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THE IMPACTS OF THE FUKUSHIMA DAIICHI NUCLEAR DISASTER ON ELECTRICITY CONSUMPTION:

AN EXAMINATION OF TEPCO'S DAILY LOAD CURVE

by

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THE IMPACTS OF THE FUKUSHIMA DAIICHI NUCLEAR DISASTER ON ELECTRICITY CONSUMPTION:

AN EXAMINATION OF TEPCO’S DAILY LOAD CURVE

This paper analyzes the effects of the Fukushima Daiichi nuclear disaster on Tokyo Electric Power Company’s (TEPCO) electricity load using alternative event study methodology. The data set includes TEPCO’s published hourly loads from January 1, 2008 to December 31, 2011. Four time series regressions are used to analyze the disaster’s effect on TEPCO’s load curve at an hourly and aggregate level. By examining the hourly impacts of the disaster, this paper provides commentary on the effects of the disaster on the daily load curve. The models control for temperature, population, time of day, week, month, and year, holidays, and trends. The results indicate a significant, negative relationship between the disaster and TEPCO’s electricity load. In addition to examining the effects of the disaster on the daily load curve, four event windows are analyzed, ranging from a week after the March 11, 2011 disaster to the end of the data set (December 31, 2011). These event windows are used to capture the short, medium, and long-term effects of the Fukushima Daiichi disaster on electricity load. These event window results combined with an analysis of the annual and disaster trend variables allow for commentary on the timeline for which TEPCO’s loads will reach pre-disaster levels. Additionally, the results provide insight into both the economic and political implications of the Fukushima Daiichi disaster both in Japan and worldwide.

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Introduction:

The Fukushima Daiichi nuclear disaster occurred on March 11, 2011 following the Tohoku earthquake and ensuing tsunami. The Tohoku earthquake was the most powerful earthquake ever recorded in Japan and its effects combined with the consequent nuclear disaster have significantly impacted the Japanese people as they have faced relocation, potential health risks due to radiation exposure, and the loss of friends and family. The economic consequences have been considerable, resulting in a 2.1 percent decrease in national GDP in the second quarter of 2011 compared to the same period in the previous year. Additionally, industrial production and exports dropped by seven and eight percent, respectively, with the most severe losses in the automobile, electronic equipment, and metal industries.[1] On a global level, the disaster has disrupted both the energy market and the supply chain for many manufactured goods. In terms of the energy market, the disaster has affected both the countries that are currently reliant on nuclear energy and the emerging markets that are in the process of constructing nuclear power plants. The Fukushima Daiichi disaster has raised questions and insecurities regarding the future use of nuclear energy both in Japan and worldwide.

This paper focuses solely on the nuclear disaster's effect on the service area of the Tokyo Electric Power Company (TEPCO), owner of the Fukushima Daiichi nuclear plant, and the direct impact of the accident on the region. The goal of this paper is to identify the magnitude of the disaster's effect on TEPCO's load curve at an hourly and aggregate level. Specifically, I investigate how the daily load shape has changed and

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[1] Masahisa Fujita and Nobuaki Hamaguchi, "Japan and Economic Integration in East Asia: Post-Disaster Scenario," *Annals of Regional Science* 48 (2012): 493, ABI/INFORM via EconLit, accessed April 2012.

connect these changes to Japanese consumer response to the nuclear disaster by identifying which hours experienced the most significant changes post-Fukushima Daiichi. In addition, I determine whether these changes are short-term and slowly reverting back to demand preferences similar to those before the nuclear crisis, or if these changes are going to have long term impacts due to more permanent shifts to alternative energy sources such as combustion gas turbines and renewable energy.

I predict that aggregate and hourly examinations of post-Fukushima Daiichi loads will demonstrate that the disaster significantly impacted the daily load curve in a negative way, and that loads are slowly shifting back to levels seen before the nuclear disaster. I predict that business hours (hours 7 to 17) will see the most significant load changes after the disaster because they are the most active time of the day for Japanese consumers and, therefore, saving efforts will be the most evident during these hours. In order to test these hypotheses I run a statistical analysis of TEPCO's hourly loads from January 1, 2008 to December 31, 2011, using interactive dummy variables and trend variables to capture the significance of the disaster on hourly electricity consumption and overall load movements.

An alternative event study approach is used to set up four regressions followed by hourly load comparisons. The first two include a single disaster dummy variable with TEPCO's hourly loads as the dependent variable in the first and the log of TEPCO's hourly loads as the dependent variable in the second. The other two have the same dependent variables as the first two, but include interactive hourly disaster variables that capture the hourly impact of the disaster on the loads. After the data is regressed, t-tests are performed, comparing the hourly variables to the interactive hourly disaster variables and testing for significance. The first two regressions yielded significant disaster variables at the one percent level, positive post-disaster trends, and negative annual trends. The third and fourth regressions yielded significant hourly and interactive hourly disaster variables at the one percent level, with the most extreme significance occurring during the on-peak hours, especially during periods of transition (hours seven to nine and seventeen to nineteen). Additionally, these regressions yielded similar trends to those in models one and two.

This event study provides an in-depth look into both consumer and government reactions to the Fukushima Daiichi nuclear disaster and provides insight into the future of the electricity industry in Tokyo. The significance of these disaster and trend variables sheds light onto the longevity of consumer saving measures as well as the recovery pace of electricity loads to pre-disaster levels. This paper provides commentary regarding the success of policy measures, specifically the fifteen percent government mandated decrease in demand, that have been in place since the disaster. Additionally, the paper comments on the further success of consumers in decreasing demand beyond what is required of them. If these changes in electricity consumption become more permanent, as this paper suggests, future policies and utility structures will be forced to adapt, possibly resulting in market liberalization, higher prices, or grid transformation. Regardless of the result, the changes in electricity demand analyzed here will force consumers, regulators, and the Japanese government to reconsider not only the future of nuclear energy but also the structure of the energy industry as a whole. This paper also comments on the disaster’s effect on Japan as a whole due to electricity’s influence in all sectors of the economy. Consequently, the results produced here will indicate movements in both consumer sentiment and overall economic recovery.

Institutional Background:

The daily load curve depicts the demand for electricity throughout a 24-hour day and provides a detailed look into consumer preferences. The demand for electricity fluctuates more sharply in Japan than it does in other countries such as the United States, Germany, and the United Kingdom. A typical load curve in Tokyo spikes at six or seven a.m. when commercial buildings open and lights and air conditioning units are turned on. The curve then continues at this load level throughout business hours with a slight decrease during lunch hours. At hour sixteen or seventeen (16:00 or 17:00) the load begins to decrease as consumers leave the office and travel home. As a result, a typical load curve's on-peak hours (higher loads) are between hours seven and seventeen as illustrated in Figure 1.[2] Significant variables that impact the load curve include temperature, humidity, and time of day, week, and year.[3] Analysis of the load curve is critical in determining changes in demand preferences in the Tokyo area post-Fukushima because the curve identifies the hours consumers have targeted to conserve energy and the magnitude of these conservation efforts.

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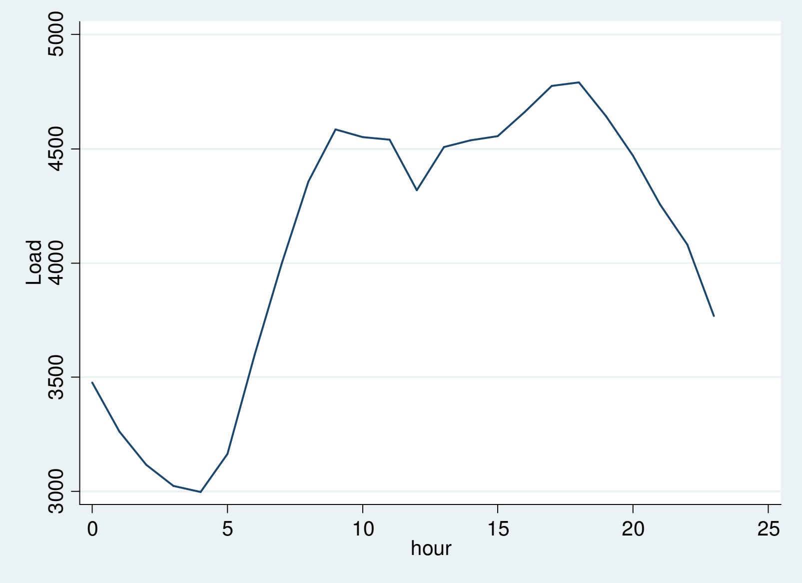
[2] TEPCO, "Electricity Market in Japan," PowerPoint Presentation to Public, July 2004. http://www.tepco.co.jp/en/news/presen/pdf-1/0406-e.pdf, accessed February 2012.

[3] Philip Price, *Methods for Analyzing Electricity Load Shape and its Variability* (Lawrence Berkeley Lab, August 2010), p. 5.

Figure 1.

Typical TEPCO Daily Load Curve (3/1/11)



In Japan, demand for electricity can be broken down into three main sectors. Industrial buildings use 61.5 percent of electricity, residential buildings use 33.2 percent, and commercial buildings use 3.9 percent, while only 1.4 percent is used for other purposes such as public, outdoor lighting.[4] In terms of volatility, the increase in industrial demand each day from trough to peak is only 25 percent, whereas households use three times as much electricity at their peak compared to their trough and commercial users use

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[4] Mark Fulton, Michael Carboy, Jane Cao, and Lucy Cotter, "Japan – The Peoples' Greener Choice," *Deutsche Bank Group*, August 2011, http://nukefreetexas.org/downloads/Japan_The_Peoples_Greener_Choice.pdf, accessed October 2011.

around ten times as much electricity at their peak compared to their trough.[5] These vast differences indicate the wide variety of consumer preferences that exist within Japan and highlight the volatility that exists within the daily load curve. The large spike within daily commercial electricity demand at peak hours suggests that saving measures within this sector could be the most beneficial because peak hours typically have the tightest margin between electricity supply and demand. The Institute of Energy Economics in Japan released a quarterly report stating that office and commercial buildings account for 40 percent of total electricity consumption during peak demand hours. The report further states that commercial consumers have the ability to cut electricity consumption by 2.8 to 4.7 GW (gigawatt) by turning off lights and increasing indoor temperatures more frequently.[6] As a result, the Japanese government directed their post-Fukushima electricity cuts towards this sector.[7]

As a whole, Japan has a limited domestic energy production and imports 83 percent of its total energy supply. The country is heavily reliant on oil and natural gas imports. In an effort to decrease this reliance, Japan built a large number of nuclear reactors and swayed public opinion on nuclear power through tax incentives. Before the Fukushima nuclear disaster, Japan's target was to have half of its total energy supply come from nuclear energy by 2030; however the nuclear disaster has put those plans on pause as nuclear power plants are reevaluated and public concern increases. Further

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[5] "Japan's energy crisis: Powerful savings." *The Economist*, April 27, 2011. http://www.economist.com/blogs/banyan/2011/04/japans_energy_crisis, accessed October 2011.

[6] "Summer Electricity Saving Measures and Their Effects for Office and Commercial Buildings," *The Institute of Energy Economics*, May 2011, accessed October 2011.

[7] Shigeru Sato, "Tokyo Power Demand Reaches Highest since Quake on Heat Wave," *Bloomberg*, June 29, 2011, http://www.bloomberg.com/news/2011-06-29/tokyo-power-demand-reaches-highest-since-quake-on-heat-wave-2-.html, accessed October 2011.

restricting Japan's energy supply is its grid system, which varies within the country. Eastern Japan's grid was set up using a German 50 Hz AC system, whereas Western Japan was designed using a General Electric 60 Hz AC system. Converting between these two frequencies requires a complex substation and Japan has only three substations capable of this conversion. The aggregate capacity of these substations is 1.2 GW, which limits the amount of electricity that can be transferred between the two regions.[8] This limitation is especially problematic during a supply crisis such as the one that occurred after Fukushima, because the two regions cannot share resources easily.

