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Hurdling Barriers Through Market Uncertainty: Case Studies in Innovative Technology Adoption

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ABSTRACT

The crisis atmosphere surrounding electricity availability in California during the summer of 2001 produced two distinct phenomena in commercial energy consumption decision-making: desires to guarantee energy availability while blackouts were still widely anticipated, and desires to avoid or mitigate significant price increases when higher commercial electricity tariffs took effect. The climate of increased consideration of these factors seems to have led, in some cases, to greater willingness on the part of business decision-makers to consider highly innovative technologies.

This paper examines three case studies of innovative technology adoption: retrofit of time-and-temperature signs on an office building ; installation of fuel cells to supply power, heating, and cooling to the same building; and installation of a gas-fired heat pump at a microbrewery.

We examine the decision process that led to adoption of these technologies. In each case, specific constraints had made more conventional energy-efficient technologies inapplicable. We examine how these barriers to technology adoption developed over time, how the California energy decision-making climate combined with the characteristics of these innovative technologies to overcome the barriers, and what the implications of hurdling these barriers are for future energy decisions within the firms.

Introduction

Beginning in the winter of 2000, California energy consumers faced a "triple whammy" of energy concerns: (1) a dramatic rise in deregulated natural gas prices (2) electricity blackouts and the threat of additional blackouts, and (3) increased electricity prices as the CPUC tried to mitigate the vast discrepancy between deregulated wholesale and regulated retail rates. In sum, consumers were faced with crises both of supply and of price.

Consumers took a variety of actions to mitigate the effects of these crises. In some cases, consumers adopted technologies that had not been widely used before, or implemented technologies in new ways. We identify these circumstances as "innovative technology adoption." This paper presents case studies of three innovative technology adoption decisions.

We first discuss theories of innovative technology adoption and predictions about firm behavior, drawing on the work of Rogers. We then discuss: (a) how these two firms fit the theory of innovative technology adoption, (b) what additional factors seemed to play a role in their adoption of these technologies, and (c) how these initial decisions influenced their views about further technology adoption. Finally, we consider what implications these firms' behavior might have for energy policies aimed at encouraging energy-efficient technology adoption.

Theory

There have been a number of studies of technology adoption conducted, but one author seems to have had a singular influence on the discussion of technology adoption and energy policy. Everett Rogers' book *Diffusion of Innovations* is regularly mentioned in discussions of market transformation and energy efficiency adoption. (The Proceedings of the 2000 ACEEE Summer Study cite him three times.) *Diffusion of Innovations* has become the classic reference for discussion of innovative technology adoption and its diffusion through society.

In the book, Rogers suggests five variables that influence decisions to adopt an innovation. (For simplicity, we will refer to an innovation as a new technology in our discussion below, but an innovation can also be a process improvement.) These variables deal with the decision maker's perceptions of specific qualities of the innovation that make it attractive. The perceived attributes include relative advantage, compatibility, complexity, trialability, and observability. Each of these variables is discussed below.

Relative Advantage

Relative advantage refers to the degree to which a decision maker perceives a new technology to be superior to an existing technology; i.e., faster, cheaper, more durable, etc. For example, a new type of light bulb might be less costly to operate than previous light bulbs. The greater advantage of the new technology over the old, the more likely it is to be adopted.

Compatibility

Compatibility refers to how a new technology relates to the decision maker's past experiences, ways of doing things, existing values, and needs – in other words, the decision maker's "operating paradigm." How easily a new technology can be introduced into the existing environment without changing these values shapes an individual's attitude and willingness to adopt the innovation. For example, if a new light bulb can simply replace the bulb in use, it has high compatibility; if a new light bulb requires replacement of existing light fixtures, has different operating characteristics (e.g., flickers when starting instead of coming on instantly), or "looks weird," it has low compatibility and is less likely to be adopted.

