CULTURAL ANTHROPOLOGY

Openings and Retrospectives

ECONOMY ELECTRIC

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An electrical engineering doctoral student studying the electric grid once told me, "The point of all we do is to better match supply and demand." This came as a surprise given that, today, discussions surrounding the grid typically focus on the integration of renewable energy and communication technologies. From U.S. Department of Energy publications to electric utilities' advertisements, this theme frames discussions of the smart grid—a term that denotes a digitalized, more robust grid structured by automated sensing technologies. Matching supply and demand, on the other hand, sounds like it belongs in an economics textbook: it is, after all, a task assigned to markets in many variants of economics, perhaps most famously in the work of Friedrich Hayek. I was also intrigued by the qualification in the student's statement: *better* match, which suggested that matching was a permanent agenda—matching ever better. Could the balance of supply and demand not be simply left to buyers and sellers to work out amongst themselves, as Hayek had envisaged? Why did this researcher think that an objective famously attributed to markets constituted her field's raison d'être?

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With this conversation in mind, in 2013 I started anthropological fieldwork on economic thinking about electricity among electricity traders and analysts, market designers, economists, and electrical engineers in the United States. Discussion of the supply and demand of electricity saturated this research. My interlocutors, in conversations and public presentations, often prefaced their words with a commentary on the practical challenges electricity poses to commoditization and marketization: that it cannot be stored in large quantities and thus should be consumed nearly instantaneously after production. These worries are by no means novel. Balancing supply and demand—when neither supply nor demand is fully known ahead of time—appeared as an engineering question at the very beginning of electrification. Today, while major imbalances resulting in blackouts are not a daily issue for the grid, the supply and demand curve still serves as an essential instrument for a variety of actors who are not themselves economists.

While recent scholarship on markets (particularly financial ones) has focused on how economists help to create conditions they purport to merely describe (Callon 1998; MacKenzie 2006; MacKenzie, Muniesa, and Siu 2008), electricity illustrates how theories—both economic and anthropological—may be challenged and resisted by commodities and their physical properties, even as a variety of experts try to standardize those commodities for market circulation. Drawing on the history of electricity and on my own ethnographic research, in this essay I mean to show how electricity alters our conventional understandings of commodities, economics, and markets.

ELECTRICITY AS A COMMODITY

Electricity emerged as a commodity in the late nineteenth century, at a time when conventional models in political economy and the nascent discipline of economics did not account for a commodity that could not be stored. Residents of cities in the United States "encountered electrification in many guises" (Nye 1992, 138): as spectacle at fairs, as public transportation that reorganized public space, and even as a therapeutic substance whose wonders waited to be unlocked. Electricity itself was not originally the principal commodity of the electrical industry: George Westinghouse and other industrial players made money by selling electricity-production equipment to city governments and industrial manufacturers. The commodity that changed hands also constituted a means of production in its own right. By the end of the nineteenth century, though, electricity's "many guises" were commoditized. Instead of selling production equipment, Thomas

Edison built a network around his central power station to sell domestic lighting to consumers (Hughes 1983). Electricity, the fleeting current, became singled out as a useful good that changed hands, ushering in the era of electricity as we know it.

Yet the commodity that electricity became in Edison's network bore little resemblance to the models used by contemporary political economists. For instance, cotton featured heavily in the first volume of Karl Marx's (1977) *Capital* to illustrate how commodities gain exchange value. Alfred Marshall, the pioneer of neoclassical economics, spoke of knives in a footnote of *Principles of Economics* (Marshall 1890, 432), which famously included the first graphic representation of the supply and demand curve. Useful objects such as cotton and knives helped reinforce the notion that production and consumption, as well as supply and demand, are separate forces that interact through time until an equilibrium is reached. Such commodities can, after all, wait in a warehouse while producers and consumers rethink their buying and selling decisions. In the case of electricity, to this day, the time window to establish equilibrium is limited to seconds in order to keep the electric grid intact and functioning. If the removal of supply (say, as a result of a tripped power station) is too sudden, blackouts can occur near and far, and similarly, transmission lines can fail or blow up if they are subjected to more power than their carrying limit allows.