Another unique facet of Japan's energy structure is that Japan has ten regional monopolies, all part of the Federation of Electric Power Companies of Japan (FEPC). While this system may seem similar to the utility structure in the United States, utilities in Japan charge residents a flat rate throughout the day, removing incentives to save electricity during peak hours[9]. Due to the lack of competition, electricity prices for Japanese consumers are nearly twice as much the electricity prices paid by Americans and three times as much as those paid by South Koreans.[10] Market liberalization has been marginal and unsupported by big businesses because they sell parts and services to the monopolies in exchange for discounted electricity.[11] Market liberalization has been implemented in stages beginning in March 2000 when consumers using more than 2MW of electricity were allowed to purchase from power producers and suppliers (PPSs) unassociated with the regional utilities. The next stage began in April 2005 and allowed

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[8] Fulton, "Japan – The Peoples' Greener Choice."

[9] "History of Japan's Electric Power Industry." Federation of Electric Power Companies of Japan. http://www.fepc.or.jp/english/energy_electricity/history/index.html, accessed February 2012.

[10] "Energy in Japan: Bright ideas needed," *The Economist*, September 17, 2011. http://www.economist.com/node/21529037, accessed October 2011.

[11] Ibid.

consumers whose demand exceeds 50kW to purchase from PPSs. The rest of the liberalization plan, which would have affected the majority of the Japanese population, was abandoned in March 2008.[12] As a result, the electricity market is still very constrained; however, Japan's consumer response to the nuclear disaster has been significant given the current structure and government involvement.

The Fukushima Daiichi disaster eliminated 1.8 percent of Japan's energy capacity.[13] Roughly 9.7 GW of nuclear power and 9 GW of thermal power went offline instantaneously and TEPCO planned rolling blackouts to ration the limited power supply although no blackouts were actually enabled. On March 21, TEPCO's supply capacity was 30 percent below normal peak demand even as TEPCO ramped up functioning plants and started up oil-fired backup plants.[14] The three major utilities affected (TEPCO, Tohoku Electric, and Hokkaido Electric) all would have faced significant negative margins if confronted with normal demand circumstances. In this paper, margins refer to the difference between current quantity supplied and current quantity demanded. In particular, they would have encountered negative six to seven percent shortfalls between post-disaster generating capacity and normal levels of demand.

However, reduced demand (by as much as 25 percent in the Tokyo area) due to government regulation and consumer savings created an eight percent reserve margin.[15]

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[12] "Fair Competition and Transparency." Federation of Electric Power Companies of Japan. http://www.fepc.or.jp/english/energy_electricity/fair_competition/index.html, accessed February 2012.

[13] "Disaster in Japan: Plutonium and Mickey Mouse." *The Economist*, March 31, 2011. http://www.economist.com/node/18488463, accessed October 2011.

[14] Tomoko Hosoe, "Japan's Power Supply Crisis: An Assesment," *East-West Wire*, March 21, 2011, http://www.eastwestcenter.org/news-center/east-west-wire/japans-power-supply-crisis-an-assessment, accessed November 2012.

[15] Fulton, "Japan – The Peoples' Greener Choice."

Japan's government regulation included electricity saving targets of 15 percent for most sectors. Specifically, for industries consuming more than 500kW, the government implemented Article 27 of the Electricity Business Act, which required companies within the industry to cut electricity consumption by 15 percent between the hours of 9:00 and 20:00 for the period from July 1, 2011 to September 22, 2011. Failure to yield to these restrictions resulted in penalties of up to 1 million yen for each hour in which the target was not met.[16] The additional power conservation beyond the Japanese government's requirements highlights consumers' ability to effectively react to a disaster and the possibility for considerable change in the daily load curve for electricity within TEPCO's service area.

In response to the tight supply of energy, Japan's Ministry of Trade, Economy, and Industry (METI), created saving measures and goals for the summer of 2011. On the demand side, METI suggested extending and staggering summer holidays, shortening operating hours, utilizing facilities outside of Tokyo, installing smart meters to keep consumers informed about the amount of electricity they are using, and increasing national awareness.[17] On the supply side, gas turbines were to be installed, thermal plants restored, private power purchased, and supply vehicles increased and diversified. In adhering to these suggestions, many industries have responded with significant changes to their schedules. Some industrial firms, such as Toyota, have delayed production and others have shifted their work hours in order to avoid high-demand periods. For example, throughout the summer the Japanese car industry took Thursdays and Fridays off and

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[16] Sara Pasquier, "Saving Electricity in a Hurry: Update 2011." International Energy Agency, June 2011. www.iea.org/papers/2011/saving_electricity.pdf, accessed February 2012.

[17] Ibid.

worked on the weekend when electricity demand is significantly lower.[18] These changes have come at significant economic costs to Japan. Specifically, Japanese automobile production in March 2011 was 57.3 percent less than that in the same month last year.[19] In an effort to support economic recovery, the government implemented a number of financial packages for small and medium enterprises, which have totaled 10 trillion yen to date.[20]

In a report on the crisis, Deutsche Bank Group divides Japan's recovery from this disaster into three phases. Phase I centers on immediate actions focused mostly on behavioral changes. Phase II addresses renewable expansion and grid transformation, while Phase III addresses long-term energy planning. The immediate removal of a large portion of nuclear energy from TEPCO's electricity supply required that additional power be attained through alternative sources. This acquisition was done largely through the procurement of natural gas and coal. TEPCO's short-term solution entailed procuring low-sulfur fuel oil from local refineries that had an excess supply due to the short-term decline in industrial activities, while also buying crude oil from the market.[21] Japan's liquefied natural gas (LNG) and coal imports increased the country's import bill for the two fuels in the five-month period from April 1 to August 31 by 31 percent to 2.45 trillion yen from the same period a year earlier.[22] From a macro perspective, Japan

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[18] "Energy in Japan: Bright ideas needed," *The Economist.*

[19] Masahisa Fujita and Nobuaki Hamaguchi, "Japan and Economic Integration in East Asia: Post-Disaster Scenario," *Annals of Regional Science* 48 (2012): 494, accessed April 2012.

[20] Joni Jupesta and Aki Suwa, "Sustainable Energy Policy in Japan, Post Fukushima," International Association for Energy Economics, Fourth Quarter 2011, accessed October 2011.

[21] Hosoe, "Japan's Power Supply Crisis: An Assesment," *East-West Wire.*

[22] Shigeru Sato and Emi Urabe, "Power Companies Borrow Record in Loans as Cost of FuelJumps: Japan Credit," *Bloomberg,* October 6, 2011. http://www.bloomberg.com/news/2011-10-06/power-companies-borrow-record-in-loans-as-cost-of-fuel-jumps-japan-credit.html, accessed October 2011.

consumes approximately 65 percent of the LNG shipments to Asia and approximately 35 percent of worldwide shipments. This increased demand has caused a 50 percent increase in spot prices (US$15/mmBTU level), which has not come at a light cost for TEPCO.[23]

The immediate effect of the disaster on TEPCO was significant and disastrous. TEPCO shares have lost four-fifths of their value and its debt has been downgraded to junk. As a result, TEPCO's president stepped down and the company intends to sell all of its assets unrelated to supplying energy. Internal cuts have been considerable, as workers have seen wage cuts of as much as 25 percent. TEPCO compensation payments to those affected by the disaster could exceed its assets of 186 billion yen.[24] A multitude of problems would be created for both TEPCO and the government if the company becomes insolvent. To prevent insolvency in the short run, TEPCO would need a five percent increase in prices contingent upon its nuclear plants restarting in a year and as much as a 10 percent price increase if the plants cannot be restarted within a year. These price changes would barely keep the utility in the black.[25] As a result, the government is in the process of discussing the future of TEPCO and has considered a few options including bankruptcy, nationalization, splitting up transmission and generation into individual

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[23] Fulton, "Japan – The Peoples' Greener Choice."

[24] "Power in Japan: The troubles of TEPCO," *The Economist*, June 30, 2011, http://www.economist.com/node/18899008, accessed October 2011.

[25] Rick Wallace, "Tokyo must decide who will pay to keep Fukushima plant owner TEPCO afloat," *The Australian*, October 7, 2011, http://www.theaustralian.com.au/business/opinion/tokyo-must-decide-who-will-pay-to-keep-fukushima-plant-owner-tepco-afloat/story-e6frg9if-1226160647274, accessed October 2011.

entities, and establishing an independent government entity that would purchase TEPCO assets in return for compensation funding.[26]

On November 4th, 2011 the METI approved the release of $64 billion dollars of government funding to TEPCO for compensation payments and to avoid insolvency; however, the nationalization of TEPCO is still a largely controversial topic throughout Japan.[27] The METI minister Yukio Edano has indicated that no additional money will be released to TEPCO "without the Japanese government gaining a right to take over and reform the utility."[28] While some Japanese officials think nationalization is appropriate to ensure successful financial and managerial restructuring, others such as Hiromasa Yonekura, the chairman of the Japan Business Federation, are against nationalization and think electricity rate increases would be a more effective approach to rebuilding the company.[29] On April 1, 2012, the company raised electricity prices for corporate clients by an average of 17 percent, citing higher fuel costs as justification for the increase. This increase is the first time the company has raised electricity prices in more than 30 years and could potentially push consumers to further increase their conservation efforts.[30] The success of this decision will have an impact on whether the company is forced to nationalize, as such the future of not only TEPCO, but also Japan's utility system as a whole remains uncertain.

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[26] "Japan's nuclear plants: Half-life," *The Economist*, May 20, 2011, http://www.economist.com/blogs/schumpeter/2011/05/japans_nuclear_plants, accessed October 2011.

[27] "Japan's nuclear conundrum: The $64 billion question," *The Economist*, November 5, 2011, http://www.economist.com/node/21536600, accessed February 2012.

[28] Mitsuru Obe, "Japan Business Lobby Head: Against Nationalization of Tepco, Support Electricity Rate Hikes," *Wall Street Journal*, February 27, 2012, http://online.wsj.com/article/BT-CO-20120227-701005.html?mod=WSJ_qtoverview_wsjlatest, accessed February 2012.

[29] Ibid., p.1.

[30] "TEPCO raises electricity prices for corporate clients," *BBC News*, January 17, 2012, http://www.bbc.co.uk/news/business-16589072, accessed February 2012.

Blame for the aftereffects of the nuclear disaster has fluctuated between TEPCO and the Japanese government as the Japanese people criticize past and present nuclear energy policies. *The Economist* calls the relationship between TEPCO, the government, and the METI "an unholy triangle" because the METI simultaneously oversees the regulator that is responsible for addressing utility safety issues and promotes the nuclear industry.[31] The Fukushima Daiichi plant has malfunctioned multiple times and TEPCO has concealed problems since its creation, yet there have been no significant consequences for their actions. In fact, Japan's Supreme Court has never ruled against any power company.[32] Furthermore, the media reporting on the issue has been regulated due to outlets' inability to scrutinize energy companies because of Japan's "press club" system, which allows the media to ask questions only at formal press conferences. One such conference occurred at the first public hearing of the Fukushima Nuclear Accident Independent Investigation Commission held on January 16, 2012, months after the nuclear disaster. The "press club" is invitation only, so no outlet has openly criticized TEPCO, the government, or METI for fear of being dropped from the hearings.[33] These media limitations have controlled public knowledge of the disaster, heightening the public's uncertainty concerning the future of nuclear energy in Japan.

The International Association for Energy Economics has reported statistics on public opinion concerning nuclear energy issues. They find that 74 percent of Japanese voters support abolishing nuclear power after a phase-out period and 65 percent want

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[31] "Disaster in Japan: Plutonium and Mickey Mouse." *The Economist*, March 31, 2011. http://www.economist.com/node/18488463, accessed October 2011.