Complexity

Complexity refers to how difficult it is to understand or use the technology. For example, a heat pump water heater is more complex than an electric resistance water heater. A manual transmission is more complex to operate than an automatic transmission. A highly complex innovation is less likely to be adopted.

Note that one can have a relatively simple technology with low compatibility (for example, replacing electric water heating with natural gas water heating in an area with no natural gas service currently installed) and a relatively complex technology with high compatibility (using the same example, replacing the electric water heater with a heat pump water heater.)

Trialability

Trialability refers to the ability to experiment with or test a new technology on a limited scale. One might consider this the degree of commitment necessary prior to deciding whether to adopt the new technology. For example, if a new light bulb can be put in one lamp for a week and then replaced with the old bulb, it has high trialability. If, on the other hand, the light fixture has to be rewired to accept the new bulb, the new bulb has low trialability. Higher trialability makes the innovation more likely to be adopted.

Observability

Observability is the degree to which the technology under consideration can be viewed in operation in other installations. Direct observation is not necessary to accomplish "viewing" – case studies, for example, can also provide information about the technology. To the degree that the decision maker can see the technology in use elsewhere, the likelihood of adoption increases.

With those five perceived attributes in mind, we turn to the two decision makers whom we interviewed about their decisions to adopt innovative technologies.

Method

Our results rest upon two distinct forms of data collection. The first is direct experience. One of the authors has been a self-employed energy and environmental services consultant for many years. Both of the business owners discussed are people with whom the author has had a long-standing personal and professional relationship. As a result, the author was closely involved in the selection and analysis of the systems in question.

The second form of data collection we used was qualitative research carried out by LBNL researchers. We interviewed the decision makers who implemented these innovative technologies by phone using a semi-structured interview protocol. The protocol covered five major discussion topics: business and energy context, consumption practice changes, incentives to change consumption practices, results of consumption practices, and future intentions. *Business and energy context* gave an overview of the business operating environment and the importance of energy as a component of that environment – essentially, the background story. *Consumption practices* provided the story of the behavioral changes that occurred, and *incentives* examined what drove those changes. *Results* provided the decision maker's interpretation of the impact of their changes. Finally, the *intentions* section gave an indication of the respondent's satisfaction with regard to the actions taken.

The semi-structured interview method allowed the respondents to respond in their own words, telling their own story of how the technology adoption had taken place. Because they were able to share their story on their terms, our respondents were willing to take quite a bit of time to discuss their experiences. The interviews were roughly an hour long.

The combination of these two data collection methods allows us to have both an expert understanding of the technologies in question and an insight into the decision process of the business owners investing in these technologies.

Case Studies

Below we provide a short description of the context in which the decision was made and an analysis of the five influence variables for each technology adoption.

The Historic Office Building

Bob[1] is the co-owner (with one other person) of a 12-story, 93,000 square foot historic office building in the downtown area of a city located in California's San Joaquin Valley. The building was historically the headquarters of a regional bank. In the 90s, the bank was bought out by another company. Eventually, the office building fell into disuse, and the company holding the title on the building went into receivership. Bob purchased the vacant building from receivership at a very favorable price.

Bob has years of experience in managing commercial office space, and his experience has led him to conclude that energy consumption is the major cost of operation. As a result, energy efficiency improvements have been an important part of the preparation of the building to accept new tenants. While Bob's opinions and actions were shaped by historically stable energy prices, the importance of controlling energy costs has been emphasized with the current electricity tariffs applicable to the building, which are roughly 12¢ per kWh plus demand charges.

LED outdoor lights. The building has three roof-mounted time and temperature signs. The existing signs had electro-mechanical switches and 378 150-watt spotlights as the "pixels" of the display. Because the lights needed to be very bright to be seen during the day, they were disturbingly bright at night. As a result, they needed to be dimmed during evening hours. The electro-mechanical switches provided this function in addition to controlling the text displayed on the sign.

Because the building is designated an historic structure, no substantial change could be made to the appearance of the signs. That eliminated the option of installing a new sign system. Continual cycling between displays of time and temperature, as well as the exposed location of the lamps, precluded a simple switch to compact fluorescent bulbs.

