Product Price Risk and Liquidity Management: Evidence from the Electricity Industry

Chen Lin
University of Hong Kong

Thomas Schmid
University of Hong Kong

and

Michael S. Weisbach
Ohio State University, NBER and ECGI

May 2, 2018

Abstract

Uncertainty about the selling price of their products is a potentially important factor affecting firms' liquidity management policies. A natural place to evaluate the importance of price risk on liquidity management is the electricity industry, since in 32 countries, producing firms sell electricity in volatile wholesale markets. Empirically, higher price volatility leads to an increase in cash holdings, and this effect is robust to instrumenting for price risk using weather volatility. Consistent with the theory of price risk as originally formulated by Sandmo (1971), cash increases more with price volatility in firms that use inflexible technologies, for which adjusting output is relatively costly. Holding cash and hedging in derivative markets appear to be substitutes, since volatility affects cash holdings more in parts of the world where firms cannot easily hedge electricity prices through derivative markets.

JEL classification: G30, G32

Key words: Electricity price volatility, cash holdings, weather volatility, operating flexibility, hedging

Contact information: Chen Lin, Faculty of Business and Economics, University of Hong Kong, Hong Kong, email: chenlin1@hku.hk; Thomas Schmid, Faculty of Business and Economics, University of Hong Kong, Hong Kong, email: schmid@hku.hk; Michael S. Weisbach, Department of Finance, Fisher College of Business, Ohio State University, Columbus, OH 43210, email: weisbach@fisher.osu.edu. We are very grateful to Heitor Almeida, Murillo Campello, Ling Cen, Steve Cicala, Igor Cunha, Shan Ge, Alan Kwan, Peter MacKay, Bernadette Minton, Seungjoon Oh, Weiling Song, René Stulz, Tracy Wang, and seminar participants at University of Kentucky, Ohio State University, University of Utah, University of Washington, the 2017 HK-SZ Summer Conference, and the 2017 University of Oklahoma Energy and Commodities Finance Research Conference for helpful suggestions.

> Moody's Investors Service says that power prices are expected to remain volatile […] Individual generators that can rapidly adjust their output in response to price swings will likely benefit, but those that cannot could prove commercially unviable over time.
>
> *Moody's Investor Service (2016)*

1. Introduction

One of the most important decisions a financial manager must make concerns the liquidity of his balance sheet, in particular, the amount of cash that his firm should hold. The most prominent explanation of corporate liquidity decisions was originally proposed by Keynes (1936), and is known as the precautionary theory of savings. This theory posits that firms hold cash as a hedge against the possibility that they will subsequently face financial constraints that distort their investment decisions. A number of studies starting with Opler, Pinkowitz, Stulz, and Williamson (1999) have documented that, consistent with this argument, firms with more volatile cash flows tend to hold more cash. The majority of these studies, however, rely on cross sectional (e.g. cross industry) variation in cash flow volatility for statistical inferences. Consequently, it is possible that unobserved heterogeneity correlated with both cash flow volatility and firms' cash holdings could affect the implications of these studies. Consistent with the notion that cross-sectional heterogeneity is an important driver of these findings, the relation between cash flow volatility and cash holdings becomes weaker and sometimes statistically insignificant when the studies control for firm fixed effects.[1]

In this paper, rather than study a cross-section of different industries, we instead focus on the effect of a new and specific source of risk facing a particular industry. The focus on one source of risk from one industry allows for precise identification of the risks each firm faces as well as the firms' management of this risk. We estimate the factors affecting the cash management decisions of a large, international sample of 398 publicly traded electricity-producing firms between 2000 and 2014. Our analysis evaluates the extent

[1] For instance, Opler et al. (1999) find a negative and statistically significant impact of industry cash flow volatility on cash after controlling for firm fixed effects (p.27). Graham and Leary (2017) find a negative but statistically insignificant relation between cash flow volatility and industry cash holdings when using a first differences estimation (p.62).

that these firms' cash holdings they depend on the distribution of electricity prices that these firms face, especially the 194 firms that operate in the 40 deregulated wholesale markets for electricity.[2]

Because these firms sell only one product, i.e., electricity, and tend to be price takers in the wholesale market where it is sold, price risk has a meaningful impact utilities' revenues and is likely to be an important factor affecting their financial policies. Electricity generation capacities are fixed in the short run, electricity demand tends to be price-inelastic, and storing electricity is prohibitively expensive, so wholesale prices fluctuate dramatically when electricity demand changes. Our analysis evaluates the extent that these firms' choices of cash holdings depend on the volatility of electricity prices. Electricity is a homogenous good that does not vary in quality, which makes its price comparable across regions and time. This paper is, to the best of our knowledge, the first to provide empirical evidence on how firms in a single industry adjust their cash holdings in response to a particular source of risk, in our case product price risk.[3]

Focusing on liquidity management decisions in the electricity industry occurring because of price risk has a number of advantages relative to prior studies. This approach allows us to identify the effect of risk on firms' liquidity management decisions clearly, and to rule out explanations for the correlation between firm risk and firms' cash holdings based on a third factor affecting both firms' risk and their liquidity management decisions. In addition, a large source of the variation in wholesale electricity prices occurs because of an exogenous factor affecting the demand for electricity, the weather. Fluctuations in weather therefore provide a valid instrument for price volatility, which we utilize in our empirical work.