[32] Masao Kikuchi and Akira Nakamura, "What We Know, and What We Have Not Yet Learned: Triple Disasters and the Fukushima Nuclear Fiasco in Japan," *Public Administration Review* 71, (2011): 895, ABI/INFORM via EconLit, accessed January 2012.

[33] "Japan's nuclear crisis: The Meltdown and the Media," *The Economist*, January 16, 2012, http://www.economist.com/node/21542992, accessed February 2012.

implementation of renewable power sources even at the expense of higher electricity fees.[34] As a result of these anti-nuclear sentiments, it is entirely possible that local governments could force a shutdown of all of Japan's nuclear capacity by choosing to keep plants in their respective areas shut down. The future of the nuclear industry is strongly linked to local government approval because of the structure of regional utilities.

For example, Kansai Electric regional utility's (KEPCO) biggest shareholder is the city of Osaka. The mayor of Osaka, Toru Hashimoto, effectively the company's largest shareholder, has threatened to "end KEPCO's monopoly on power generation and distribution" if the utility does not keep ten of its eleven nuclear reactors shut down.[35] Due to similar sentiments throughout Japan, 48 out of 54 nuclear reactors were out service as of January 7, 2012 without any sign of being turned back on in the near future.[36] Aggregately, these anti-nuclear efforts could potentially lead to a 30 percent decrease in energy supply and, therefore, alternative measures would need to be taken. However, in the short term Japan's prime minister Yoshihiko Noda insists that it is "absolutely impossible" for Japan to survive next summer's demand needs without nuclear power.[37] On April 13, 2011, the Japanese government announced that two nuclear reactors at the Oi plant in western Japan were safe to restart; however, the government is now faced with the decision of whether or not to turn them on.[38] While it

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[34] Jupesta, "Sustainable Energy Policy in Japan, Post Fukushima."

[35] "Japan's energy crisis: Nuclear winter," *The Economist*, December 10, 2011, http://www.economist.com/node/21541464, accessed February 2012.

[36] "The Fukushima Black Box: A dangerous lack of urgency in drawing lessons from Japan's nuclear disaster," *The Economist*, January 7, 2012, http://www.economist.com/node/21542437, accessed February 2012.

[37] "An Anti-nuclear Protest in Japan: Sayonara, nukes, but not yet," *The Economist*, September 24, 2011, http://www.economist.com/node/21530147, accessed February 2012.

[38] Mari Iwata and Eleanor Warnock, "Japan Government Deems 2 Reactors Safe," *Wall Street Journal*, April 13, 2012,

is deemed necessary in order to avoid blackouts this coming summer and the national government has the final say regarding the plant's operation, the government and the utilities also have a duty to act in line with the wants and needs of the Japanese people.

The government ended "setsuden", its energy conservation protocols, on September 9, 2011 as energy demand decreased due to cooler temperatures and energy supply increased as Japan's energy portfolio expanded. However as Japan looks ahead, there are many additional factors to consider regarding daily electricity consumption.[39] Japan's energy demand is declining due to its aging and shrinking population, which could lead to a decrease in the daily load curve for all hours.[40] In addition, if the Japanese continue their conservation measures Deutsche Bank Group reports an estimated annual improvement in electricity intensity (primary energy consumption/GDP) of 2.2 percent rather than the 1.5 percent estimated before Fukushima. This increased efficiency in electricity use combined with a declining population could yield notable changes in future demand for electricity.

Continued conservation measures can already be seen by some practicing self-imposed "setsuden" in the winter months even though all government restrictions have expired. The Japan Soft Drink Association is not refrigerating vending machines during the day and is changing fluorescent bulbs to LED lighting in areas with a sensitive energy supply.[41] Another example is the Tokyo Tower, which has cut the number of hours it will

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http://online.wsj.com/article/SB10001424052702303624004577341591983335470.html, accessed April 2012

[39] "Energy in Japan: Bright ideas needed," *The Economist*.

[40] Hosoe, "Japan's Power Supply Crisis: An Assesment," *East-West Wire*.

[41] "Electricity Demand Hits 93% as Tokyo Chills," *Wall Street Journal*, December 9, 2011, http://blogs.wsj.com/japanrealtime/2011/12/09/electricity-demand-hits-93-as-tokyo-chills/, accessed February 2012.

be lit up by half as of December 2011.[42] While each of these efforts might seem insignificant individually, the effect on total electricity demand in Japan has been substantial and Reuters reported in January 2012 that Japan was experiencing the "eleventh straight month of year-on-year declines."[43] When coupled with a shrinking population, these "setsuden" have the potential to significantly decrease the daily load curve. In order to promote this long-term shift, TEPCO plans on deploying smart meters to a minimum of 80 percent of the utility's total service territory, allowing consumers to monitor real-time price signals.[44] While all of these efforts suggest a decrease in energy demand for Japan in the long run, nuclear energy will most likely remain a necessary element to Japan's energy portfolio until substantial progress has been made regarding the implementation of a new grid system, which is necessary in order to deal with the intermittencies and transmission associated with renewable integration. This substantial progress could take many years to implement.

Literature Review:

Disasters have become a growing topic in economic research as heated discussion about global warming, population growth, and urbanization indicate that disasters will become increasingly relevant economically. Global warming is expected to bring more frequent, volatile disasters and urbanization increases the damage of disasters in heavily populated, localized areas, thus the economic effects of disasters are becoming

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[42] Ibid.

[43] "Japan electricity demand falls 5.2 pct y/y in Jan," *Reuters*, February 1, 2012, http://www.reuters.com/article/2012/02/01/japan-power-idUSL3E7G20FJ20120201, accessed February 2012.

[44] Mark Fulton, Michael Carboy, Jane Cao, and Lucy Cotter, "Japan – The Peoples' Greener Choice," *Deutsche Bank Group*, August 2011, http://nukefreetexas.org/downloads/Japan_The_Peoples_Greener_Choice.pdf, accessed October 2011.

increasingly more significant.[45] There are two distinct types of disasters: natural disasters and complex emergencies. Natural disasters are caused by a natural phenomenon and affect "a population or area and may result in severe damage and destruction and increased morbidity and mortality that overwhelm local coping capacity".[46] In contrast, complex emergencies are caused by human actions and "mortality among the civilian population substantially increases above the population baseline mortality, either as a result of the direct effects of war or conflict, or indirectly through the increased prevalence of malnutrition and/or transmission of communicable diseases."[47] Paul Spiegel's 2005 paper, "Differences in World Responses to Natural Disasters and Complex Emergencies," explores the similarities and differences between the two forms of disasters.

Spiegel (2005) argues that response to natural disasters is greater than response to complex emergencies, both politically and financially, because natural disasters are less politically risky, easier to address, and often more sudden and unexpected.[48] The consequences of both types of disaster usually result in increased basic health needs and short and long-term mental health effects; however, natural disasters such as the one that occurred in Japan in March 2011 typically result in deaths and injuries rather than long-term food scarcity and migration. Another major response catalyst is media coverage and the socioeconomic status of those affected by the disaster, as countries will respond with

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[45] Derek Kellenberg and A. Mushfiq Mobarak, "The Economics of Natural Disasters," *Annual Review of Resource Economics* 3 (June 2011): 298, ABI/INFORM via EconLit, accessed April 2012.

[46] Paul B. Spiegel, "Differences in World Responses to Natural Disasters and Complex Emergencies," *Journal of the American Medical Association* 293 (April 2005): 1915, ABI/INFORM via EconLit, accessed April 2012.

[47] Ibid., p. 1915.

[48] Ibid., p. 1917.

greater magnitude if their citizens are empathetic to the disaster victims.[49] Each of the numerous natural disasters that Spiegel (2005) examines received immediate and significant funds from sources worldwide, whereas funding was less evident for the complex emergencies analyzed. Spiegel (2005) concludes that "it is easier to 'do no harm' when responding to a natural disaster than a complex emergency.[50] While it may be "easier" to respond to a natural disaster, the factors that go into that response and their results prove to be complex and vary by country and disaster type.

While research on disasters has become more extensive, the results are divided on both the short-term and long-term level. Raddatz (2007) compares the short-term effects of humanitarian disasters (wars, famines, etc.) and climatic disasters (floods, droughts, etc.), finding that both have a negative relationship with per-capita income. On average, climatic and humanitarian disasters cause two and four percent real per-capita income losses, respectively.[51] Noy (2009) examines natural disasters worldwide, specifically those from 1970 to 2003, and finds a relationship similar to Raddatz, adding that adverse short-run effects are worsened by a lack of development, education, income, openness to trade, and government spending.[52] Sarmiento (2007) looks at the effect of climatic disasters on short-run, local employment by analyzing a US flood panel data set and finds that local employment falls by an average of 3.4 percent after a climatic disaster.[53] However, Xiao (2011) runs a time series regression on data from the 1993 Midwest Flood and finds stable employment levels in the disaster year and after, contradicting Sarmiento. In addition, Xiao (2011) finds short-run declines in per-capita income in the

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[49] Spiegel, "Differences in World Responses to Natural Disasters and Complex Emergencies," p. 1917.
[50] Ibid., p.1917.
[51] Kellenberg and Mobarak, "The Economics of Natural Disasters," p. 302.
[52] Noy, "The Macroeconomic Consequences of disasters," p. 221.
[53] Kellenberg and Mobarak, "The Economics of Natural Disasters," p. 303.

year of the event, which rebounded the following year.[54] Belasen and Polacheck (2009) did a similar study looking at hurricane data, finding that income in the affected area grew by 4.35 percent due to increased labor demand and decreased labor supply in the affected area and fell by 4.51 percent in neighboring counties due to increased labor supply resulting from relocation.[55] While views on the short-run impacts of disasters on unemployment seem to vary by region and time, these economists agree that short-run per-capita income decreases immediately following a disaster.

Albala-Bertrand (1993) finds contrasting results when using a simple macroeconomic model to look at the effect of sudden, large (at least 5 percent of loss-to-GDP ratio) natural disasters on the growth rate of output. He argues that "economic effects of large localized natural disasters … rarely affect negatively actual aggregate output. If anything there often appears to be a positive short-term effect on GDP."[56] Bertrand examines six disasters in six different countries, three climatic and three geologic, and finds that in four of the six instances countries show both positive and improved growth rates in the disaster year and thereafter. The two exceptions are shown to be the result of causes unrelated to the disaster.[57] Albala-Bertrand (1993) further argues that natural disasters result in positive short-term growth in the book, *Political Economy of Large Natural Disasters*. In this work, his before-after statistical analysis of 28 natural disasters in 26 countries resulted in a 0.4 percent average increase in GDP, unchanged inflation, increased capital formation, increases in agricultural and

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[54] Yu Xiao, "Local Economic Impacts of Natural Disasters," *Journal of Regional Science* 51 (2011): 817, ABI/INFORM via EconLit, accessed April 2012.

[55] Kellenberg and Mobarak, "The Economics of Natural Disasters," p. 303.

[56] J. M. Albala-Bertrand, "Natural Disaster Situations and Growth: A Macroeconomic Model for Sudden Disaster Impacts," *World Development* 21 (February 1993): 1418, ABI/INFORM via EconLit, accessed April 2012.

[57] Ibid., p. 1425.

construction output, increases in fiscal and trade deficits, and increased reserves.[58] More recently, Noy and Vu (2010) performed a case study to measure the forgone production resulting from natural disasters in 64 Vietnamese provinces from 1965 to 2006. They find that more costly disasters appear to boost the economy in the short-run.[59] Tol and Leek (1999) further support these results by suggesting that GDP increases after natural disasters because GDP focuses on the flow of new production, which occurs because natural disasters destroy capital stock and therefore ensure increased production in the short-run.[60] Their results are supported by the creative destruction hypothesis, which states that natural disasters foster adoption of new technology and are an opportunity to increase the efficiency of capital stock.[61] Although the research seems fairly evenly divided on the short-term effects of natural disasters, the literature that results in positive, short-term growth seems to include more evidence involving geologic disasters, such as the Tohoku earthquake and tsunami.

