MODELLING THE COST OF ELECTRICITY OUTAGES IN ZIMBABWE

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ABSTRACT

This study provides the model to be used when estimating the cost of unserved utility especially electricity. It also identified different impacts of outages for different stakeholders. A three model framework has been provided to show the demand and supply of electricity with outages. The segment demand model assesses demand for electricity given outages and backup supply from own private sources. The modeling framework for electricity outages highlights two cost of outages, the direct cost and backup cost and if summed provides total outage cost. The framework can also be used in assessing direct cost for interruption in services such as water supply and telephone services.

Keywords: *Electricity outage, direct cost, backup cost, cost of electricity interruption, demand for electricity.*

INTRODUCTION

Electricity outages can deter new investment, which in turn retards the future growth of a country (Whittington, Briscoe, Mu and Barron, 1990). Similarly, reduced consumer surplus may induce mobile, but valuable human capital to depart - with a similar negative impact on economic growth. In addition, firms may stay out of business thus exacerbating problems of unemployment and inducing other related welfare costs (Eto, Divan and Brumsickle, 2004). Another possible cause of electricity outages is high birth rates due to lack of entertainment (Saghir, 2005). The high birth rate increases demand for resources by the households, so reducing the income available to satisfy other needs (Saghir, 2005). Outages also have negative health and living condition effects (Terreblanche, Nel and Opperman, 1992; Fiil-Flynn, 2002). Ill-health and poor standards of living also increase the cost of trade and commerce, by making it harder to reap the full gains from the activities that would otherwise have improved societal income and/or welfare (Hamouid and Sachs, 1999). A poor standard of living reduces productivity and performance of labourers, thereby inhibiting ability to earn (Saghir, 2005).

The prevalence of poverty compels many households to subsist on the natural resources (like firewood), causing overexploitation of these resources and resulting in social 'bads' like deforestation, smoke and contaminated drinking water sources (Saghir, 2005). Around most urban areas in Zimbabwe the signs of deforestation, soil erosion and polluted water sources are already evident. For an agrarian economy like that of Zimbabwe, power supply is critical to both economic and social development. Electricity outages thwart growth and food security; typically, hurting the poor the most (Pouliquen, 1999). When there are adequate communication networks, roads, storage and electricity, farmers can obtain the information they need to grow the most profitable crops, store them, move them to market and receive the best prices for them (World Bank, 2007). Up to 15 percent of production is lost between the farm gate and the consumers because of electricity outages, thus reducing incomes for farmers and raising the cost of food for urban consumers (World Bank, 2007). There are many costs associated with electricity outages and these costs are borne by a wide spectrum of users. An outage is a symptom of disequilibrium - excess demand for electricity. This study presents a three model approach for analysing electricity demand and supply and combines these into a three segment-model of demand for electricity in Zimbabwe. The model was formulated against the background that:

i Some consumers are prioritised to receive electricity,
ii Some consumers are investing in backup to mitigate the impact of outages,
iii Some consumers are putting up with the power outages, and
iv A power utility (ZESA) is unable to cover its cost and attempting to provide the poor with access to electricity,

THE DEMAND OF AN OUTAGE

The demand for electricity is both direct and derived (Choynowski, 2002). Direct demand is the use of electricity by consumers mostly households. Derived demand is the use of electricity as an input into production of goods and services by firms (Choynowski, 2002). Electricity outages result in both types of demand not being met.

Direct Demand Impact (Households)

Households demand electricity for lighting, heating, cooking, and driving of mechanical equipment (Filippini and Pachauri, 2002). In all cases the household combines electricity and capital equipment to produce a composite energy commodity (Becker, 1965). The household utility function (U0) from electricity use can be written as:

$$U^0 = U^0(S(E^0,CS)) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

where S is the composite energy commodity,
E is electricity and
CS is the capital stock (electrical appliances).

Households may change both their rate of utilisation and stock of electrical appliances due to power outages (Filippini and Pachauri, 2002). In the short run, a household may lower the rate at which it utilises its current stock of appliances. In the long run, since interruptions in electricity supply can result in changes in the use of other inputs, it may alter the mix of inputs. Alternatively, households may invest in alternative backup systems to avoid consequences of power outages. This investment causes an adjustment of the household's capital stock. One of the adjustments may be the substituting of highly electricity-sensitive appliances for less sensitive (and less efficient) appliances. This way, power outages negatively affect household utility. The major immediate cost of an outage is inconvenience. For more protracted outages, there are also the costs of lost food-stuffs, time, damage to household appliances and emergency cost of alternative power. The cost of inconvenience is difficult to quantify. However, where it is estimated, it usually is far much higher than the intrinsic cost of the outage. This is because the inconvenience could lead to several hazards to the individual person.