Since the conventional solution of screw-in CFLs was not an option, Bob had basically resigned himself to leaving the signs unchanged. Indeed, he felt that no change was possible.

With the energy crisis underway, a consultant made the suggestion that there might be a way to reduce the energy consumption of the signs by adapting LED turn signals for use as the signs' lamps. Given the potential savings projected, Bob agreed to try it.

The signs were retrofitted with a solid state controller DC controller replacing the AC electro-mechanical switching and 12-volt 4.5-watt LED lamps replacing the incandescent bulbs. The LED lamps were modified from commercial vehicle tail lights by the addition of a screw-in base. The delivered cost of these modified lamps was roughly $40 per bulb.

The sign retrofit from 150 watt incandescent bulbs to 4.5 watt LEDs will save 55 kW x 8400 hrs, or 462,000 kWh per year. At 12¢ per kWh, that will produce an annual cost savings of over $55,000 in consumption charges alone. In addition, the reduction of

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[1] Pseudonyms have been used to identify both respondents.

controller maintenance and lamp replacement costs will save approximately $18,000 per year.

The total cost of retrofitting the signs was roughly $60,000, so the retrofit has an expected simple payback of a under one year.

The LED lamps case seems to be a pretty straightforward example of innovation adoption, as almost all of the theoretical criteria of high adoption probability were met. The relative advantage of the lamps was high – the energy consumption of the LED lamps was significantly lower than the incandescent lamps they replaced. The LED lamps were compatible with the existing framework of lamp operation – they could be used in the same way the incandescent bulbs had been. The one exception to their operational similarity was actually a benefit – because the LEDs could be easily viewed during the day without being annoyingly bright at night, the need for dimming the signs was eliminated. The LEDs were a simple technology to understand, and their ubiquity in other applications made them highly observable. The one criterion which rated low was trialability – installing the DC voltage lamps required the installation of a new sign controller system and rewiring of the sign itself. A summary of these attributes is presented in Table 1.

Table 1. Summary of Perceived Attribute Values for LED Lamps

Relative Advantage	Compatibility	Complexity	Trialability	Observability
High	High	Low	Low	High

In this case, compatibility was determined by outside forces as much as the decision maker's own values via the historic preservation requirements on the building. These requirements mandated that the external appearance of the building, including the time and temperature sign, remain significantly unaltered. Rather than replacing or removing the sign, the owner had to find a way to make the existing sign work better. The typical lighting choices one might consider – for example, compact fluorescent lamps instead of incandescent bulbs, could not be used because the sign was outdoors and turned on and off so frequently. With the impetus of high electricity and demand charges caused by the energy crisis, the building owner (through the consultant's recommendation) broke through the "barrier" of standard efficiency choices not meeting the specific operational needs and adopted an innovative technology. Absent the impacts of the energy crisis, it seems quite likely that the sign would have remained unchanged.

Combined heat and power fuel cell. In the same office building, a public agency has committed to take approximately 70,000 square feet of space. The lease negotiations between Bob and the prospective tenant occurred during the period of rolling blackouts in California, and the tenant was very concerned about the need for uninterruptible power. In addition, the tenant was concerned about fluctuating energy costs. The prospect of paying sharply rising energy costs with a fixed annual budget was seen as a very serious problem, and the agency was willing to pay a significant premium for electricity in order to receive a guaranteed fixed energy cost from Bob over the life of the lease.

One answer to the issue of reliability was an uninterruptible power supply system. The required size of the system made that an unwieldy idea; furthermore, a UPS system did nothing to relieve the concern of cost fluctuation. On-site generation of power could meet both concerns, but generation through combustion processes (e.g., diesel generator sets or natural gas turbines) brought air quality regulations into the decision calculus. The time and effort necessary to secure such permits dissuaded Bob from following that path.