There is no evidence that the commodification of electricity prompted economists (or economic anthropologists) to rethink the equilibrial conditions of supply and demand. Yet, interestingly, the topic commanded the attention of electrical engineers from the very beginning of electrification. Building on his earlier experience with telegraphy, Edison devised electromagnetic devices—regulators and exciters—that stabilized minor deviations from standard supply (Hughes 1983, 43). In his centrally orchestrated system there was only one source of supply and, with a known number of light bulbs (around ten thousand), forecasting demand—or "load" in electrical parlance—was also not a major problem. By the early twentieth century, however, small grids were increasingly integrating into each other, connecting different kinds of power stations and carrying alternating current across long distances. The poorly understood dynamics of this integration resulted in power surges in transmission lines and frequent blackouts, attracting the attention of the electricity industry and newly emerging electrical engineering departments (Mindell 2004, 144).

Massachusetts Institute of Technology (MIT) electrical engineering professor Harold Hazen saw firsthand the challenges of maintaining system stability, having worked in the 1920s on General Electric's five-hundred-mile transmission line between Quebec and New York. Hazen compared its operation to the "towing of one car by another with a long elastic cable stretched almost to the breaking point. Under these conditions, any mishap, such as a short circuit or a sudden adding of load, would in effect snap the towing cable" (Mindell 2004, 151). At MIT's electrical engineering department, Hazen, under the supervision of Vannevar Bush and in collaboration with mathematicians Norbert Wiener and Claude Shannon, led the building of the network analyzer, an analog computer that modeled the electric grid for researchers to study the stability of voltage and frequency as different sources of alternating current interact. The mechanical calculators built to analyze the electric grid were then turned into general-purpose machines open to the use of other scientists and engineers on campus. During the wartime and after, engineers and mathematicians of the electric grid, like Hazen, deduced general theories for feedback, control, and computing from their studies, which would later obscure their roots in the study of the electric grid (Mindell 2004). By the second half of the twentieth century, major stability issues were resolved, the computing revolution had been born out of electrical engineering departments, and the academic study of the grid had fallen out of fashion. The study of supply and demand, however, has remained a critical component in day-to-day grid management and has garnered scholarly interest once again in the age of the smart grid.

ELECTRICITY EXCHANGE AS ECONOMICS

As an unusual commodity, electricity has prompted various communities of practice to pursue fundamentally economic agendas. The history and anthropology of electricity as a useful and exchangeable good, then, addresses recent debates on the relationship between economic theory and economic facts on the ground. Recently, the work of economists in creating theory that is not only descriptive but also prescriptive has been brilliantly spotlighted by Michel Callon's (1998) formulation of the performativity of economic models and the enthusiastic response his work has received in anthropology and sociology (e.g., Lépinay 2011; MacKenzie 2006; MacKenzie, Muniesa, and Siu 2008). However, electricity exchange is rife with examples of noneconomist experts creating economic theory concerning electricity and/or adapting the tools of economics to the specificities of electricity.

The scarcely known contribution of the electrical industry to the science of economics has to do with the advent of large, integrated grids. Samuel Insull—

originally a protégé of Edison and later the head of a small electric utility in Chicago—was able to build an empire, Commonwealth Edison, which swallowed all but a few competitors in the Chicago area by mobilizing an old economic argument—the natural monopoly. According to John Stuart Mill (1848), in industries with large starting costs and large demand, only one firm could meet demand in a given territory while continuing a profitable existence. To legitimize his claims to monopoly, Insull created demand for electricity by investing heavily in research on electrical appliances.[1] Insull pitched Mill's argument to state politicians, to whose campaigns he had financially contributed, asking for exemption from antitrust laws and for the right to exclusive use of the transmission grid. To the shock of American industrialists touting ideals of free enterprise and competition, Insull announced his advocacy for state regulation that would allow monopolistic activity (McDonald 1958). The notion of "natural monopoly" made it into neoclassical economics textbooks as fact only in the mid-twentieth century (Mosca 2008), decades after Insull had successfully, if controversially, introduced it as the economic justification for his network-building.

The economic order of electricity is now intended to be competitive. Since the beginning of the deregulatory process in the 1990s, states have been able to pass laws to disassemble monopolies and enable new competitors to join the industry. In 1996, the Federal Energy Regulatory Commission invented the concept of electricity markets—computational processes, operated by nonprofit transmission operators, by which participants' bids and offers are computed to generate prices binding for all. The first electricity market came online in California in 2000, and today there are seven across the United States, each with hundreds of utilities and generators as participants. The economic order of electricity is now populated by traders employed by participants, virtual traders who make profit by way of speculation and arbitration, and market analysts selling trading advice. These actors are primarily programmers, whose work revolves around forecasting supply and demand (and hence prices) ever more precisely and accurately—an elusive goal that they describe in terms of the granularity of data. On the face of things, trading electricity may not look different from, say, trading bonds and securities. But upon closer inspection, the "art of association" (Beunza and Stark 2004) that traders and analysts engage in to forecast changes in prices is dependent on electricity-specific tools that programmers are designing.