In terms of the long-run economic effects of natural disasters, Skidmore & Toya (2002) are widely cited, but many counter-arguments exist as well. Skidmore & Toya (2002) use a semi-logarithmic regression containing disaster data for 89 countries between 1960 and 1990. Their statistical analysis "yields a positive and statistically significant relationship between number of disasters and economic growth, explaining as

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[58] Eduardo Cavallo and Ilan Noy, "The Economics of Natural Disasters," *Inter-American Development Bank* 124 (May 2010): 15, ABI/INFORM via EconLit, accessed April 2012.

[59] Ilan Noy and Tam Bang Vu, "The Economics of Natural Disasters in a Developing Country: The Case of Vietnam," *Journal of Asian Economics* 21 (March 2010): 352, ABI/INFORM via EconLit, accessed April 2012.

[60] Ibid., p.347.

[61] Mark Skidmore and Hideki Toya, "Do Natural Disasters Promote Long-Run Growth?" *Economic Inquiry* 40 (October 2002): 665, ABI/INFORM via EconLit, accessed April 2012.

much as nine percent of the variation in the growth of per capita GDP."[62] They further divide the data set by region, finding Asia is the most disaster-prone region both in terms of number of events and deaths.[63] Their final conclusion, dividing the set by disaster type, resulted in a positive correlation between climatic disasters and "economic growth, human capital investment, and growth in total factor productivity, whereas geologic disasters are negatively correlated with growth."[64] Miguel & Roland (2010) find similar positive long-term results from national disasters, but rather than looking at natural disasters, they examine war disasters, specifically the effects of the US bombing in Vietnam. They look at bombing intensities in 458 Vietnamese districts and find that the US bombing in the Vietnam War did not have negative impacts on "local poverty rates, consumption levels, infrastructure, literacy, or population density through 2002."[65] They cite the neoclassical growth model as a possible explanation, stating "if war leads to the partial destruction of the physical capital stock but the production function remains unchanged, there will be a temporary increase in capital accumulation until the steady state is again attained."[66]

Hallegatte & Dumas (2009) contrast this theory of positive, long run growth post-disaster by arguing that a "poverty trap" exists that decreases the positive effect of a disaster on GDP. This decrease was especially evident in low-income countries, because instead of investing in newer, more efficient technology, countries replace damaged

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[62] Ibid., p. 665.
[63] Ibid., p.666.
[64] Ibid., p.682.
[65] Edward Miguel and Gerard Roland, "The Long Run Impact of Bombing Vietnam," NBER Working Paper No. 11954, 2006, p.1.
[66] Ibid., p. 8.

capital with the same capital used in the past to prevent short-term productivity losses.[67] Noy & Nualsari (2007) and Raddatz (2009) provide further counterarguments to Skidmore & Toya (2002). Both find that disasters have contractionary long-run effects on GDP using panel data of five-year country observations and cumulative impulse response functions, respectively. Long-term research is fairly divided due to the difficulty in constructing models that account for what would have happened to GDP in the absence of the natural disaster. [68]

Rather than looking at the short-term vs. long-term effects of natural disasters, economists have looked at a country's level of development as an explanation of the varying economic effects of natural disasters. Kallenberg & Mobarak (2007) find an inverse U-shape relationship between a country's level of development and its economic losses due to floods and windstorms. However, they find a negative relationship between increased development and economic losses for geologic disasters. They find a similar inverse U-shape when looking at the relationship between income and deaths from natural disasters.[69] Both of these relationships indicate more developed countries are less affected by a natural disaster than are less developed countries. Noy & Nualsri (2011) further analyze this relationship between development and post-disaster economic effects, exploring fiscal behavior in a study involving quarterly disaster data from 22 developed countries and 20 developing countries.[70] They find post-disaster counter-cyclical fiscal behavior in developed countries and post-disaster pro-cyclical fiscal behavior in

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[67] Kellenberg and Mobarak, "The Economics of Natural Disasters," p. 302.

[68] Cavallo and Noy, "The Economics of Natural Disasters," p. 18.

[69] Kellenberg and Mobarak, "The Economics of Natural Disasters," p. 304.

[70] Ilan Noy and Aekkanush Nualsri, "Fiscal Storms: Public Spending and Revenues in the Aftermath of Natural Disasters," *Environment and Development* Economics 16 (2011):119-120, ABI/INFORM via EconLit, accessed April 2012.

developing countries. In developed countries, their results yield an immediate 1.27 percent of GDP decrease in government revenue, a 0.46 percent of GDP increase in government payment (peaking in the third quarter of the disaster year), and a 0.28 percent of GDP decrease in government cash surplus. In developing countries, inverse results are presented, including decreases in government consumption, government revenue, government payment, and outstanding debt on impact.[71] This paper further defines the relationship between natural disasters and economic development, highlighting the adverse effects of poor economic strategies post-disaster in developing countries and their extended, undesirable macroeconomic outcomes.

In addition to the economic development literature mentioned thus far, Schumacher & Strobl (2011) find more complex results when they take into consideration the level of hazard exposure a country faces. They find that the relationship between wealth and losses depends on hazard exposure. If a country has low hazard exposure, they find an inverse U-shape relationship similar to the one mentioned by Kallenberg and Mobarak (2007) with low wealth countries facing increasing losses due to the small marginal benefit for adaption expenditure.[72] However, if a country faces high hazard exposure they find a U-shape relationship between wealth and economic losses. They explain this relationship by citing the effect of decreasing marginal returns on excessive investment in preventative measures for wealthy countries and by identifying that poorer countries are more willing to take preventative measures because they will

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[71] Ibid.

[72] Ingmar Schumacher and Eric Strobl, "Economic Development and Losses Due to Natural Disasters: the Role of Hazard Exposure," *Ecological Economics* 72 (October 2011): 98, ABI/INFORM via EconLit, accessed April 2012.

have a greater percent of their wealth destroyed by a disaster.[73] This argument provides an interesting supplement to the existing literature because many developed countries, such as Japan, face significant economic losses following natural disasters, suggesting that they could be inefficiently allocating resources to preventative efforts.

Further studies have been done in hopes of explaining the effects of disasters at different levels of development, including examining the impacts on a country's government structure, business cycle, technological development, and household structure. Kallenberg & Mobarak (2011) examine the relationship between disaster recovery and democratic governments, finding that "democratic governments are expected to have a positive effect on addressing the impact of disaster because they will be held accountable for their disaster preparations and respond to post-disaster assistance."[74] Hallegatte & Ghal (2008) argue that economies are more likely to suffer negative consequences to growth during periods of expansion because their productive capital is more vulnerable, whereas countries in a recession are able to use their excess capacity to respond to a disaster.[75] Escaleras & Register (2008) analyze 146 earthquake-generated tsunamis between 1966 and 2004 and find that countries that employ advanced technologies are better able to predict disaster events and disseminate warnings to the public.[76] Carter et al. (2007) examine household response to natural disasters and find "households above a certain threshold will be more likely to borrow against their assets or future earnings" and therefore recover from the disaster more quickly.[77] Another study involving household response to disasters was done by Smith et al. (2006) and further

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[73] Ibid., p.99.

[74] Kellenberg and Mobarak, "The Economics of Natural Disasters," p. 305.

[75] Ibid., p. 306.

[76] Kellenberg and Mobarak, "The Economics of Natural Disasters," p. 306.

[77] Ibid., p. 306.

highlights the differing responses to disasters that occur based on wealth. The paper indentifies that higher income households do not relocate post-disaster, middle-income household move away from the disaster zone, and lower-income households often move into the disaster area in order to benefit from decreased property prices.[78] The multiple factors involved in estimating the post-disaster effects of a natural disaster illustrate the existing complexities in interpreting the economic and political implications that result in both the short term and long term following a natural disaster.

This paper's focus on the Tohoku earthquake and tsunami of 2011 and the resulting nuclear disaster will add a special case study to the existing literature because it examines the economic effects of both a natural disaster and a complex emergency. While this paper highlights the localized impacts of the disasters on the electricity market in Tokyo specifically, it estimates the magnitude of the disaster and proposes a timeline for the recovery of the Japanese electricity market. As a result, this paper provides insight into the reactions of both the Japanese government and the consumer to the March 2011 disasters, as well as explains the implications of these reactions on Japan's economy as a whole.

Event Study Methodology:

This paper will use event study methodology to formulate the framework for analyzing the significance of the Fukushima disaster on TEPCO's electricity loads. The majority of event study papers have used this methodology to "measure the effects of an

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[78] Ibid., p. 309.

economic event on the value of firms."[79] The data used in these academic papers is largely based on the stock prices of a specific firm or industry. The null hypothesis for an event study is typically that the event has no impact on the behavior of returns. Three periods are used to calculate and analyze the significance of these returns. These periods include the estimation window, which is a period of time before the event, an event window, which includes the event being examined, and the post-event window, which is a period of time after the event has occurred. To determine the effect of an event on stock prices, abnormal returns are calculated based on the difference between actual returns that occurred in the event window and the expected returns, which are based on returns in the estimation period.[80]

Expected returns are calculated based on one of two approaches: the constant mean return model or the market model. The constant mean return model uses the mean return of the firm or industry being examined during an estimation period to calculate predicted returns. The market model uses a market return (typically based on a major index) and is the method more widely chosen because it takes "explicit account of the risk associated with the market and mean returns" given the model has a strong R^2 value.[81] Abnormal returns are then assumed to be normally distributed around zero and are tested for significance. There are many ways of analyzing these abnormal returns including aggregating the abnormal returns into a cumulative abnormal return or taking

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[79] A. Craig MacKinlay, "Event Studies in Economics and Finance," *Journal of Economic Literature* 35 (March 1997): 13., ABI/INFORM via EconLit, accessed November 2011.

[80] Donald Siegel and Abagail McWilliams, "Event Studies in Management Research: Theoretical and Empirical Issues," *The Academy of Management Journal* 40 (June 1997): 628, ABI/INFORM via EconLit, accessed February 2012.

[81] Spyridon Repousis and Panagiotis Liargovas, "The Impact of Terrorism on Greek Banks' Stocks: An Event Study," *International Research Journal of Finance and Economics* 51 (2010): 91, ABI/INFORM via EconLit, accessed February 2012.

an average abnormal return.[82] The significance of these returns is then used to represent the power of the event in shifting stock prices unexpectedly within the event window. The event window ranges in size based on the event being studied, but is often fairly small due to the ability for stock prices to respond quickly to events.[83]

For example, one event study in the *International Research Journal of Finance and Economics* titled "The Impact of Terrorism on Greek Banks' Stocks" looks at three terrorist events: the September 11 attacks, the 2004 Madrid train bombing, and the 2005 London train bombing. A wide range of event windows are used, ranging from thirty days before and after the event to one day before and after the event.[84] The abnormal returns are calculated using the Market Model Method and the Athens Stock Exchange, and the results show that only September 11 had significant abnormal returns.[85] Another example is Andreas Keller's "Competition effects of mergers: An event study of the German electricity market," which examines the effect of eight different public announcements by the Swedish company Vattenfall, which acquired three regional utility companies in Germany during the period 1999 to 2002. The announcements vary from announcing interest in a utility to acquiring one. A seven-day event window, ranging from two days before the announcement to four days after, is used for each announcement along with an estimation period of 89 days that ends 11 days before each event. Abnormal returns for the utility companies are calculated using the Market Model Method and the DAX (German index). The results indicate that Vattenfall did not have

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[82] Siegel and McWilliams, "Event Studies in Management Research: Theoretical and Empirical Issues," p. 629.