Ultimately, Bob decided that on-site generation using fuel cells could meet the goals. Bob reported that he was "fairly familiar" with fuel cell technology due to a relative in the fuel cell research and design industry. The fuel cell has a reliability index of 99.999, so it could provide power at the level of reliability required by the public agency. (The perceived validity of this conclusion was certainly strengthened, as mentioned, by the experience of electric utility unreliability due to rolling blackouts and the predictions of additional blackouts throughout the summer.) Furthermore, the fixed cost of electricity to which the agency agreed was high enough to cover the cost of generation via fuel cells. Finally, the fuel cells could be operated in a co-generation mode, reducing the space conditioning costs of the building.

The critical loads in the building dictated three 200 kW fuel cell units in parallel. The installation is intended to "float" online with the utility grid so that any sudden surges or ongoing use above 600 kW will be made up from the grid, but no power is intended to be exported to the grid.

The co-generation aspect of this fuel cell installation is twofold. (1) During the period when cooling is required, the waste heat will drive a 100-ton capacity adsorption chiller to provide chilled water to the HVAC system. (2) When heating is required, the fuel cell waste heat loop will provide hot water to the HVAC system via a heat exchanger.

Taking advantage of grants offered for fuel cell development, Bob was able to receive incentives totaling roughly 50% of the $4.4 million installed cost of the fuel cells and associated equipment.

This second case, installation of fuel cells, is a little less straightforward example of adoption of innovation. While the relative advantage of the fuel cell lay in its ability to offer on-site, reliable power generation in a way that other systems could not easily, the installation cost of the unit was quite high. It is only the fixed energy charge associated with the lease agreement that mitigates the risk of the high initial investment to install the fuel cells. Compatibility was somewhat low – installation of a stand-alone energy generation system is a substantially different mode of operation than is common for commercial office buildings; however, this was mitigated by the idea of the fuel cell as an alternative type of backup generator, since diesel generators are fairly common. Complexity was high, but the decision maker's familiarity with fuel cell technology in general likely helped mitigate that. Trialability was high. Because the fuel cell operates in parallel with the utility grid, a failure of the fuel cell would not necessarily cause the interruption of electricity supply to the building. Therefore, the fuel cell did not commit Bob to a method of operating his building from which he could not revert. Finally, observability was low to mixed. Bob had never observed a fuel cell used to provide on-site generation to an office building. This was partially mitigated by the fact that he was aware of fuel cell technology through his brother's involvement in the fuel cell production industry. A summary of these attribute values is provided in Table 2.

Table 2. Summary of Perceived Attribute Values for Fuel Cells

Relative Advantage	Compatibility	Complexity	Trialability	Observability
Mixed	Mixed	Mixed	High	Low to Mixed

Here again we see that the innovation's compatibility with existing ways of doing business was influenced by outside forces. The prospective tenants of the office space experienced the supply crisis of rolling blackouts as their lease was being negotiated. Since they were highly adverse to interruption of power, they pressed the building owner for means of guaranteeing power reliability as a part of the lease agreement. The owner's ability to provide this guarantee through a standard response – a diesel-powered backup generator – was constrained by the time and energy necessary to receive the appropriate air quality permits to operate a diesel unit. On the other hand, a waiver of air quality permits could be easily acquired for operation of the fuel cell. Given the building owner's desire to meet the tenant's needs and have them occupy the space promptly, adopting the fuel cell provided a means to push past the regulatory hurdle of air quality restrictions. Without the impetus for onsite generation caused by the energy supply crisis, it seems quite likely that the reliability of the local utility would have remained unquestioned. Without the restrictions imposed by air quality regulations, the common technology of diesel generation would have sufficed and the fuel cell would not have been adopted. The combination of energy supply crisis and regulatory hurdles led to adoption of an innovative technology.