Notably, the price algorithm used by transmission operators is an imposition of marginal utility theory onto the physics of electricity transmission. Pioneered in the 1980s by an electrical engineering professor at MIT, spot prices of electricity (now known as Locational Marginal Prices or LMPs) are calculated differently for each node across the grid, depending on the different spatial costs of injecting and withdrawing electricity. As I observed in 2013 at a market intelligence company selling trading advice to participants, those who exchange electricity need to forecast the supply and demand data that go into LMPs on a daily basis. In the morning hours before bids and offers were due, market analysts, who were often former or future electricity traders, stayed glued to multiple screens as they drafted written advice to participants under a deadline. They rarely uttered a word except to exchange opinions with other analysts working on the same market. While their fast-paced rhythm is reminiscent of the work culture described by scholars of financial markets (e.g., MacKenzie et al. 2012), electricity traders and analysts deal with a commodity that is not only volatile but also essential to modern life, involving continuous feedback from its actual physical usage. The analysts I observed pulled real-time information into their models (often advanced data spreadsheets) from multiple public and private sources—which power station reported an outage, which regions had an expected spike in demand due to weather, and how the wind and solar stations would fare that day.

Figure 1. Control room of the Electric Reliability Council of Texas (ERCOT). Photo courtesy of ERCOT.

The supply and demand information periodically published by transmission operators remains insufficient for market actors who seek to gain competitive advantage from superior forecasts of supply and demand. They are encouraged to excavate and incorporate every possible grain of information about real-time electricity conditions at ever-shorter time scales into the mass of data analyzed by their models. As the main factor that influences demand, weather has become a subject of particular interest. The analysts whom I observed were assisted by in-house meteorologists who expanded the analysis of weather conditions to include factors other than temperature, such as cloud cover, which determines the amount of sunlight that reaches solar stations. While meteorological expertise can now be harvested to improve electricity markets, science helps less with the treatment of other supply and demand factors than do professional experience and common sense. Every analyst knew, for instance, that their models would get somewhat confused on the day of the Super Bowl when television viewing, and hence electricity usage, spikes for reasons that are not coded into the models. It fell to the analysts to translate this cultural phenomenon into the language of the models by making manual changes to anticipated demand.

The expert performativity of engineers and programmers thus remains in constant balance with the dynamics of real-time consumption. Electricity illustrates how noneconomist experts put novel or adapted economic theories and tools to use in creating conditions for exchange. These markets depend on an understudied version of economics—a vernacular one that, nevertheless, "makes its world" (Mitchell 2005, 297).

THE FUTURE OF MARKETS

The current turn in the electrical industry toward smart grid technologies presupposes a particular vision for the future of markets: an increasing temporal frequency for trading activities and an increasing number of participants. As Hirokazu Miyazaki (2003) argues, markets are often animated by market actors' desire to respond to temporal challenges. Traders of financial derivatives, for example, seek ever-faster-paced action for increased opportunities of arbitrage (MacKenzie et al. 2012). Electricity's material requirements for deliverability and growing centrality to modern life imposed a sense of urgency on actors in the electricity industry even before the creation of markets. Today the smart grid, as a research effort into increased temporal sensitivity to changing conditions in supply and demand, constitutes a new step in electricity's transformation. Envisaged as a system of decentralized information circulation—hence a market in the

Hayekian sense of the word (see Hayek 1945)—the smart grid promises markets that are trading almost constantly. But unlike markets in financial derivatives, the smart grid is intended to encompass all of society, turning all electricity consumers into active market actors.[2] I argue that the tradition and contemporary aspirations of electrical engineers organically generate a vision that we might otherwise misrecognize as generically neoliberal. Smart grids are key to understanding this vision.

