A NEW METHOD TO ESTIMATE THE ECONOMY-WIDE CONSEQUENCES OF WIDESPREAD, LONG DURATION ELECTRIC POWER INTERRUPTIONS

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Overview

We partnered with a utility in the U.S. state of Illinois to develop and pilot a new approach to estimate the economic impacts of widespread, long duration (WLD) power interruptions. We surveyed their customers about hypothetical blackouts, identifying and classifying mitigating/resilience behaviors and quantifying their costs and benefits. Survey results are scaled-up to the broader regional economy, and used to drive a computational general equilibrium (CGE) simulation of the effects of power interruptions and attendant customer responses (e.g., relocation, backup generation). Impacts are severe: 1-, 3- and 14-day interruptions reduce the utility service area's three-month GDP by $1.8 Bn (1.3%), $3.7 Bn (2.6%) and $15.2 Bn (10.4%), respectively, with losses driven overwhelmingly by "disequilibrium" responses to shortages as opposed to price signals (71%-88%). Doubling backup power penetration moderates GDP losses by 11%-14%, and is relatively less beneficial during the longest interruption duration. Results highlight previously unquantified economic losses that can potentially be avoided by investments in power system resilience. The analysis provides basic elements of decision-support software we refer to as the Power Outage Economics Tool (POET), which is intended to inform public and private sector decisions that will influence the future of electric power systems in both the U.S. and abroad.

Methods

Our approach consists of the following three steps

(1) Advanced survey-based techniques specifically tailored to identify actions by residential, commercial, and industrial customers to reduce risk before, respond during, or adjust in the aftermath of a WLD interruption, and elicit the associated private costs and benefits;

(2) Quantification of the broader economic implications of (1), by scaling up survey results and translating them into additional disequilibrium demands for commodity inputs to sectors and households, factors inputs to sectors, and shocks to sectoral productivity and household income; and

(3) Construction and simulation of a CGE model incorporating the direct effects of curtailment of electricity inputs to sectors and households on the benchmark equilibrium of the multi-regional economy, used to estimate the indirect effects of disequilibrium shocks caused by residential and non-residential resilience tactics.

We constructed a static CGE simulation model of the Upper Midwest Illinois-Indiana-Wisconsin regional economy. The application is over a time horizon of a single three-month period from the onset of an electricity supply disruption. The core of the POET model is the supply side, which employs a hierarchical nested constant elasticity of substitution CES production structure. The lifeline input bundle nest is produced from electric power generation and transmission and distribution service.. The vectors of technical coefficients and the benchmark endowments, are calibrated using IMPLAN (2020) county social accounting matrices for Illinois, Indiana and Wisconsin for the year 2019, in conjunction with values of the elasticities of substitution, transformation and supply based on a mix of assumptions and previous modeling studies. The model is formulated as a mixed complementarity problem using the MPSGE subsystem for GAMS.

Power interruptions' economic losses emanate from two sources. The first, market equilibrium impacts, arise from curtailment of electricity supply, and hence consumption, below the level demanded in the baseline state. Firms and households respond by substituting other inputs for electricity, which in turn stimulates price and quantity adjustments across the economy. Such responses generally increase electricity-using firms' production costs and the prices of their commodities, reduce factor hiring and remuneration to households, and, as consumers simultaneously face rising prices and declining incomes, reduce households' real consumption and economic well-being. The second, disequilibrium impacts, arise when power disruptions trigger breakdowns in the normal functioning of markets by disrupting utility services, transportation links, and movements of goods and people. The short-run consequences are that commodity demands exceed supplies (including inventories), and prices neither reflect true scarcity nor incentivize producers to increase supply to alleviate shortages. Firms and households take actions—uncoordinated by price signals—to preserve their profits and well-being, respectively (e.g., the use of back-up generators). Such "resilience tactics", although privately beneficial, incur additional costs that fall directly on the customers and affect prices in unanticipated ways. In such settings, the price and quantity adjustments necessary to restore the economy to its baseline state are likely to diverge significantly from those manifesting in market equilibrium. Survey responses revealed access to backup generators as a key determinant of resilience. We tested the importance of this tactic via a high-backup generation sensitivity scenario that combined surveyed customer costs with rescaled customer weights to approximate a doubling of observed customer penetration of backup power. (Responses were scaled up geographically to ComEd's service area by linking customer characteristics with regional economic accounts and translated into impacts to broad industry sectors and household income groups. The resulting shocks were then introduced into the CGE model.

Results

Backup generation is available to 12% of residential, 22% of small businesses, and 71% of large businesses, with the most common fuel being diesel or gasoline (54-63% of all backup generation). For residential and small business customers, this was followed by natural gas and propane. GDP loss estimates, by county/region, are presented below:

	Electricity curtailment only			Electricity curtailment + ancillary impacts			Electricity curtailment + ancillary impacts + high backup generation		
	1 day	3 day	14 day	1 day	3 day	14 day	1 day	3 day	14 day
Cook	140	439	2,628	1,242	2,492	9,895	1,064	2,135	8,827
DeKalb + Kendall	4	12	93	33	72	301	28	59	249
DuPage	35	109	610	262	473	1,803	230	408	1,647
Grundy + Kankakee	6	18	99	29	60	237	25	50	200
Kane	11	35	252	91	183	788	77	150	681
Lake	24	74	414	187	357	1,420	166	310	1,252
McHenry	4	13	99	43	90	392	37	78	357
Will	21	63	330	121	221	977	108	193	862
Rural ComEd	23	71	384	156	334	1,282	138	284	1,144
ComEd Total	268	834	4,909	2,164	4,280	17,094	1,874	3,666	15,221
IL-IN-WI Region	257	801	4,715	2,338	4,509	17,665	2,036	3,867	15,768

Conclusions

We offer key principles, an operational roadmap, and basic data to facilitate improved estimates of power interruption-related losses in the U.S. and abroad. A fruitful next step is exploring whether our survey results can be combined with different data on population characteristics and economic structure, to extend characterization of the economic consequences of WLD electric power interruptions to a broader range of contexts. Perhaps most importantly, the information generated from these types of studies can be used to help utility planners and policymakers estimate the economic benefits—in the form of avoided losses—of proposed investments in power system resilience.

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