The Microbrewery

Tim is the president of a small microbrewery in central California. Since 1989, his business has grown from a brew pub producing beer for on-site consumption to a wholesale distribution business. In 1999, Tim opened a new 28,0000 square foot manufacturing facility with the capacity to produce 60,000 barrels of beer annually. The capacity reflects Tim's optimistic nature about the growth potential of his business; current production is about 6,000 barrels. The brewery currently employs 3 full-time and 4 part-time people. Because of the small size of the business, Tim identifies his role as president as something "that encompasses in our new company the wearing of a lot of different hats." His main responsibilities are financial manager, purchasing agent, and assisting in the production as needed. As a result, Tim is the sole decision-maker about technology change within the firm.

Tim characterized the impact of the summer's energy crisis as "very significant." His utility costs increased by 50%. "Utility costs are damn near where our ingredients costs are, and that's not a good place for any manufacturer to be." Besides cost, Tim was also concerned whether he would have reliable power, given that there are "critical times in the brewing process" during which an interruption in power would cause the entire production run to be lost. Blackouts do more than prevent production for Tim – they can also ruin production in process.

Tim looked to consultants to provide him with information about how he could reduce the impact of these high prices and reliability concerns. He wanted an investment that would pay for itself within 6-12 months:

> "Most small businesses are looking like, hey, what can we do to impact our bottom line so we're going to be here six months to a year from now, not five years, seven years down the road."

Tim felt that the majority of utility incentive programs he had encountered provided that return on investment of 5-7 years, not 6-12 months.

Gas heat pump/refrigeration system. The production process at the brewery includes the use of both refrigeration and hot water. The refrigeration is used to chill the product at several points in the production process. During fermentation, for example, the need for refrigeration is essentially continuous (at a refrigeration load of 8 to 15 tons) to maintain a constant batch temperature. Additional cooling is required after pasteurization, requiring a peak refrigeration load of 30 tons. This refrigeration system uses approximately 1 kW per ton.

Large amounts of hot water are used to flush and clean the production system. A natural gas-fired boiler produces 125 psi steam that is fed to jackets on a large storage tank to heat and store the water for use. To heat 3,000 gallons of water from supply to the desired operating temperature requires approximately 3 million BTUs.

To satisfy both of these process load requirements at reduced energy consumption, a consultant recommend to Tim a developmental gas-fired heat pump called a Thermosorber™. The Thermosorber™ supplies 160° F hot water and 26° F refrigeration. In this application, it can supply refrigeration loads as low as 6 tons and as high as 30 tons. This ability to scale with production need nicely matched the brewery's variable load and desire to accommodate future production growth. The Thermosorber™ can operate in parallel with the existing system, providing preheated water to the storage tank and pre-cooled refrigeration to the main refrigerator loop. In addition, because it was a developmental technology, an incentive program sponsored by the California Energy Commission to encourage the penetration of such technologies covered about half the total cost of the unit. Based on these factors, Tim chose to install the Thermosorber™.

The installed cost of the Thermosorber™ to the brewery was approximately $60,000. With regard to the cost of this installation, Tim said:

> The cost is significant. Now the fact that the California Energy [Commission] is going to pick up 50% of it makes it attractive. …[T]he only way that I would even consider it… I believe that if we finance this correctly, the …return will not only finance the financing, it will also return a portion on our bottom line our first year.

In other words, it is Tim's expectation that the electricity savings generated by the Thermosorber™ will more than cover the monthly loan payments necessary to finance the installation. Essentially, his overall costs will be slightly lower while the Thermosorber "purchases itself." By financing the system in this way, Tim hopes to have the loan paid off in 3-5 years while at the same time improving his cash flow.