Indirect Demand Impact (Firm): The impact of power outages on a firm is influenced by:

i The sensitivity of its equipment to outages, and

ii The elasticity of its demand for electrical power (Choynowski, 2002).

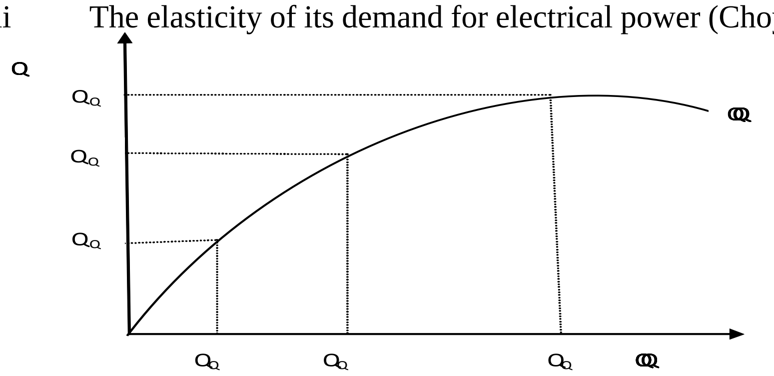


Figure 1: Electricity Production Function. ***Source:*** Coelli, Rao and Batesse (2005:22)

A production function for electricity-consuming equipment (using electricity as an intermediate input) is shown in Figure 1. As the stock increases, there is an increase in output, ceteris paribus. Initially access to power yields a high return in output (Q0 for X0). If there are outages, there is zero access and output declines to zero. Also, demand for complementary factors of production declines (Rose, Oladosu and Salvino, 2004; Coelli, Rao and Battese, 2005). An alternative response to shutting production as a result of power outage is to use analternative power source, for example, one's own generator. However, this usage may result in technical inefficiency, with the firm producing Q1 at TC1 instead of Q2 at TC1.The optimising input choice when only P0 power is available from the grid is to use P0 own power, namely point B (Figure 2). The efficient choice (A) is not available where grid access is denied. In addition to lost output and inducing technically-inefficient choices, power outages can damage equipment, destroy materials in stock, require restarts of production, reduce goodwill, and lost sales orders (market share).

Figure 2: Effect of using alternative own power generation

Impact on the nation: Power outages undermine the contribution (productivity) of the stock of electricity-consuming equipment (capital) and other factors of production (Choynowski, 2002). They reduce production potential. This impact is shown in a two good model in Figure 3. The two goods are consumer goods and capital goods. Power outages cause the Production Possibilities Frontier (PPF) to shift inwards, thereby retarding economic growth.