[83] Ibid., p. 636.

[84] Repousis and Liargovas, "The Impact of Terrorism on Greek Banks' Stocks: An Event Study," p. 93.

[85] Ibid., p. 93.

an anti-competitive effect on the German electricity market due to the lack of significance in stock price changes during their announcement event windows.[86]

Many of the details mentioned in the papers discussed above are not implemented here because this paper is not centered on financial data, but rather the electricity loads of an individual utility. An "abnormal return" cannot be used in this paper because a Market Model Method cannot be applied to electricity loads due to the lack of a market index that would provide an accurate benchmark for the Japanese electricity market. As a result, the significance of the event is captured through a different lens: a time series regression. This paper looks at the effect of the Fukushima nuclear disaster on electricity loads through a regression that highlights the hourly shifts in electricity load after the event. Similar to the studies mentioned above, this study tests the significance of hourly loads after the disaster by comparing them to the hourly variables for the entire data set. However, rather than doing this significance test by calculating abnormal returns, dummy variables are used to capture the significance of the hourly load changes. Due to the large scale of the nuclear disaster, four event windows are used, ranging from a week after the disaster to the end of 2011 (the end of the data set). The goal of these event windows is to capture both short-term and long-term effects of the disasters. A thorough explanation of the model is presented in the following section.

Model:

The first time series regression model, Model (1) is:

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[86] Andreas Keller, "Competition effects of mergers: An event study of the German market," *Energy Policy* 38 (2010): 5269, ABI/INFORM via EconLit, accessed February 2012.

$$(1)\quad Load = \beta_o + \beta_1 disaster + \beta_2 holiday + \beta_3 Max + \beta_4 Min + \beta_5 atrend + \beta_6 dtrend + \beta_7 lpopulation + \beta_8 Sun + \beta_9 Mon + \beta_{10} Tue + \beta_{11} Thu + \beta_{12} Fri + \beta_{13} Sat + \beta_{14} Feb + \beta_{15} Mar + \beta_{16} Apr + \beta_{17} May + \beta_{18} Jun + \beta_{19} Jul + \beta_{20} Aug + \beta_{21} Sep + \beta_{22} Oct + \beta_{23} Nov + \beta_{24} Dec + \beta_{25} one + \beta_{26} two + \beta_{27} four + \ldots + \beta_{45} twentytwo + \beta_{46} twentythree + u_t$$

The second model, Model (2), looks identical to the first except the dependent variable is *lLoad*, the log of *Load*. The log form is used in addition to the unmodified loads to make the variable more comprehensible. The third regression, Model (3), includes interactive hourly disaster dummy variables:

$$(3)\quad Load = \beta_o + \beta_1 holiday + \beta_2 Max + \beta_3 Min + \beta_4 atrend + \beta_5 dtrend + \beta_6 lpopulation + \beta_7 Sun + \beta_8 Mon + \beta_9 Tue + \beta_{10} Thu + \beta_{11} Fri + \beta_{12} Sat + \beta_{13} Feb + \beta_{14} Mar + \beta_{15} Apr + \beta_{16} May + \beta_{17} Jun + \beta_{18} Jul + \beta_{19} Aug + \beta_{20} Sep + \beta_{21} Oct + \beta_{22} Nov + \beta_{23} Dec + \beta_{24} zero + \beta_{25} one + \beta_{26} two + \beta_{27} four + \ldots + \beta_{45} twentytwo + \beta_{46} twentythree + \beta_{47} dzero + \beta_{48} done + \beta_{49} dtwo + \beta_{50} dfour + \ldots + \beta_{68} dtwentytwo + \beta_{69} dtwentythree + u_t$$

Model (4) looks identical to the third except the dependent variable is *lLoad*.

The dependent variables, *Load* and *lLoad*, represent the hourly electricity loads (unit of 10 thousand KW) and log of hourly electricity loads for TEPCO from January 1, 2008 to December 31, 2011, respectively. The independent variables that determine the significance of the Fukushima Daiichi nuclear accident are *disaster* (*dweek, dmonth, dsummer*), hourly variables *one* through *twentythree*, interactive hourly disaster variables *done* through *dtwentythree*, and a trend variable *dtrend*. *disaster* is a dummy variable that is zero until March 11, 2011 and then one through the rest of the data set, representing the event window. The event window extends through the rest of the year due to the magnitude of the event. While the earthquake and ensuing tsunami took place on March

11, nuclear reactors were exploding through March 15 and operations at the Fukushima Daiichi plant were not suspended until March 16.[87] Beyond that, a cold shut down of the plant was not achieved until December 2011.[88] On a macro level, nuclear reactors in Japan are still being shut down; the last of the 56 nuclear reactors shuts down in April or May of 2012.[89] As a result of these continued consequences of the Fukushima Daiichi disaster, the event window extends to the end of the data set. Additionally, alternative event windows are substituted for *disaster* in order to further analyze the short and long-term effects of the disaster. *dweek* is a dummy variable that is one from March 11, 2011 to March 16, 2011, representing the immediate effects of the disaster. Finally, *dmonth* is a dummy variable that is one from March 11, 2011 to March 31, 2011, representing the short-term effects of the disaster. *dsummer* is a dummy variable that is one from March 11, 2011 to August 31, 2011, representing the medium-term effects of the disaster. These variables provide a detailed look into the lasting impacts of the Fukushima Daiichi disaster.

The hourly disaster interactive variables, *done* through *dtwentythree* are *disaster* multiplied by corresponding hourly dummy variables, *one* through *twentythree*. A disaster trend variable, *dtrend*, is included to capture the load movement after the nuclear accident. The variable starts at one on March 11, 2011 and increases monthly by one, ending at 10. An annual trend variable, *atrend*, is also used to indicate movements in the

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[87] "Summary Report of RSMC Beijing on Fukushima Nuclear Accident Emergency Response," World Meteorological Organization, October 31, 2011, accessed February 2012.

[88] Ken Buesseler, "What Fukushima accident did to the ocean." *CNN*, March 10, 2012, http://www.cnn.com/2012/03/10/opinion/buesseler-fukushima-ocean/index.html, accessed March 2012.

[89] S. Williams, Brian Spegele, and Chester Dawson, "Nuclear Pushes on Despite Fukushima," *Wall Street Journal*, March 9, 2012, http://online.wsj.com/article/SB10001424052970204276304577265240284295880.html, accessed March 2012.

load throughout the entire data set. The variable starts one and increases annually, ending at four. A population variable, *lpopulation*, is included in log form to account for annual changes in the Japanese population, which is slowly declining. *time* increases hourly throughout the entire data set.

Daily maximum and minimum temperatures for Tokyo, *Max* and *Min* (measured in degrees Celsius), are used in order to control for temporal impacts on load such as higher temperatures leading to the use of more air conditioning units and therefore greater demand for electricity. Dummy variables will be used to control for month (*Feb* to *Dec*), day of the week (*Sun* to *Sat* excluding *Wed*), hour (*zero* to *twentythree* excluding *three*), and holidays (*holiday*). The holiday dummy variable is one for every major holiday in Japan and is used to control for load changes based on businesses being closed.

I chose to eliminate Wednesday, January, and hour three from the regression to avoid multicollinearity. I am assuming that these time variables are the least significant in terms of load volatility. *Wed* was chosen because it is in the middle of the week and therefore fairly predictable in comparison to the other days. *Jan* was eliminated because it is in the winter, which tends to be less volatile than the summer months when comparing temperature swings and the use of air conditioning units. *three* was eliminated because it is one of hours with the lowest demand for electricity because businesses are not running and consumers are sleeping. In addition to eliminating these dummy variables, *dtrendsq*, the disaster trend variable *dtrend* squared, and lagged load variables were eliminated due to their insignificant effect on the model. Table 1 provides a brief description of all of the variables used in this paper's models.

Table 1.

Variable Descriptions

Variable Name	Description	Variable Name	Description
Load	Electricity load (10 thousand KW)	eight	Hour 8
lLoad	Log of Electricity load (10 thousand KW)	nine	Hour 9
Max	Maximum Temperatures (Celsius)	ten	Hour 10
Min	Minimum Temperatures (Celsius)	eleven	Hour 11
holiday	Holidays	twelve	Hour 12
disaster	March 11th – December 31st 2011	thirteen	Hour 13
dweek	March 11th – March 16th 2011	fourteen	Hour 14
dmonth	March 11th – March 31st 2011	fifteen	Hour 15
dsummer	March 11th – August 31st 2011	sixteen	Hour 16
hour	Hours 0 -23	seventeen	Hour 17
atrend	Annual Trend (2008-2011)	eighteen	Hour 18
dtrend	Monthly Trend post-disaster (3/11-12/11)	nineteen	Hour 19
population	Japan Population	twenty	Hour 20
lpopulation	Log of population	twentyone	Hour 21
time	Time Series variable	twentytwo	Hour 22
Jan	January	twentythree	Hour 23
Feb	February	dzero	Disaster Hour 0
Mar	March	done	Disaster Hour 1
Apr	April	dtwo	Disaster Hour 2
May	May	dthree	Disaster Hour 3
Jun	June	dfour	Disaster Hour 4
Jul	July	dfive	Disaster Hour 5
Aug	August	dsix	Disaster Hour 6
Sep	September	dseven	Disaster Hour 7
Oct	October	deight	Disaster Hour 8
Nov	November	dnine	Disaster Hour 9
Dec	December	dten	Disaster Hour 10
Sun	Sunday	deleven	Disaster Hour 11
Mon	Monday	dtwelve	Disaster Hour 12
Tue	Tuesday	dthirteen	Disaster Hour 13
Wed	Wednesday	dfourteen	Disaster Hour 14
Thu	Thursday	dfifteen	Disaster Hour 15
Fri	Friday	dsixteen	Disaster Hour 16
Sat	Saturday	dseventeen	Disaster Hour 17
zero	Hour 0	deighteen	Disaster Hour 18

one	Hour 1	dnineteen	Disaster Hour 19
two	Hour 2	dtwenty	Disaster Hour 20
three	Hour 3	dtwentyone	Disaster Hour 21
four	Hour 4	dtwentytwo	Disaster Hour 22
five	Hour 5	dtwentythree	Disaster Hour 23
six	Hour 6	datef	Date (1/1/08 – 12/31/11)
seven	Hour 7		

Data:

Observations for this paper were taken every hour for years 2008 through 2011, creating a time series data set. There are 35,064 observations for each variable. The hourly electricity loads, *Load*, are published on TEPCO's website and the data set is updated daily. The data represents the demand for electricity for the entire service area.[90] The maximum and minimum temperatures for Tokyo, *Max* and *Min*, were collected from a website, TuTiempo, which provides weather information for regions around the world.[91] The temperatures are daily and a macro was used to format the data into my hourly data set. Japanese holidays, identified in the dummy variable *holiday*, are chosen based on the observed holidays listed on timeanddate.com.[92] The annual Japanese population size, *population*, was taken from data collected by The World Bank.[93]

The data was collected in January 2012 and entered into STATA. The variables and summary statistics seem reasonable and as a result provide reasonably accurate estimates of the variables' effects on TEPCO's electricity load; however, autocorrelation

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[90] Tokyo Electric Power Company, "Electricity Forecast," Tokyo Electric Power Company website, http://www.tepco.co.jp/en/forecast/html/download-e.html, accessed September 2011.

[91] Tu Tiempo, "Climate Tokyo – Historical Weather," Tu Tiempo website, http://www.tutiempo.net/en/Climate/Tokyo/476620.htm, accessed December 2011.

[92] Time and Date, "Calendar for year 2011 (Japan)," Time and Date website, http://www.timeanddate.com/calendar/?year=2011&country=26, accessed February 2012.

