change. As Haab and McConnell (2002) show, if the error term is distributed as type I extreme value, then this expression is given by:

$$WTP = \beta_y^{-1} \cdot \left[\ln \left(\sum_{n=1}^J \exp(-\beta_y c_n^* + s_n^* \gamma) \right) - \ln \left(\sum_{n=1}^J \exp(-\beta_y c_n + s_n \gamma) \right) \right], \quad (12)$$

where β_y and γ are unknown parameters, c_n is the initial price of service n before the change, s_n is the initial vector of attributes of service n , c_n^* is the price of service n after the change, s_n^* is a vector of attributes of service n after the change, and n denotes a specific scenario from a range of J scenarios. In order to convert the value of willingness to pay into monetary units, the expression in Equation (12) is normalized by marginal utility of income β_y . Willingness to pay can be computed for changes in the price and quality of a service or for a removal of a choice option.

The most common sources of data for this approach are conjoint choice surveys, in which a series of hypothetical experiments are presented to each surveyed customer. The alternatives in the experiments are characterized by a range of service attributes, such as frequency and duration of service interruptions, voltage or pressure levels, and so on,

as well as the service price (e.g., Cai et al. 1998; Goett et al. 2000; Louviere et al. 2000; Henscher et al. 2004). Each attribute, such as the service price or quality or the type of service provider (e.g., public or private), varies across respondents to provide data variation. The advantage of this method is that it allows the marginal willingness to pay to be calculated for each service attribute.

The obstacles to a wider use of the conjoint choice approach in valuation of infrastructure service quality are related to the complexity of survey design and the potential biases associated with the hypothetical nature of stated preference data. In general, welfare estimates generated from contingent valuation surveys, or any other stated preference methods, have been criticized because of the hypothetical nature of the data. This is considered to be the main drawback of stated preference methods and is frequently revisited in the literature on contingent valuation (Diamond and Hausman 1994; Carson et al. 2000).¹³ However, estimates of willingness to pay for infrastructure services obtained from stated preference data may be more reliable and suffer less from hypothetical bias than similar estimates for environmental quality changes, for which these methods were originally developed (Briscoe et al. 1990; Whittington et al. 1990; Griffin et al. 1995). This is likely to be true when respondents are very familiar with the infrastructure services described in a survey.

Griffin et al. (1995) compare the results from a contingent valuation survey of households' willingness to pay for a piped water connection in Kerala, a state in India, with whether these households actually chose to connect after the service was offered. In the survey, households stated whether they would choose to connect based on scenarios specifying the connection charge, monthly fees, and future service reliability. The results of this survey were remarkably precise in predicting the share of households that chose to be connected to the newly provided piped water supply, thus validating the use of the contingent valuation approach in the valuation of infrastructure services.¹⁴

¹³ Devicienti et al. 2005 offer a summary of the references on this issue.

¹⁴ Another study compared willingness to pay for infrastructure services from contingent valuation surveys with revealed preference data in three Latin American countries and came to a different conclusion (Walker et al. 2000). Survey estimates of willingness to pay fall below the actual expenditures on substitute sources of water, which, contrary to the earlier finding in Kerala, suggests that willingness-to-pay estimates are not reliable. Of course, the results depend on specific conditions in survey areas and on the survey framework.

An example of an application of the conjoint choice approach in the infrastructure context is given by the research on water and wastewater services in Canberra, Australia (Henscher et al. 2004). This study is based on a survey that presents two choice experiments, one regarding the drinking-water service and the other regarding wastewater services. The experiments specify the price of a service and a range of service attributes, including the frequency, duration, time of the day, and prior notification of service interruptions. Analysis of the responses using a discrete choice model produces estimates of willingness to pay for each service attribute. A similar survey was recently conducted in Sri Lanka to evaluate demand for high quality water services (Yang et al. 2005).

Contingent behavior data could also be analyzed by discrete choice modes if the survey experiment simulates a choice of a source or provider of a service. In a study of Chinese households in the Wolong nature reserve area, An et al. (2002) model a household choice of wood or electricity for cooking and heating. The respondents report whether they would switch from fuel wood to electricity within a specific price and electricity reliability scenario. Scenarios vary among respondents. Using the share of respondents that would switch to electricity under each scenario, the authors estimate a decrease in the volume of wood consumption and the impact on the panda habitat in the nature reserve.