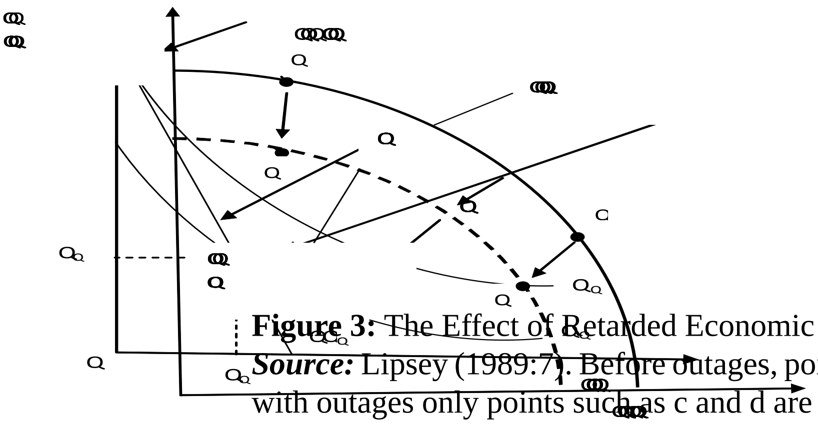


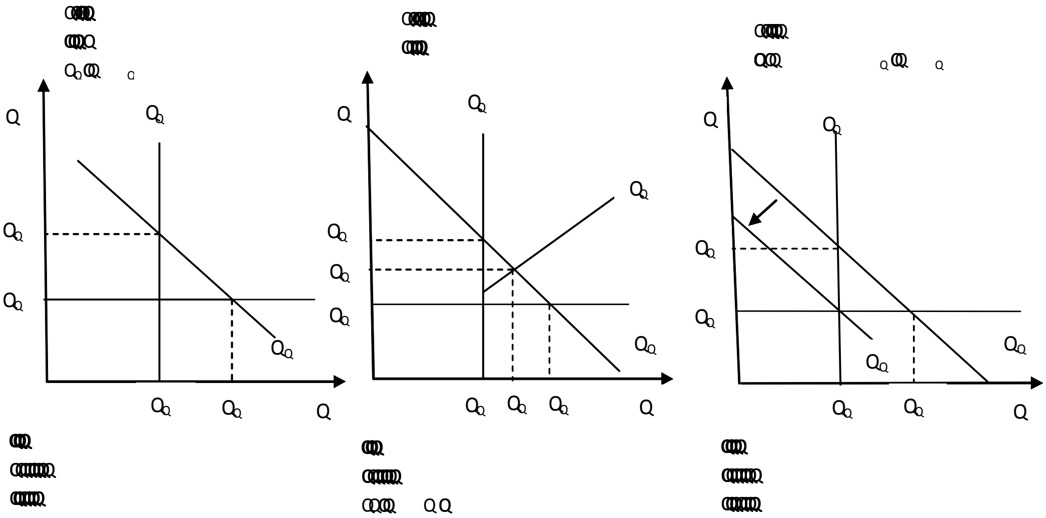
Figure 3: The Effect of Retarded Economic Growth Due to Power Outages
Source: Lipsey (1989:7). Before outages, points a and b on the PPF are feasible, but with outages only points such as c and d are attainable.

MODELLING ELECTRICITY DEMAND AND SUPPLY WITH OUTAGES

A Three Model Approach for Analysing Demand and Supply of Electricity: The cost of electricity outages can be expressed in unattained profit or utility (Klytchnikova and Lockshin, 2007). A primary attribute of electricity service supply is its service reliability (interruptions) and intrinsic service quality (frequency and timing of outages) (Klytchnikova and Lockshin, 2007). Figure 4 depicts three characterisations of this (combined) attribute. The quantity of electricity delivered (X) is shown on the horizontal (x-axis), and the price (P) is shown on the vertical (y-axis).

In all three models, the power utility can supply S_g, sets the price of the power it supplies at P_0 and demand for the power is D_1. In model A an under-supplied X_gX_1 disequilibrium results. The marketing clearing price is P_1 which is greater than P_0 (P_1>P_0). In model *B* private generation (at a higher cost) enables part of the excess demand X_gX_1 not supplied by the power utility to be met from own generation, namely X_gX_2. Letting S_2 be the marginal cost of private supply, the market for private supply establishes a price of P_2. In model *C* reducing quality of supply reduces demand (D_1 to D_2) until equilibrium is achieved at P_0 and X_g.

Figure 4: A Three model framework for demand and supply adjustment for outages



Source: Klytchnikova and Lokshin (2007:17) and own drawing

All three models yield relevant predictions about the impact on the market by power outages - the market is under-supplied, the electricity under priced, the quality of service poor and there is a significant market for private (higher cost) power generation. The three models are combined into a single one in Figure 5 by means of introducing segmentation of demand into the analysis. The three segments of the model are identified as A, B and C, and link to the models described in Figure 4. This model assumes that segmentation is feasible or an inevitable consequence of the state of the electricity sector in Zimbabwe. Within this framework, a firm may find itself operating in more than one segment, for example, being able to cover part of the outage through backup generation, but not all, and thus falling into both segments B and C.

In Figure 5, segment A consists of customers prioritised by the government to receive electricity. The tariff (price) is set or administered by government. It is set below the optimal price level but the demand (D_1) for electricity is met. If electricity supply is allocated by government, electricity tariffs or prices frequently do not reflect the marginal utility of consumption and this arrangement will be supported by the favoured customers (Deaton, 1981).The observed consumption expenditure on allocated electricity demand cannot be used in welfare measures of electricity interruptions because none are experienced by those customers (Hentschel and Lanjouw, 2000).