The adoption of the Thermosorber™ is the most complex case of the three we studied. Only some of the theoretical criteria predicted a high likelihood of adoption: the relative advantage of the Thermosorber™ unit, while still providing enough improvement to generate a two-year simple payback, was lower than the other cases. It was not as clearly a "no-brainer" answer to the specific problems faced by the company. Compatibility was relatively high, as the general production process did not need to change with the adoption of the unit. At the same time, though, the Thermosorber™ is a brand new technology, so there was no way to have any sense of how it would integrate in operation. Complexity of the system was relatively high, therefore this did not help with the adoption. This may have been mitigated by the trust in the technical advice of the consultant, who understood the technology. Trialability of the Thermosorber™ was high, due to the fact that it was a parallel system to the main production process. If it did not work, it would not limit or interfere with production capability. Observability was very low – because the unit is developmental, there were no instances of such a unit in operation available to be observed. A summary of these attributes is provided in Table 3 below.

Table 3. Summary of Perceived Attribute Values for Gas-fired Heat Pump

Relative Advantage	Compatibility	Complexity	Trialability	Observability
Mixed	Mixed	High to Mixed	High	Low

Discussion

Overall, then, what can we learn from the examples of these three cases? Rogers says that decisions to adopt innovations are predicted by the five perceived attributes. We summarize the perceived attributes of the adopted technologies in Table 4 below.

Table 4. Summary of Perceived Attribute Values

Technology	Advantage	Compatibility	Complexity	Trialability	Observability
LED Lamps	High	High	Low	Low	High
Fuel Cells	Mixed	Mixed	Mixed	High	Low to Mixed
Heat Pump Refrigeration	Mixed	Mixed	High to Mixed	High	Low

We see from our case studies that the perceived attributes were not all high. The predictive value of these results is vague; the technologies seem to be somewhat borderline in their value to the decision maker.

We know, obviously, that the technologies were adopted. To what can we ascribe the choice? It seems that the decision making context of the energy crisis caused the scales of choice to weigh in favor of adopting these technologies. Before the crisis occurred, external factors such as historic preservation requirements and air quality regulations were enough to stymie the search for solutions. The crisis caused the search for solutions to be taken up again, and the decision makers were therefore more receptive to the innovative ideas proposed by the consultant. As a result, the barriers that had impeded the initial search were hurdled by the adoption of unusual solutions – solutions that would not have been considered in the initial search. The decision makers became innovators as a result of the energy crisis circumstances.

This insight implies a strong component of time dependency to Rogers' adoption of innovation model. There are moments at which the window of opportunity for innovative technology adoption is enlarged, and in such moments, innovations that might not occur in usual circumstances can take place. We might identify this with an analogy of decision inertia. In the steady-state case, the inertia of considering only common solutions combined with the impact of choice constraints led to the rejection of any change . The energy crisis broke down the supporting framework of the steady state, instead building an inertia for change. This, combined with the innovative technology's ability to address the constraints, led to the adoption of the technologies we've examined.

If one follows this analogy to its logical conclusion, there would seem to be an impetus for additional change in place. There is some mild evidence that such an impetus existed in both businesses. In the case of the office building, Bob went from "standard" efficiency technologies like better lighting and windows to the retrofit using LED lamps to the installation of the fuel cells. In the case of the micro-brewery, Tim was aware of (and pleased with) the energy efficiency features required in his new building by California's Title 24 energy code. The fact that the building was new indicated to Tim a lack of opportunities for efficiency improvements, a lack that was confirmed to him by the low payback periods he saw being offered by participation in utility rebate programs. The energy crisis caused him to consider the efficiency opportunities suggested by the consultant, and he adopted the Thermosorber™. While Tim has not adopted any additional technologies yet, he has been considering installing a combined heat and power (CHP) unit to provide electricity for his production process. The waste heat from the CHP unit could be used to power the Thermosorber™. We can therefore posit the same progression of events – one technology adoption feeding the next.

This suggests a policy implication of strong coordination between public programs to enhance energy efficient technology adoption. If a decision maker is receptive to technology adoption in one case, there is a greater likelihood that they will be amenable to additional efficiency improvements. A program implementation approach that identifies and attempts to capture the efficiency potential of a wide range of measures in a particular setting may be more likely to realize substantial energy savings than an approach that only targets a specific technology or small set of technologies.

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