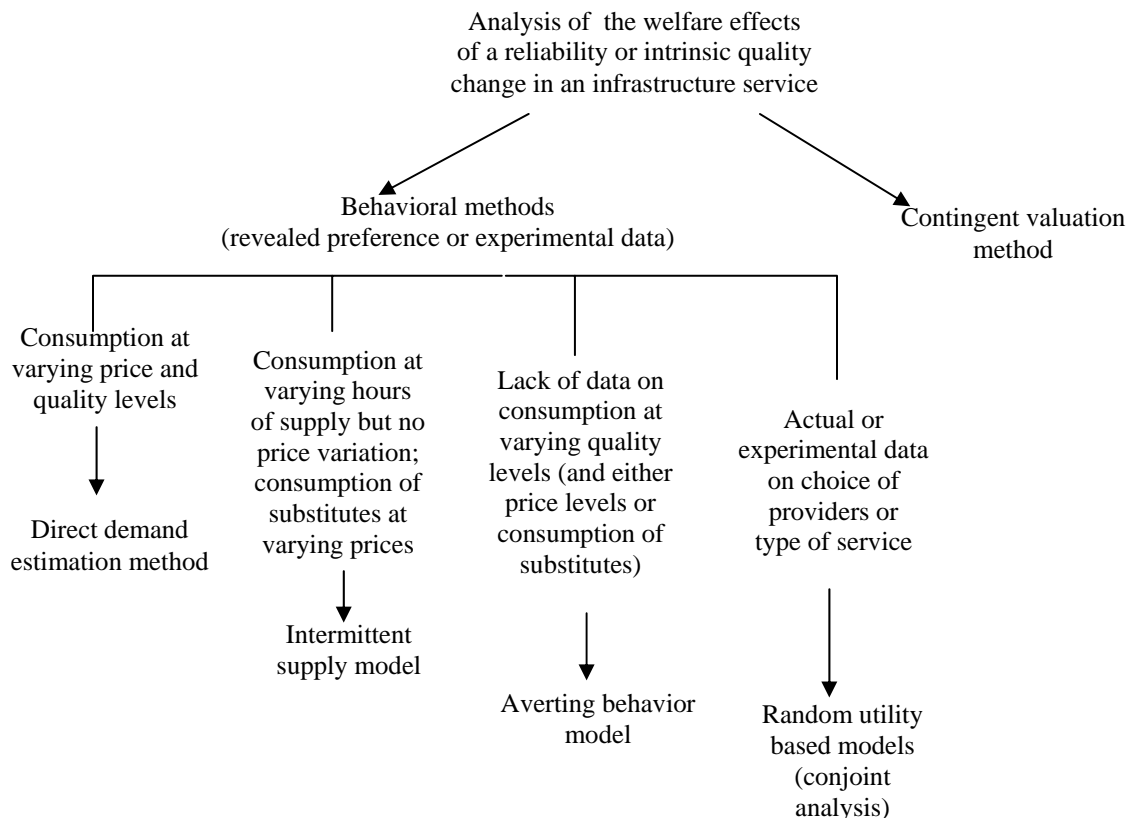
The discrete choice framework can also be applied to modeling actual choices of infrastructure service providers and substitutes for publicly provided services. Humplick et al. (1993) analyze the behavioral responses of households to changes in water quality supply in Istanbul, Turkey, and Faisalabad, Pakistan. The authors suggest that households' demand service attributes that can be classified as reliability, availability, and accessibility. Water supply reliability is defined in terms of service adequacy, which is measured by pressure, supply interruptions, and the water quality (odor, color, taste, and turbidity). Availability is measured for each water source (piped water, streams, lakes, rivers, or rainwater). Accessibility is defined based on the ability of a household to use each source. The study argues that the prevalence of supply interruptions was one of the service attributes that determined a household's choice of water source. This approach implicitly assumes that if severe supply interruptions are associated with a particular source, households would choose not to use that source even part of the time.

This assumption precludes, for example, households using piped water if it were available and backup sources in the event of interruptions. When this is not a realistic assumption, an intermittent supply model is a more appropriate modeling approach.

4. Criteria for Choosing a Welfare Evaluation Method

In practice, the choice of a modeling approach to evaluate the welfare effects of changes in infrastructure service quality is determined by data availability, the plausibility of a model's assumptions in a given setting, and the desired accuracy of resulting estimates. The first decision is whether to elicit willingness to pay for a service improvement directly through a contingent valuation survey or whether to resort to behavioral methods that use revealed preference data derived from observed household behavior or stated preference data in conjoint choice or contingent behavior surveys (Figure 4). If behavioral methods are the preferred route, the second decision involves the choice of a specific approach.