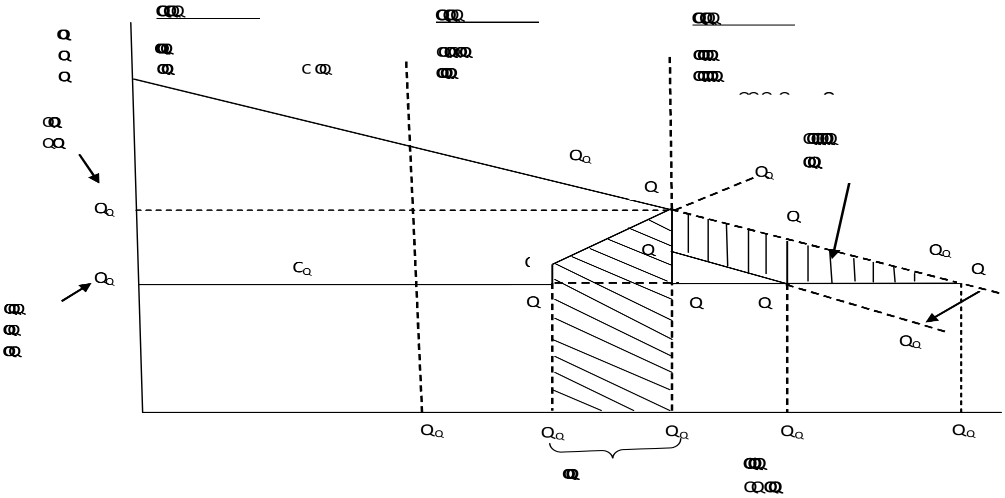


Figure 5: Electricity demand - the three segment demand curve model

Segment B in Figure 5 consists of customers whose demand is not met (they face outage) and they have a Willingness To Pay (WTP) to purchase private power. Consumers meet their excess demand of Q_1Q_2 during outages from private generation (Q_0Q_1 of their demand being met from the grid). These consumers have a reliable energy source as electricity is generated in-house when an outage occurs. Supply takes a stepped curve shape from S_1 to S_2 reflecting the higher cost of private generation. The additional backup cost due to outages (under supply) is shown by the shaded area BIQ_1Q_2. Some of the cost would have had to have been incurred by the public utility, had it supplied the power, namely Q_1Q_2CH.

In Figure 5, Segment C consists of customers without the means or WTP to meet their excesses demand Q_2Q_4 over what is supplied by the grid, namely $0Q_2$ (so they only have the option of adjusting demand according to quality). Demand among these customers shifts from D_1 to D_2. The result is that the consumers incur a welfare cost due to inferior quality of ABFE. They are only willing to pay for up to $0Q_4$. The total welfare cost of the outage is the sum of excess cost paid for own (backup) power generation plus inferior quality power, namely welfare surplus areas HIBC + ABFE.

Production Cost and Supply: The supply options shown in Figure 5 were defined by government choices, but costs are determined by other factors, like long run economies of scale and the high cost of shortrun supply. The associated cost structure is illustrated in Figure 6. Figure 6 highlights the different cost options in the short and long run. The first cost structure is the downward sloping short-run average cost (SAC) where public utility supplies electricity up to Q_1 from the current generation capacity. Up until this point there is sufficient capacity to avoid outages, but unless there is an increase in plant capacity, outages may occur beyond this point, possibly requiring private generation backup. Foster and Steinbucks (2009) estimate that own generated electricity is on average 313% more expensive than that from the grid. On the other hand, if there is investment in increased plant capacity, the costs defined by the long-run average cost (LAC) will be incurred. This curve is typically L-shaped (indicating a natural monopoly). Capacity expansion enables the utility to enjoy economies of scale in generation.