[93] The World Bank, "Data: Japan," The World Bank website, http://data.worldbank.org/country/japan, accessed March 2012.

was initially a problem for all of my regressions. A Durbin Watson test produced values of 0.288, 0.321, 0.097, and 0.106 for models (1), (2), (3), and (4) respectively, indicating significant autocorrelation. A Prais-Winston transformation was initially done to correct for this autocorrelation, but yielded Durbin-Watson values that were still well below the desired values. This result led me to believe that an AR(1) correction would not fix the issue, so Newey West standard errors were used instead. Using a Breusch Godfrey test, lags of 6, 12, 18, and 24 were tested and found to be significant. However, a lag of 24 was chosen due to the hourly division of the data. These tests and the resulting Newey West transformation are assumed to have corrected the autocorrelation.

Table 2.

Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
Load	3519.566	704.245	2048	6089
lLoad	8.146	0.199	7.625	8.714
Max	20.284	8.151	1.7	37.2
Min	13.057	8.229	-1.1	28.6
holiday	0.044	0.206	0	1
disaster	0.203	0.402	0	1
dweek	0.004	0.064	0	1
dmonth	0.023	0.148	0	1
dsummer	0.120	0.325	0	1
hour	11.5	6.922	0	23
atrend	2.499	1.118	1	4
dtrend	1.145	2.598	0	10
population	127297030	482639.9	126475664	127704040
lpopulation	18.662	0.004	18.656	18.665
time	17532.5	10122.25	1	35064
Feb	0.077	0.267	0	1
Jan, Mar, May, Jul, Aug, Oct, Dec	0.085	0.279	0	1
Apr, Jun, Sep, Nov	0.082	0.276	0	1

Sun, Mon	0.142	0.349	0	1
Tue, Wed, Thu, Fri, Sat	0.143	0.350	0	1
zero, one, two…twentythree	0.042	0.200	0	1
dzero, done, dtwo…dtwentythree	0.008	0.091	0	1
datef	18262	421.760	16532	18992

Results:

I expected the Fukushima Daiichi nuclear disaster to have a significant, negative impact on TEPCO's electricity load and found results consistent with this hypothesis. All results for Models (1) and (2) can be found in Table 3 in the Appendix.

All of the variables are significant at the one percent level except for *Tue*, *Thu*, *Fri*, *Feb*, and *atrend*. These variables are insignificant because load is more predictable and less volatile during the week and in the winter. As seen in Table 3, the *disaster* variable is extremely significant with a t-statistic of -13.18. These results estimate that if the *disaster* variable is triggered (if the date is within the event window), there is a 652.752 (10 thousand KW) decrease in electricity load. This significant decrease in load showcases the magnitude of the disaster's impact on electricity load. The trend variable *atrend* suggests a decrease in the demand for electricity throughout the entire data set, which coincides with Japan's declining population. Although the variable is not significant, each additional year shows decreased electricity load by 19.069 (10 thousand KW). Conversely, the disaster trend variable, *dtrend*, is significant and positive suggesting that load is increasing as time passes post-Fukushima. For every month after the nuclear disaster, electricity load increases by 33.592 (10 thousand KW).

Taking a deeper look into the significance of the *dtrend* and *atrend* variables on *Load*, an approximate timeline is estimated regarding the disaster's lasting effects on electricity load. An average of hourly pre-disaster loads is taken from January 1, 2008 to March 10, 2011 and is used as a benchmark for reaching pre-disaster loads (3604. 976 10 thousand KW). The *disaster* coefficient is used as a representation of the disaster's lasting effects on the load (-652.752 10 thousand KW). To calculate the number of months until pre-disaster load is reached, the *dtrend* and the *atrend* are combined by first dividing the *atrend* coefficient by twelve and then adding them together to get a monthly averaged increase in load since the disaster date, March 11, 2011. Based on these averaged calculations and ignoring all other variables and factors, Model (1) approximates load will take 20.396 months to reach the pre-disaster hourly load average. Although this model suggests TEPCO's loads will recover in November 2012, factors such as the future structure of both TEPCO and the utility industry as a whole, as well as other future economic and political implications could disrupt this recovery timeline.

Figures 2 and 3 visually depict the annual trend, disaster trend, and the significant, extended decrease in load due to the Fukushima Daiichi disaster (marked with a red line). Both Figures 2 and 3 are based on average daily loads over time.

Figure 2.

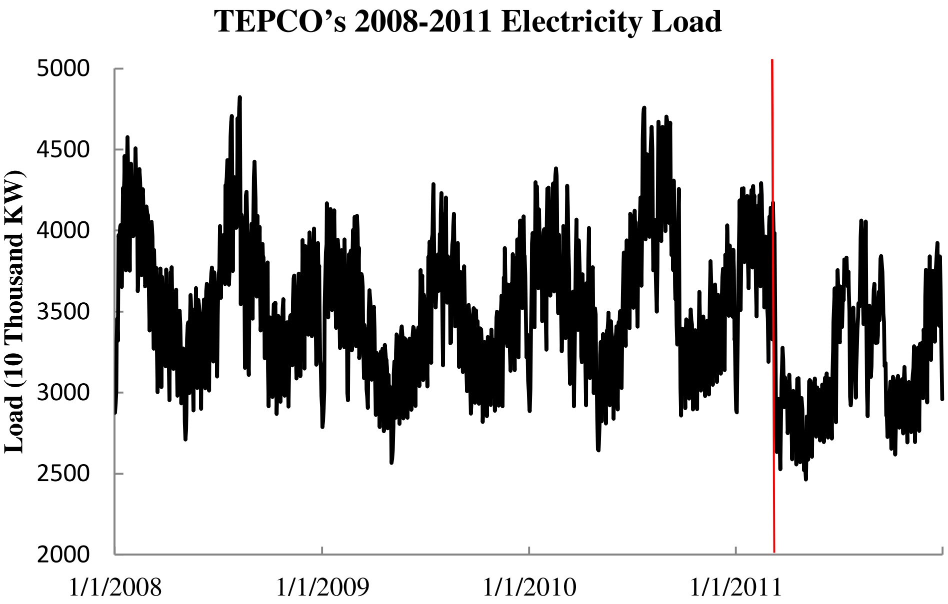
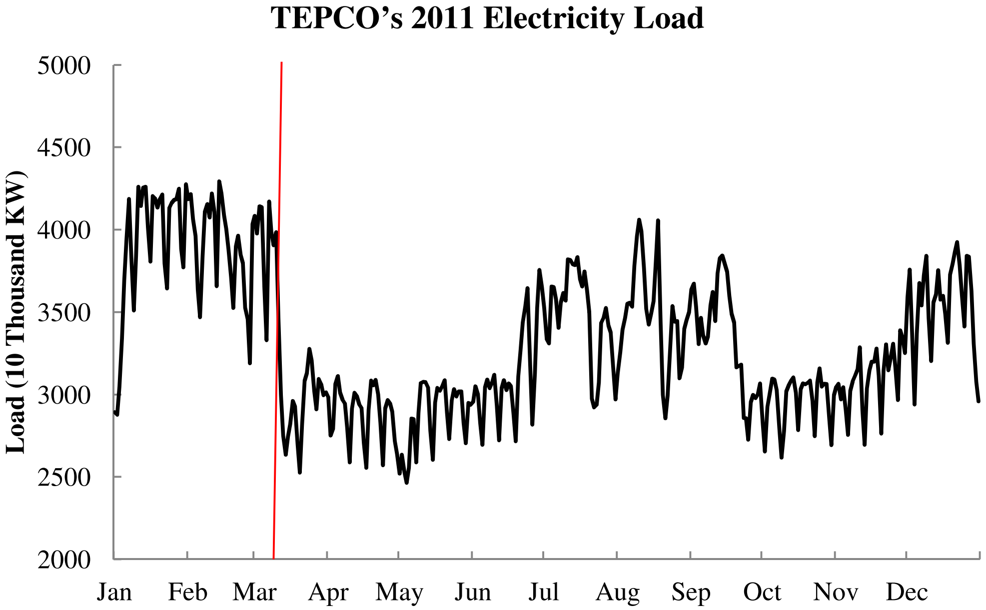


Figure 3.



Additional event windows are substituted for the variable *disaster* in order to determine the lasting impacts of the disaster on electricity load. Model (1) is used for the regression and the event window variables are substituted in for the dummy variable, *disaster*. Table 4 includes the varying event windows and their corresponding regression results.

Table 4.

Model (1) Results Substituting Different Event Windows

Load	Event Window	Coefficient	t	P>|t|
dweek	(0,5)	-424.3112	-3.04	0.002
dmonth	(0,20)	-361.418	-6.84	0.000
dsummer	(0,173)	-377.105	-11.6	0.000
disaster	(0,295)	-652.752	-13.18	0.000

All of the disaster variables are significant at the one percent level. The variable *dweek*, representing the short-term event window, yields a 424.3112 (10 thousand KW) decrease in load. This variable highlights the significant, immediate impact of the disaster on Tokyo's electricity market. *dmonth* and *dsummer* are slightly more significant, largely due to their lengthier event windows, but decrease load by 361.418 and 377.105 (10 thousand KW), respectively, which is less than the short-term event window variable, *dweek*. The most notable result is the original variable, *disaster*. The magnitude of this variable, in comparison to the smaller event windows, is unexpected due to its large impact on electricity load. Given that the other variables' effect on load decreased as the event window increased, the contrary effect of *disaster* suggests an additional underlying cause for lasting, decreased load beyond the factors that are controlled for in this model (temperature, seasonality, etc.). Figures 4 (*dweek*), 5 (*dmonth*), 6 (*dsummer)*, and 7 (*disaster*) illustrate the various load levels for the different event windows. The Fukushima Daiichi disaster is marked with a red line.

Figure 4.[94]

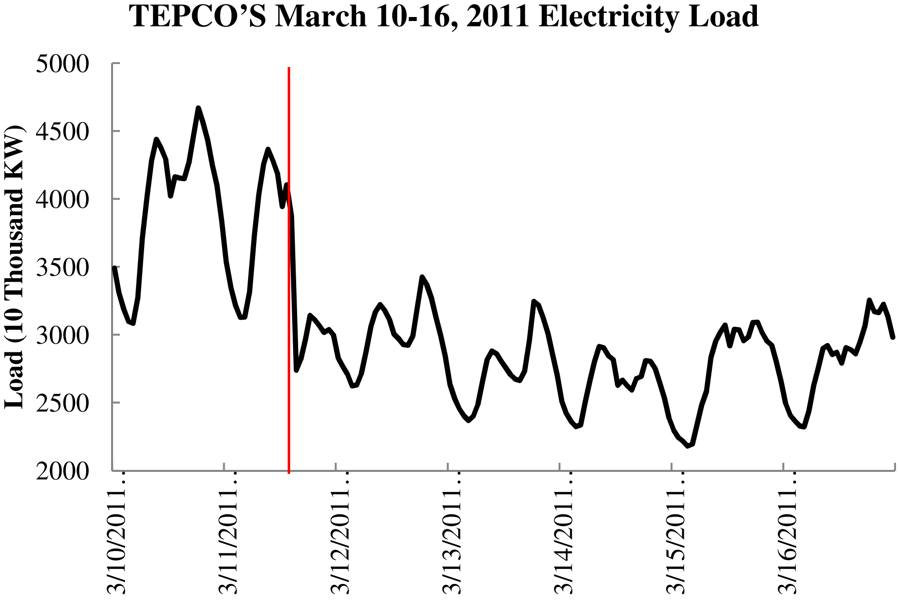
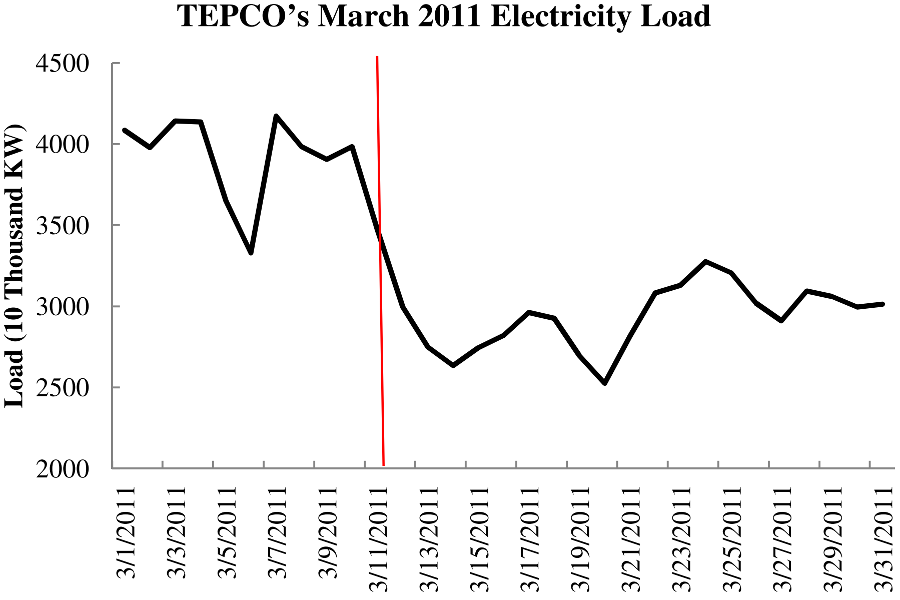


Figure 5.



