Energy Economics 73 (2018) 258–273

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

# Valuing electricity-dependent infrastructure: An essential-input approach

Jed Cohen[a], Klaus Moeltner[b,*], Johannes Reichl[a], Michael Schmidthaler[c]

[a] Energy Institute, Johannes Kepler University, Altenberger Strasse 69, Linz 4040, Austria
[b] Virginia Tech208 Hutcheson Hall (0401), 250 Drillfield Drive, Blacksburg, VA 24061,United States
[c] University of Applied Sciences Upper Austria,Wehrgrabengasse 1-3, Steyr 4400, Austria

ARTICLE INFO

*Article history:*
Received 24 May 2017
Received in revised form 11 May 2018
Accepted 11 May 2018
Available online 17 May 2018

*JEL classification:*
C11
C35
D13
H42
Q40
Q51

*Keywords:*
Power outages
Public infrastructure
Multivariate probit
Bayesian estimation

ABSTRACT

Electricity is an essential input to both the production of household commodities, and the provision of public infrastructure services. The latter, in turn, are essential to the generation of additional household goods. Thus, customers' willingness to pay to avoid power interruptions will reflect both aspects of foregone household production. We recognize this as an opportunity to value infrastructure services via stated preference methods based on power outage scenarios. We motivate our model using household production theory, and implement it empirically within a Random Utility framework to derive European households' willingness-to-pay to avoid disruption of electricity provision to the "front door," as well as the loss of important public services. We find that a considerable portion of total willingness-to-pay, to the order of 20–80%, relates to the public service component. This stresses the importance of explicitly specifying the scale of outages and their effect on public services in stated preference elicitation. Failure to do so will produce welfare estimates that are unfit to inform policy, and normalized outage cost estimates that are biased - potentially by a very large margin.



## 1. Introduction

Severe weather events, which are expected to become more frequent due to climate change, pose increasing risks to the reliable provision of electricity around the globe. On the supply side, increasing temperatures and more frequent heat waves decrease the efficiency of thermal and nuclear power plants by hampering thermal conversion, and by reducing the availability and ability of water for cooling. Hydropower plants, in turn, are vulnerable to extreme precipitation and flood events, as well as inter-annual variation in inflows (Arent et al., 2014). All types of supply installations in low-lying areas are at an increased risk of flooding (Davis and Clemmer, 2014). On the transmission and distribution side, more frequent violent storms damage transmission lines and other elements of the electric grid year-round. Wildfires, which are increasing in frequency and ferocity, directly destroy electric infrastructure, and interfere with the conductivity of transmission lines (Davis and Clemmer, 2014). On the demand side, rising temperatures and intense heat waves increase the demand for cooling in many regions, further taxing the capacity of the electricity system (Davis and Clemmer, 2014). All these risks lead to more frequent and prolonged power interruptions. For the example, in the U.S. the average annual number of weather-related power outages has doubled between 2003 and 2012, affecting an average of 15 million customers each year (Kenward and Raja, 2013).

Extreme weather and a changing climate also affects other elements of the public infrastructure, such as water supply, sanitation services, and transportation. Water supply is affected both in terms of quantity due to reduced renewable surface and groundwater resources in many regions, and in terms of quality due to increased sedimentation and runoffs, as well as disruption of treatment facilities during floods (IPCC, 2014). More frequent heavy rainfall events can also overload the capacity of sewer systems and wastewater treatment plants, causing disruptions in sanitation

* Corresponding author.
*E-mail addresses:* cohen@energieinstitut-linz.at (J. Cohen), moeltner@vt.edu (K. Moeltner), reichl@energieinstitut-linz.at (J. Reichl), Michael.Schmidthaler@fh-steyr.at (M. Schmidthaler).

https://doi.org/10.1016/j.eneco.2018.05.018
0140-9883/

services (Arent et al., 2014). Transportation services, in turn, are vulnerable to flooding, will require higher maintenance due to larger temperature swings, and face cooling challenges in many parts of the world (Arent et al., 2014). Naturally, disruptions in any of these primary services can, in turn, affect the provision of health and emergency services (IPCC, 2014).

Importantly for our study, all of these public services rely to a large extent on the provision of electricity. Therefore, climate change is expected to exacerbate disruptions of basic infrastructure services *directly*, via the factors mentioned above, and *indirectly*, by increasing the risk of power outages. In consequence, the economic value of electric service reliability is intrinsically linked to the societal value of other segments of the public infrastructure. Our analysis exploits this linkage to elicit values for both power provision and power-dependent infrastructure services (ISs).

This study adds to the outage cost literature by dis-aggregating total willingness-to-pay (WTP) to avoid a power interruption into values lost due to electricity not delivered directly to the household (i.e. the "front door"), and values lost due to interrupted ISs in the households' neighborhood or region. This informs decisions regarding the optimal provision of these services, which are often largely funded by taxpayers, as well as the prioritization of infrastructure protection from power interruptions.