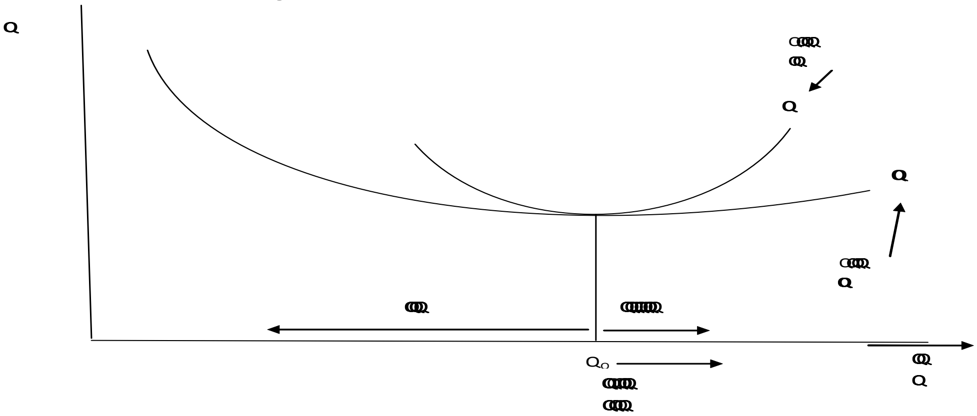
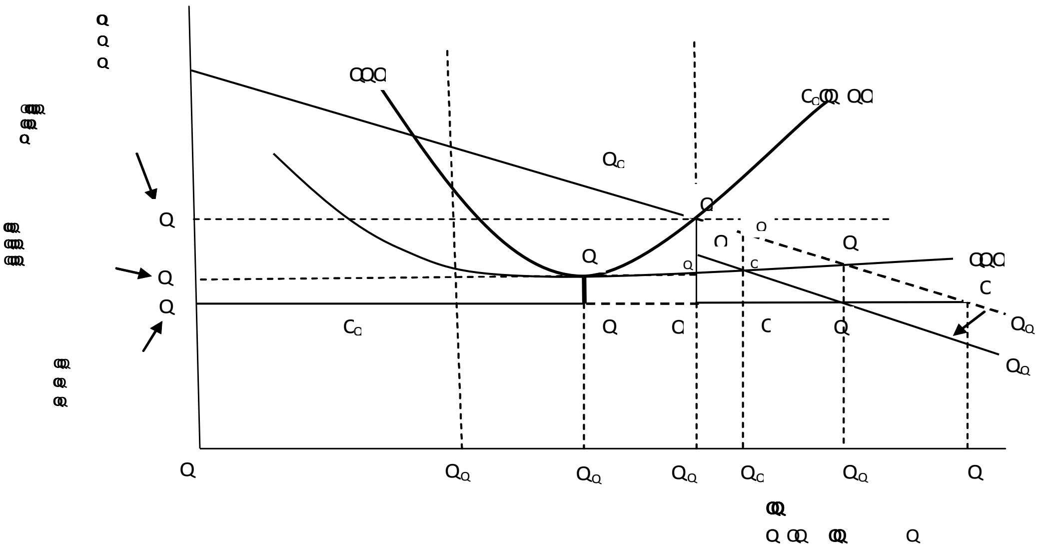


Figure 6: Cost structure options for electricity generation and distribution

Losses Due to Under-Cost Recovery in Tariff Setting: The welfare costs shown in Figure 5 assume that the administered tariff P0 to be a cost recovery one, but it may not be. Administered (regulated) prices do not necessarily reflect cost. Cost recovery tariff setting entails generating revenue to cover total cost. Figure 7 shows a situation where average cost (AC) pricing exceeds administrated pricing by the public utility. Figure 7: Electricity outage cost determination



When there is under-cost recovery pricing, economic losses are incurred on the electricity supplied, viz on $0Q_1 + Q_2Q_3$. The losses are P_0P_2IH + JKLC and benefit the $0Q_1+Q_2Q_3$ customers with equivalent consumer surplus. The welfare loss incurred by customers receiving poor quality electricity (Q_2Q_4) may be related to the fact that some have a low WTP. A commitment by the government to supply customers who cannot afford the service (Q_3Q_4) can only be achieved by reducing the quality of supply to this segment of the market (Q_2Q_4). If it is assumed that AB is equal to their cost of unserved electricity, the welfare cost of poor quality supply may be estimated from the cost incurred by those under-supplied who do not have backup alternative power generated, viz ABGE (Figure, 7), less than the equivalent cost identified in the demand model (Figure 5). To sum up this modelling analysis, Figures 5 and 7 identify two types of outage costs:

a Lost producer and consumer surplus due to poor quality of supply causing (dissatisfied consumers, damage to equipment, idle time, restart cost and lost production) losses by those who cannot avert those impacts (ABGE).The approach taken to estimate this cost (termed the welfare cost) is the direct assessment method.