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[94] Figure 4 includes hourly loads, whereas Figures 5, 6, and 7 include daily averages of hourly loads

Figure 6.

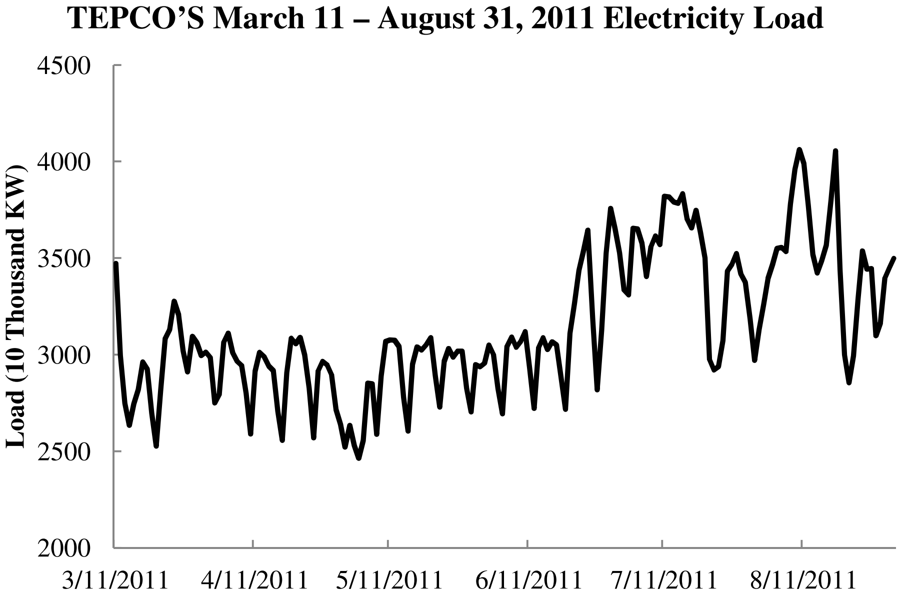
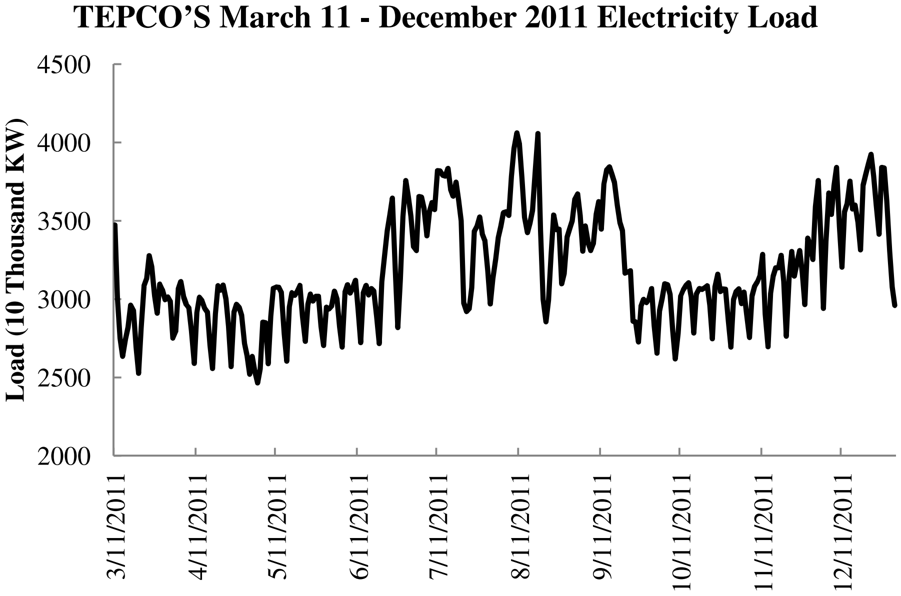


Figure 7.



Other time dummy variables that have a notable effect on electricity load include *Sat*, *Sun*, and the cooler months such as *Sep* through *Dec* (Table 3). All of these variables impact the load negatively. *Sat* and *Sun* decrease load by 305.572 and 489.199 (10 thousand KW) respectively. *Sep*, *Oct*, *Nov*, and *Dec* decrease load by 458.222, 757.613, 521.464, and 217.244 (10 thousand KW) respectively. These results are somewhat expected and supported by my Literature Review as the decreased demand for electricity on the weekends resulted from businesses being closed. Similarly, decreased demand in the winter months resulted from cooler temperatures and the lack of air conditioner use. *holiday* is also negatively significant, decreasing load by 360.843 if triggered, due to consumers staying at home and businesses being closed. Daily temperatures, *Max* and *Min*, impacted the load in slightly unexpected ways. *Max* decreased load by 9.592 (10 thousand KW), which does not follow the assumption that higher temperatures lead to an increased load. However, the *Min* coefficient supported this assumption in that the higher the minimum temperature the higher the demand for electricity, with a coefficient of 24.938.

As seen in Table 3, Model (2) produced similar results in terms of the significance of the independent variables. Again *Tue, Thu, Fri, Feb,* and *atrend* are insignificant whereas the rest of the variables are significant at the one percent level. The variable *disaster* suggests that if the dummy variable is triggered there is a 19.192 percent decrease in TEPCO’s electricity load. This decrease is extreme and could suggest that consumers in the TEPCO service area decreased their electricity consumption by more than was required by the Japanese government, a hypothesis that is supported in my Institutional Background and Literature Review. These excess saving measures are even more notable in a country that has fixed electricity prices because even though there were tight supply margins there were no price spikes to provide additional incentive to save during these hours.

The disaster trend variable *dtrend* indicates for a monthly increase in time after the disaster, load increases by 1.061 percent (Table 3). The hourly variables *zero* through *twentythree* are the most significant variables in the regression with t-statistics ranging from 9.83 (hour *five*) to 192.34 (hour *eighteen*). Due to the significance of these variables and their relationship to the daily load curve, models (3) and (4) examine the effect of the hour on electricity load by looking at hourly and interactive hourly disaster variables and comparing their magnitude and direction. All results for Models (3) and (4) can be found in Table 5 in the Appendix.

The regression results for model (3) indicate significance for all variables except *atrend*, *lpopulation*, *Tue*, *Thu*, *Fri*, *Feb*, and the constant. Examining the hourly variables, the hourly dummy variables that represent the entire data set, *zero* through *twentythree*, have a positive effect on the electricity load; whereas, the disaster hourly interactive variables, *dzero* through *dtwentythree*, have a negative effect on *Load*. In both sets of hourly variables, on-peak hours, especially hours nine, ten, and seventeen through nineteen, are the most significant and have the largest standard errors. This result supports my hypothesis that on-peak hours are critical when determining demand because they are the hours in which consumers are the most active either at home or at work and they are also the most volatile due to changes in temperature, work hours, and other unexpected conditions.

The results for model (4) indicate the same significant variables as model (3). Again, the on peak interactive hourly disaster variables are the most significant in representing the effect of the disaster on electricity load. The most significant morning on-peak hours are hours *deight*, *dnine*, and *dten* which typically represent the morning spike in load due to the start of the business day. These hours decrease electricity load post-disaster by 17.49 percent, 18.22 percent, and 16.16 percent respectively. The most significant afternoon on-peak hours are hours *dseventeen*, *deighteen*, and *dnineteen* which typically represent the highest demand hours and are followed by significantly lower demand. These hours decrease electricity load post-disaster by 18.8 percent, 18. 52 percent, and 17.89 percent respectively.

Table 6.

Variable Comparison Results: Hourly vs. Disaster Hourly Interactive Variables

(Hour) - d(Hour) = 0	Model (3)		Model (4)	
Hour	F(1, 34994)	Prob > F	F(1, 34994)	Prob > F
0	310.51	0.000	430.8	0.000
1	173.29	0.000	253.58	0.000
2	99.52	0.000	149.62	0.000
4	49.84	0.000	73.9	0.000
5	82.2	0.000	120.8	0.000
6	250.04	0.000	339.66	0.000
7	613.4	0.000	774.66	0.000
8	1166.29	0.000	1363.42	0.000
9	1589.7	0.000	1774.9	0.000
10	1671.08	0.000	1852.65	0.000
11	1565.04	0.000	1746.04	0.000
12	1279.48	0.000	1478.13	0.000
13	1361.63	0.000	1533.67	0.000
14	1327.64	0.000	1492.13	0.000
15	1350.63	0.000	1516.46	0.000
16	1604.68	0.000	1770.03	0.000
17	1941.69	0.000	2087.25	0.000
18	2119.79	0.000	2282.39	0.000
19	1934.2	0.000	2116.38	0.000
20	1591.51	0.000	1800.85	0.000
21	1200.05	0.000	1419.91	0.000

22	969.1	0.000	1179.57	0.000
23	635.8	0.000	820.81	0.000

The results in Table 6 further support my hypothesis by showing that when comparing the hourly variables to the interactive hourly disaster variables, the on-peak hours are the most significant. Again this result shows that the greatest conservation efforts and government regulation occurred between hours seven to twenty. It is also important to note that these hours have been targeted in response to a supply shock because these hours have the highest demand and therefore have to be closely monitored and regulated in order to prevent blackouts. These results support the absence of blackouts post-Fukushima and reveal the magnitude of the conservation measures that were taken, both by regulation and choice. Table 6 further displays the significance of hours nine and ten as well as hours seventeen through nineteen as holding the greatest shifts in demand after the accident. Looking at these results through the lens of the daily load curve, it is possible that these hours observed the greatest change post-Fukushima because they were the points in the day with the greatest amount of transition. In terms of going to and from work, this period marked the time when people could take measures such as turning off all of the lights and air conditioning units before heading to work and businesses could turn off unused lights and raise internal temperatures at the end of the business day. As a result of these seemingly minor changes, large decreases in demand can be explained.