Figure 4. Data availability and the choice of a modeling approach



Direct demand estimation may be preferable in many settings, since it imposes only innocuous assumptions of weak complementarity and non-essentiality on the household preference structure. This method permits accurate welfare measurement of an impact of a service quality change with CV (EV); however, variations in price and service quality in consumption data are rarely sufficient to enable demand estimation. Even when such data exist, if the anticipated service quality and price changes fall outside the range of observable data, the estimated welfare measures would be inaccurate. Experimental data from contingent behavior surveys can be particularly useful in supplementing observed data in such cases.

The intermittent supply model serves a special case of direct demand estimation, since it takes supply constraints into account, enabling rationed consumption data to be used without further need for adjustments. The intermittent supply approach is useful in situations where data on consumption, the price of service substitutes, and variation in the hours of supply per month are available, but price variation is insufficient to estimate a demand function; thus, estimated parameters from the demand equations can be used to calculate the CV (EV) of price and service quality changes. In its current version, the intermittent supply model estimates a short-run welfare impact of changes in service quality, treating the stock of appliances as constant and assuming that supply interruptions are frequent and unanticipated.

In contrast to direct demand estimations and intermittent supply models, averting behavior models depend on stringent assumptions; otherwise they can only provide bounds on consumer willingness to pay. The averting behavior approach enables the estimation of lower (upper) bounds on welfare gains (losses) from an improvement (deterioration) in service quality. In rare cases when the mitigating inputs and service quality can be assumed to be perfect substitutes, a change in averting expenditures gives an exact measure of CV rather than a lower bound. This approach is particularly useful in cases where neither the direct demand estimation method nor the intermittent supply models can be applied.

In some situations, random utility models represent household behavior better than continuous utility maximization models. This happens when consumers choose from a finite number of service providers and types of substitutes or other options. This choice

could be observed in data on service consumption or modeled using conjoint choice or contingent behavior surveys. These surveys are beginning to be used in welfare analysis of quality changes of infrastructure services; however, they require rather complex survey instruments, and results may be prone to bias—a common drawback to stated preference methods.

When revealed preference data are inadequate, stated preference data can be a useful supplement. Revealed preference data result in better model calibration in the range of observed data, while data from contingent behavior surveys can be used for estimating behavior beyond the bounds of observed data. All four methods described in this paper can use revealed preference or stated preference data, or a combination of both. Contingent valuation surveys, also called willingness-to-pay surveys, are useful tools for welfare evaluation in the absence of revealed preference data on consumer demand for service quality improvements (e.g, Pattanayak et al. 2005). These surveys elicit willingness to pay for a service quality improvement, thereby producing a direct measure of CV (EV). Contingent valuation and conjoint analysis are the only welfare measurement methods discussed in this paper that do not rely on the weak complementarity assumption. A willingness-to-pay survey makes it possible to obtain a respondent's valuation of a quality improvement even if he or she does not consume the service in question. As previously stated, welfare estimates generated from contingent valuation surveys, or any other stated preference methods, may be prone to bias because of the hypothetical nature of the data.

The approaches to welfare measurement we discussed in this paper are not likely to reflect the “non-economic” welfare gains from infrastructure improvements. Recent papers by Ravallion and Jalan (2003), Fay, et al. (2006) and Ravallion (2006) discuss the implications on the improved access to basic infrastructure services (piped water, sanitation and electricity) on child health.

5. Conclusion

This study reviews methods of evaluating the welfare effects of changes in quality of infrastructure services. The study demonstrates that the issues of service quality or supply changes can be analyzed using a variety of methods: the direct estimation method, the

averting behavior model, or approaches based on the random utility model. The model of intermittent supply proposed in this paper to analyze the welfare effects of changes in service reliability provides another approach based on data availability and the plausibility of the model assumptions of the case in question.

While the direct demand estimation method and the intermittent supply model could be considered the most reliable methods, they are also the most data demanding approaches. Typically, the price and quality of infrastructure services do not differ sufficiently to allow the associated welfare effects to be accurately estimated using these methods, although this problem can sometimes be overcome using supplemental data from contingent behavior surveys. The combined use of revealed and stated preference data can significantly expand data, thereby enabling thorough welfare analysis of prospective reforms at relatively low cost. Most models described in this paper can be estimated using data on actual or hypothetical behavior, or a combination of these two sources.

Omitting the quality component of the overall welfare impact of projects that entail changes in access, price, and quality of a service can lead to erroneous conclusions about the welfare outcomes. A minimum set of demand-side indicators, sufficient for welfare evaluation using the averting behavior method, needs to be routinely collected by including a standard set of questions in the infrastructure modules of multi-topic household surveys. Inclusion of quality indicators is particularly important in order to establish baseline service levels, enhance accountability and monitoring by stakeholders, and facilitate targeting of social assistance transfers.

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