b Supplementary power generating cost, or the cost of backup power - losses by those who can avert the impact of an extra private cost of BIQ_1Q_2. The approach taken to estimate this cost is the captive generation method. An alternative to private generation is for the public utility to install a bigger plant size. In this case it could generate $0Q_4$ power at an average cost of 0P2 and produce the extra Q_1Q_2 power at a total cost of JI Q_1Q_2. For this reason the extra (or excess) cost incurred due to the outages caused by the Q_1Q_2 under-supply is BI Q_1Q_2 - JI Q_1Q_2 = IBJ.

Within this model, a policy imposing outage costs will always be more costly (and less efficient) than a policy that seeks to satisfy demand through distorted pricing. But if the loss through inefficiency is small relative to other benefits achieved, for instance, providing electricity access to the poor, then the distorted pricing policy still may be the better policy. Clearly, the empirical question of how big or small the extra cost is, is a very important one to which we now turn our attention.

A distinct, but very relevant and related efficiency matter is the additional tax burden imposed to cover the loss on generating the electricity (P_0P_2IH + JKLC). This study does not estimate this entire burden as it is not an outage cost. But merely notes that economic efficiency could be determined through the redistribution from tax payers to electricity consumers.

Outage Cost Functions and the Outage Cost Estimation Framework Employed

The welfare cost function

The welfare cost is a function of the outage characteristics (equ. 2):

$$ABGE = h(\text{outage characteristics}) \quad \text{..2}$$

Outage characteristics include outage duration, outage frequency, season and capacity utilisation (Bental and Ravid, 1982; Beenstock and Goldin, 1997; Billinton and Wangdee, 2005).

The captive cost function

Similarly, backup costs are a function of backup characteristics (equ. 3):

$$IBQ_1 Q_2 = g(\text{Backup characteristics}) \quad \ldots\ldots\ldots\ldots\ldots\ldots 3$$

Backup characteristics include hours of backup use, frequency of backup use, backup capacity, annual units of electricity generated by backup and years of backup use. The backup cost is estimated using the captive generation method. Only a portion of these costs (IBJ) can be attributed to outages because the public utility would otherwise have incurred JIQ1Q2 to produce this electricity (Figure 7).

The Economic Loss-not an outage cost: The economic loss in power production is the excess of total cost over revenue collected. There may be two elements to this loss - financial under-recovery and excluded economic cost (external ones). Neither of these costs can be attributed to outages.

Framework linking alternative methods of estimating the cost of outage: This study estimates the costs of power outages imposed on four main sectors of the economy. The approach on how the costs are estimated is shown in Figure 8. A number of studies have identified different costs of outages. The direct cost/savings which occurs during, or following an outage, as identified by Munasinghe (1979), are the labour cost or savings, cost of lost of production or utility and damage, spoilage and start-up cost. These form the components of the direct assessment cost method (welfare cost). Even though power outages cause cost beyond the duration of the outage (Jyoti, Ozbafli and Jenkins, 2006) such costs are difficult to measure and are not included in this estimate.

Electricity outages, as highlighted by Munasinghe (1979), result in mitigating costs as consumers and producers take actions to minimise or avoid outage cost. These costs come in the form of investment in backup sources (Adenikinju, 2005). As shown above, the excess (not total only excess) expenditure on backup power provision is part of the cost of power outages (Adenikinju, 2003, 2005; Bose, Shukla Srivasta and Yaron, 2006;   De Nooij, Kopmans and Bijvoet, 2006).

Figure 8: Framework for electricity outages cost estimation

CONCLUSION

Power outages affect the production function, factor productivity and efficiency in the use of factors. A sectoral analysis of demand for electricity shows that, the costs of outages are not borne evenly but more by certain segments of the user population. Particularly hard hit are those with no backup generating option and not prioritised by the public utility. An analysis of cost shows that there are two main types of cost - direct welfare loss and cost of backup arrangements. Two approaches are proposed by which to estimate these costs - the direct assessment method and the captive generation method. Following the segmented approach, the welfare (direct) cost is a different outage cost from the backup cost. Therefore, the two costs must be added together to derive total outage cost.

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