Conclusion:

By creating a model to analyze the impact of the Fukushima Daiichi nuclear disaster on TEPCO's electricity load, this paper determined the magnitude of the accident by collecting a large hourly data set and determining an event window that would indicate the lasting effect of the disaster on the demand for electricity. This paper successfully indicates the magnitude of the Fukushima disaster, both aggregately and hourly. Overall, the results reveal that the disaster significantly decreased electricity load. The large event window supports this result as it highlights the continuous negative impact of the disaster through the end of 2011 and most likely for a long period into the future. Given that Model (2) approximates the disaster to have decreased load by almost twenty percent for the period, the recovery period for electricity demand to return to pre-accident levels could take years, and may never return to these levels, especially given the declining population and consumer resistance to nuclear energy. These results are therefore economically and politically significant given the future uncertainty within the Japanese electricity industry. Furthermore, by presenting evidence on the severity of the economic impacts of the Tohoku earthquake and Fukushima Daiichi nuclear disaster, this paper supports the need for changes in preventative measures. A possible solution is to expand the country's supply chain to be dispersed more evenly throughout the country and to invest in foreign production facilities in order to limit production setbacks in the future.

While this paper provides a solid platform in terms of analyzing the effects of the Fukushima Daiichi disaster on TEPCO's daily load curve, it may be possible to obtain more refined, explanatory results by further dividing the data set. One approach would be to divide the service area into coastal and inland regions or regions that are closer to Fukushima compared to those farther away. By further refining the regions, a more precise impact of the disaster could be detected. A second method would be to divide the load by industrial sector in order to see which industries observed the most significant decreases in electricity, how those decreases affected the industry’s productivity, and for how long decreases last and have an impact. This method would also provide more refined evidence regarding industries that are severely impacted by the disaster and therefore which industries could disperse their suppliers and production in order to minimize the economic blow of a disaster.

Another approach could be to look at disaster-month and disaster-weekday interactive variables in order to further determine which months and days observed the most significant changes in load post-Fukushima. While my paper indicates that load is increasing as we move away from the disaster date (significance and direction of *dtrend*), a closer look into regulated decreases versus consumer chosen decreases in load is needed to fully capture the direction in which future load is headed and how these changes will affect the daily load curve. By controlling for the fifteen percent decrease in electricity demand mandated by the Japanese government, one could quantify the excess saving measures being taken, which could lead to a deeper analysis of the lasting demand changes taking place in the Tokyo area.

Although this paper does not differentiate between government mandated load reductions and consumer chosen reductions, it does highlight the hours that have seen the greatest change in load post-Fukushima. By revealing these hours as the transition periods in the daily load curve, future policies can target these hours if additional saving measures need to be taken. Utilities can also take advantage of these changes when forecasting future electricity demand and signing future supply contracts. Utilities often use different types of energy based on demand, price, and time of day so long term changes in the daily load curve could affect the type of energy policies they use. Furthermore, changes in utility operations could affect the prices and policies directed towards TEPCO customers. Given the complex relationship between Japanese regulators, utilities, and customers it is hard to predict the long-term effect of the supply shock and decreased demand that resulted from the Fukushima Daiichi disaster; however, this paper provides initial insight into the effects of the disaster.

Appendix:

Table 3.

Models (1) and (2) Regression Results

	Coefficients			Coefficients	
	Model 1	**Model 2**		**Model 1**	**Model 2**
Variables	Load	lLoad	**Variables**	Load	lLoad
disaster	-652.752	-0.192	***zero***	346.77	0.119
	(13.18)**	(13.93)**		(84.59)**	(106.68)**
holiday	-360.843	-0.105	***one***	174.364	0.062
	(10.93)**	(10.74)**		(56.69)**	(69.49)**
Max	-9.592	-0.003	***two***	67.361	0.024
	(3.94)**	(4.16)**		(30.34)**	(38.15)**
Min	24.938	0.006	***four***	-25.417	-0.01
	(6.92)**	(6.50)**		(11.88)**	(15.63)**
atrend	-19.069	-0.006	***five***	31.237	0.01
	(-1.4)	-1.67		(9.56)**	(9.83)**
dtrend	33.592	0.011	***six***	265.517	0.09
	(6.88)**	(7.40)**		(44.24)**	(49.11)**
lpopulation	-17,596.88	-5.187	***seven***	571.111	0.186
	(2.64)**	(2.92)**		(71.76)**	(85.58)**
Sun	-489.2	-0.138	***eight***	922.415	0.287
	(24.18)**	(25.16)**		(94.19)**	(119.22)**
Mon	-65.884	-0.022	***nine***	1,191.39	0.359
	(3.00)**	(3.86)**		(104.77)**	(137.10)**
Tue	-0.324	-0.001	***ten***	1,269.96	0.379
	(-0.02)	(-0.13)		(104.81)**	(137.26)**
Thu	1.302	0.001	***eleven***	1,280.59	0.381
	(-0.07)	-0.15		(99.66)**	(129.28)**
Fri	-16.177	-0.003	***twelve***	1,126.78	0.342
	(-0.74)	(-0.61)		(90.57)**	(116.20)**
Sat	-305.573	-0.081	***thirteen***	1,237.44	0.369
	(14.59)**	(14.40)**		(92.70)**	(117.97)**
Feb	47.212	0.015	***fourteen***	1,241.92	0.37
	(-1.17)	(-1.39)		(90.08)**	(114.24)**
Mar	-287.047	-0.074	***fifteen***	1,225.17	0.366
	(7.14)**	(6.71)**		(91.71)**	(116.34)**
Apr	-597.998	-0.16	***sixteen***	1,307.97	0.388
	(12.62)**	(12.31)**		(104.12)**	(135.43)**
May	-775.04	-0.213	***seventeen***	1,378.78	0.408
	(13.90)**	(13.91)**		(124.52)**	(166.46)**
Jun	-629.228	-0.164	***eighteen***	1,409.55	0.417
	(9.64)**	(9.31)**		(141.57)**	(192.34)**
Jul	-237.756	-0.058	***nineteen***	1,333.75	0.399
	(2.84)**	(2.58)**		(142.05)**	(188.93)**
Aug	-236.731	-0.061	***twenty***	1,177.77	0.36
	(2.77)**	(2.64)**		(133.79)**	(173.61)**
Sep	-458.222	-0.119	***twentyone***	981.552	0.308

	(6.39)**	(6.06)**		(117.89)**	(149.20)**
Oct	-757.613	-0.204	***twentytwo***	850.942	0.272
	(13.73)**	(13.56)**		(113.30)**	(143.22)**
Nov	-521.464	-0.137	***twentythree***	619.663	0.205
	(12.07)**	(11.55)**		(92.19)**	(114.17)**
Dec	-217.244	-0.053	***Constant***	331,622.41	104.851
	(5.23)**	(4.60)**		(2.66)**	(3.16)**

t statistics in parentheses **** significant at 5%; ** significant at 1%***

Table 4.

Models (3) and (4) Regression Results

	Coefficients			Coefficients	
	Model 3	**Model 4**		**Model 3**	**Model 4**
Variables	Load	lLoad	**Variables**	Load	lLoad
holiday	-361.38	-0.105	***thirteen***	1,367.89	0.405
	(10.94)**	(10.75)**		(84.16)**	(101.81)**
Max	-9.726	-0.003	***fourteen***	1,372.18	0.405
	(4.00)**	(4.21)**		(82.02)**	(99.29)**
Min	24.874	0.006	***fifteen***	1,355.87	0.401
	(6.90)**	(6.46)**		(83.51)**	(101.00)**
atrend	-10.912	-0.003	***sixteen***	1,443.95	0.424
	(-0.81)	(-0.9)		(94.23)**	(114.72)**
dtrend	24.4	0.007	***seventeen***	1,523.62	0.446
	(5.40)**	(5.62)**		(111.25)**	(134.69)**
lpopulation	-9,435.48	-2.41	***eighteen***	1,553.42	0.455
	(-1.54)	(-1.46)		(123.08)**	(147.61)**
Sun	-489.351	-0.138	***nineteen***	1,470.54	0.435
	(24.25)**	(25.18)**		(120.78)**	(142.91)**
Mon	-65.931	-0.022	***twenty***	1,304.50	0.395
	(3.01)**	(3.86)**		(109.81)**	(128.76)**
Tue	-0.336	-0.001	***twentyone***	1,096.34	0.341
	(-0.02)	(-0.13)		(93.58)**	(109.42)**
Thu	1.322	0.001	***twentytwo***	955.228	0.302
	(-0.07)	(-0.15)		(85.75)**	(100.49)**
Fri	-16.613	-0.004	***twentythree***	713.882	0.233
	(-0.76)	(-0.64)		(66.97)**	(78.74)**
Sat	-305.671	-0.081	***dzero***	-403.066	-0.13
	(14.60)**	(14.37)**		(10.36)**	(11.85)**
Feb	47.176	0.015	***done***	-368.795	-0.123
	(-1.17)	(-1.39)		(9.50)**	(11.31)**
Mar	-304.939	-0.08	***dtwo***	-333.241	-0.113
	(7.55)**	(7.17)**		(8.56)**	(10.40)**
Apr	-621.433	-0.168	***dfour***	-295.253	-0.101
	(13.24)**	(13.02)**		(7.61)**	(9.34)**
May	-795.231	-0.22	***dfive***	-325.417	-0.11
	(14.29)**	(14.36)**		(8.44)**	(10.27)**
Jun	-646.483	-0.17	***dsix***	-403.411	-0.131
	(9.89)**	(9.60)**		(10.42)**	(11.99)**

Jul	-251.757	-0.063	***dseven***	-514.29	-0.157
	(2.99)**	(2.78)**		(13.30)**	(14.41)**
Aug	-248.324	-0.065	***deight***	-615.302	-0.175
	(2.89)**	(2.80)**		(15.87)**	(16.03)**
Sep	-468.173	-0.123	***dnine***	-675.293	-0.182
	(6.51)**	(6.20)**		(16.93)**	(16.32)**
Oct	-766.345	-0.207	***dten***	-692.767	-0.185
	(13.86)**	(13.72)**		(16.91)**	(16.16)**
Nov	-528.967	-0.14	***deleven***	-675.869	-0.18
	(12.24)**	(11.76)**		(16.06)**	(15.37)**
Dec	-223.382	-0.055	***dtwelve***	-641.575	-0.177
	(5.37)**	(4.76)**		(15.07)**	(14.91)**
zero	428.431	0.146	***dthirteen***	-643.862	-0.173
	(45.05)**	(53.83)**		(14.81)**	(14.31)**
one	249.082	0.086	***dfourteen***	-642.948	-0.172
	(27.48)**	(33.12)**		(14.62)**	(14.08)**
two	134.876	0.047	***dfifteen***	-645.12	-0.174
	(15.41)**	(18.73)**		(14.85)**	(14.33)**
four	34.402	0.011	***dsixteen***	-671.162	-0.179
	(3.99)**	(4.36)**		(15.87)**	(15.12)**
five	97.168	0.033	***dseventeen***	-714.879	-0.188
	(10.72)**	(12.25)**		(17.40)**	(16.34)**
six	347.249	0.116	***deighteen***	-710.114	-0.185
	(32.50)**	(36.91)**		(17.77)**	(16.66)**
seven	675.307	0.218	***dnineteen***	-675.14	-0.179
	(56.40)**	(65.07)**		(16.94)**	(16.11)**
eight	1,047.08	0.323	***dtwenty***	-625.553	-0.171
	(79.40)**	(93.59)**		(15.82)**	(15.48)**
nine	1,328.21	0.396	***dtwentyone***	-566.586	-0.161
	(92.45)**	(111.46)**		(14.46)**	(14.65)**
ten	1,410.32	0.416	***dtwentytwo***	-514.731	-0.15
	(94.58)**	(114.92)**		(13.30)**	(13.78)**
eleven	1,417.52	0.417	***dtwentythree***	-465.043	-0.142
	(90.41)**	(110.03)**		(12.11)**	(13.13)**
twelve	1,256.77	0.378	***Constant***	179,187.07	52.977
	(82.16)**	(100.05)**		(-1.57)	(-1.72)
t statistics in parentheses			**** significant at 5%; ** significant at 1%***		

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