We find that a sizable portion of average hourly outage costs, to the order of 20–80 %, can be attributed to lost ISs for our sample of residents from eight European countries. Customers are especially sensitive to losing medical, communication, transportation, and sanitation services. Our findings raise serious concerns about using the common "WTP/kilowatt hour (kwh) unserved" metric to express outage impacts to residents, since kwh unserved are traditionally computed at the "front door," whereas, as shown in this study, household WTP relates to a much broader set of impacts and thus a much larger volume of lost electric load.

### 1.1. Power outages and infrastructure services

It is well documented that large-scale power outages can severely affect critical elements of the public infrastructure. For example, as summarized by Public Safety and Emergency Preparedness Canada (2006), the Northeastern Interconnection power outage of 2003, attributed to an overloaded grid, affected 50 million people in the U.S. and Canada, and impacted "virtually all ten critical infrastructure sectors," such as banking services, food distribution, waste water treatment, traffic lights, highway signs, gas pumps, and even internet services and firewalls, which exposed customers to multiple cyber threats.

A 2003 storm-related outage that affected most of Italy brought trains to a standstill and disrupted communication and telephone services (BBC News, 2003). An overload in Germany's power network triggered widespread outages in five European countries in late fall of 2006, leaving people stuck in elevators and delaying numerous trains (BBC News, 2006). A 2007 winter storm that hit the U.S. Midwest caused large-scale outages that left people without electric heat or lights, halted airport operations, and disrupted water supply to thousands of residents due to the failure of electric pumps (NBC News, 2007). In 2012, a series of thunder storms caused power outages affecting nearly four million customers in the mid-Atlantic and South-Eastern region of the U.S., cutting out traffic lights, halting train services, and even knocking out Amazon's cloud (data storage) services, with the cascading effect of interrupting popular internet sites and services such as Netflix and Instagram (CNN News, 2012).

It is therefore well conceivable that respondents have these IS interruptions in mind when asked to think about their WTP to avoid a specific outage scenario. However, with the exception of Reichl et al. (2013), none of the published outage cost studies based on survey methods elaborate on the *spatial scale* of a stipulated interruption.[1] Households are either told that, for additional payments, front-door delivery of power will remain uninterrupted (Layton and Moeltner, 2005; Carlsson and Martinsson, 2007), or asked to choose from a set of outage bundles that vary in timing, length and / or frequency, and are each linked to a specific fee added to the electricity bill (Beenstock et al., 1998; Carlsson and Martinsson, 2008; Baarsma and Hop, 2009; Blass et al., 2010).

In the first case, elicited WTP can only be interpreted as values for household commodities produced exclusively with front-door electricity (refrigeration, meals, hair drying, etc.) and provides no guidance as to the broader societal value of protecting or maintaining ISs. The second approach raises even bigger issues, as it is not clear which outage scale, and thus the extent of impact on ISs, respondents have in mind when they select from a given outage choice menu. This makes it impossible to clearly assign derived WTP estimates to front-door losses versus ISs-related damages, and, in turn, makes it difficult to use resulting estimates for policy purposes.

### 1.2. Valuing infrastructure services

The ISs considered in this study are best described as quasi-public goods, as they are all associated with fees, and are - at least to some extent - provided by commercial entities. However, most of them are typically subsidized by the government (medical care, water and sanitation services, public transit) or require publicly financed infrastructure (gas pipelines, road maintenance, traffic lights and signage, land and access roads for cell phone towers, etc.). In addition, some of them are overseen by public utility commissions that have considerable control over service scope, quality, and pricing (e.g water and sanitation).

Thus, to the extent that taxpayer moneys are involved in the provision and maintenance of these services, it is economically meaningful to think of an optimal level of provision. This, in turn, requires information on costs and benefits. In many cases, the latter will be difficult to gauge based on observed behavior alone, given muddled price signals due to subsidies, regulation, or lack of temporal or spatial variability. As in many other such cases, this suggests elicitation approaches based on Stated Preferences (SP) methods.

We are aware of only a handful of studies that have attempted to value essential public services in developed countries. For example, Hensher et al. (2005) and Willis et al. (2005) use a Choice Experiment (CE) approach to estimate households' WTP for uninterrupted water and sanitation services in Australia and England, respectively. Hackl and Pruckner (2006), using contingent valuation (CV) methods, elicit Austrian households' values for publicly funded emergency medical services, using a scenario of "possible future privatization." Schwarzlose et al. (2014) implement a CE in three Texan counties to elicit stakeholders' values of various public transportation attributes, with focus on expanded services for the elderly and using private car registration fees as payment vehicle. Savage and Waldman (2009), also employing a CE, estimate customers' WTP for various attributes of home internet service, such as reliability, speed, and independence of phone connections.

While all these studies find that people care about these services, such direct SP approaches also carry with them a set of empirical risks. As discussed in Hensher et al. (2005) and Willis et al. (2005), given the critical nature of some of these services to cover basic human needs, and a lack of historic problems with service provision, respondents may question the realism of stipulated interruption

[1] Using a repeated discrete choice format similar to that employed in this study, Reichl et al. (2013) stipulate outages that differ in scale between "street-only" and "province-level" to their sample of Austrian households. However, they do not report scale-specific WTP estimates.