Smart grids repopularized the academic study of electric grids after a prolonged hiatus. After the stability problems of the electric grid were solved to a large extent in the second half of the twentieth century, the study of the electric grid became marginalized in electrical engineering departments, gradually giving way to the study of electronics (Ceruzzi 1988). Until recently, one researcher told me, graduate students did not want to study electric grid management because "all you did was design a transmission line." Through the smart grid, researchers now aim to bring computing back into electrical engineering, both to fix the vulnerabilities that caused blackouts like the one in 2003 that affected forty-five million people across the northeastern United States and to accommodate a growing number of renewable energy sources within the grid. In 2013, I spent a semester at a smart grid research center at Carnegie Mellon University (CMU). In the doctoral researchers' spartan office, grid models have now moved from Harold Hazen's analog calculating machines to researchers' personal laptop computers. Modeling now means numerically inputting the quantity and direction of electricity flows into programming software like MATLAB.

One researcher used her model to test different algorithmic and technological means of calculating LMPs. Instead of once-a-day submissions of bids and offers, she foresaw participants iteratively interacting until they reached an improved equilibrium (Joo 2013). This researcher proposed devices inserted into electricity buyers and sellers' equipment that could continually communicate without human intervention to negotiate the price—the point at which supply and demand meet. For her doctoral project, she tested her algorithm successfully in the realm of her model—that is, the lights would have stayed on if her model had been an actual electric grid. Of course, like many other researchers I met, this researcher did personally care about a grid that accommodated more renewable energy. But her primary goal was to demonstrate a grid in which supply and demand could be manipulated in ever-smaller quantities, even as the lights remained on. Because of the intermittent nature of sources like wind and solar, electricity from renewable sources comes in smaller quantities than electricity from fossil fuels and is less reliable. If we could achieve the integration of small amounts of electricity from renewable sources without compromising reliability, my interlocutor argued, we could decrease waste and match supply to demand within ever-finer ranges. Renewables, in other words, have become a new component of the age-old research program of balancing supply and demand.

But what exactly is demand? By whom is this emergent market, the smart grid, supposed to be populated? A major part of smart grid research consists of demand-side management (DSM), which involves the manipulation of consumers' electricity use through technological equipment, education, and various incentives. DSM researchers whom I met at CMU and elsewhere envision a new electricity consumer. Lamenting consumers' indifference to electricity prices and their failure to act as proper economic actors—the learned passivity that can be traced back to Edison's centralized carbon-fueled system—these researchers hope to create what one could call a new *homo economicus*. The new consumer, as one researcher of automated home technologies explained, is best characterized as striking a balance between activity and passivity: she is active insofar as she is interested in shifting consumption behavior, but passive insofar as she lets automated home devices run without interfering with them. These devices would make decisions for consumers in a way that would advance the goals of the smart grid by accomplishing electricity tasks—like charging one's electric car—while electricity is cheap or when renewable sources are available.

Other researchers proposed devices that would deliver information to homes about real-time conditions of supply and demand (and one day, they hope, real-time prices). The nonautomatic forms of decision-making called forth by these technologies are the purview of psychologists who are increasingly entering the DSM field to study which factors are most effective in instilling an urge to adapt consumption behavior. Regardless of their different beliefs about humans' economic proclivities, DSM researchers hope to turn us—as electricity consumers—into a new homo economicus, upgraded with new expertise and technological equipment and making decisions for a more balanced grid either automatically or deliberately. Electricity, in other words, has become a vehicle for the expansion of the economic grid into previously non- or semieconomic domains, in line with Michel Foucault's (2008) description of the workings of American neoliberalism.

Neither the market quality of the smart grid nor the new electricity consumer as a homo economicus is taken for granted by smart grid researchers. What Hayek described as the market, these researchers take as a research agenda: a guiding ideal that can only be approximated, at best. While anthropologists drawing on the performativity literature have identified some of the previously unsuspected actors who are involved in the making of markets, more attention must be paid to the actors operating at the limits of what we usually understand to constitute a market—a technoscientific space ever expanding in its meanings and its scope.

CONCLUSION

Electricity can teach us to see commodities, markets, and economies in a new light, especially when the materiality of electricity and its centrality to so many technologies of modern life exceeds or troubles traditional imaginaries of political economy and economics. Electricity can teach us to see the economic performativity of programmers and engineers, as well as how new market forms and informational systems are helping to redefine familiar grid infrastructure. Economic anthropology has much to learn from anthropology electric, an anthropology that explores where economics meets physics, undergoes mediation by computers, and travels as far as the wires can reach.

NOTES

1. For instance, home economists knocked on doors to tell women that good homemaking depended on using electrical appliances (Goldstein 1997).
2. Gökçe Günel (2014) describes similar aspirations in a planned city in Abu Dhabi to create an everyday market by redefining energy use in terms of a shared currency.

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