Our estimates suggest that our sample firms do increase their cash holdings in response to higher volatility of wholesale prices. Based on models which only exploit time series variation of price risk over time within an electricity market, a one-standard deviation increase of the product price volatility leads to

[2] These markets are in 32 countries, and represent virtually all markets around the globe that operate a day-ahead market for electricity and have hourly pricing. Section 2.1 provides an overview on the markets and the criteria for their inclusion.

[3] Theoretically, the idea that uncertainty about the product price affects firms dates back to the classic paper by Sandmo (1971). A related strand of the literature focuses on the financial consequences of other product characteristics, such as fluidity or similarity, which are mainly based on firms' product descriptions (e.g., Hoberg and Phillips, 2010; Hoberg, Phillips, and Prabhala, 2014).

an increase in cash holdings (normalized by assets) of 0.7 percentage-points, which corresponds to a ten percent increase relative to the mean of seven percent. If we additionally consider cross-sectional variation of price volatility, the effect doubles, with a one standard deviation increase in price volatility leading to a 1.4 percentage-point increase in cash holdings. We perform a series of robustness checks that ensure that this result does not occur because of the measurement of the variables in our equations, fluctuations in input prices, or from the small number of firms in our sample that have large market shares and therefore are unlikely to have no influence on the market price.

To isolate the channel through which price risk affects liquidity decisions, we rely on the fact that electricity prices are heavily influenced by an exogenous factor – the weather. Electricity capacity is fixed in the short-run and the actual supply of electricity is also not very flexible because power plants take time to start or stop. In contrast, electricity demand varies considerably over time. An important determinant of electricity demand is the weather (Perez-Gonzalez and Yun, 2013), so higher fluctuations in temperatures can lead to a higher volatility in electricity prices. For this reason, we instrument for electricity price volatility using the volatility of daily temperatures within an electricity market. The instrumental variables estimates also indicate that price uncertainty increases cash holdings, with the effect of a similar magnitude to the OLS estimates: the instrumental variables estimates imply that a one-standard deviation increase in the price volatility leads to an increase of 1.2 percentage-points in cash holdings.

Since our results imply that firms hold more cash because of the wholesale price risk and holding cash is costly, the results suggest that the price risk electricity producers face is potentially an additional cost of deregulation. Our estimates imply that the introduction of a wholesale market for electricity leads to an increase in cash holdings of about 1.5 percentage-points, which corresponds to a 20 percent relative increase. This result suggests that a hidden cost of deregulation is that it increases the risk faced by firms. Firms react to this additional risk by changing their liquidity management policies; the cost of doing so represents a cost of deregulating electricity markets.

Our focus on one particular type of risk in one industry allows us to measure the way in which the particular method of production used by individual firms affects the way they manage risk. Using data on about 45,000 individual power plants, we estimate how firms' liquidity adjustments depend on characteristics of their method of production. Operating flexibility, i.e., the ability to shut down and subsequently restart their plants at low cost, provides a partial hedge against product price fluctuations.[4] Using data on the production techniques of a firm's power plants, we evaluate the extent to which operating flexibility and liquidity management are substitutes for one another.

We find that product price risk has little effect on liquidity management for firms using relatively flexible plants such as gas-fired plants. In contrast, for firms that rely on less flexible methods like coal, it is more difficult to shut down and subsequently restart plants, typically requiring several hours and involving considerable cost.[5] Therefore, for firms using inflexible methods of production, price risk is relatively costly. Consistent with the notion that firms with inflexible production have greater demand for hedging price risk, our estimates indicate that for firms which predominately use plants that are relatively inflexible, cash holdings increase substantially with wholesale price volatility. For the bottom third of our sample firms ranked in terms of operating flexibility, a one standard deviation increase in price volatility leads to a 1.1 percentage point increase in cash holdings, compared to 0.7 percentage points for the average firm. The corresponding increase for the top third of firms ranked by flexibility is 0.3%, which is not statistically significantly different from zero. We find similar results if we exclude firms using particular technologies like nuclear power plants, suggesting that this pattern does not occur because of the characteristics of firms using any particular method of production.

To address concerns that production assets are endogenously determined, we use firms' operating flexibility based on production assets in 1995 instead of contemporaneous values. Because deregulation and privatization of the electricity market took place in the early 2000s in most countries, power plants that were active in 1995 were planned in a time when political considerations, not factors relating to finance

[4] The idea that flexibility in production affects how firms react to price risk goes back to theoretical work by Turnovsky (1973) and Epstein (1978).
[5] Instead of shutting down a plant, the operator could also reduce its load. However, there are considerable technical limitations to this approach, and the efficiency of thermal power plants decreases significantly for low load levels.

had the most impact on power plant investment decisions (Peltzman and Winston, 2000).[6] All these tests confirm that the impact of product price risk on cash holdings is most pronounced for firm with low levels of operating flexibility.

Pre-selling electricity through a liquid futures market also partially protects electricity-producing companies from volatile prices, at least in the short run. Because of differences in the liquidity of local electricity derivative markets, some firms can hedge price risk more easily than others. During our sample period, the existence and liquidity of futures markets for electricity varied substantially across regions. These differences allow us to examine whether hedging through derivative markets and cash holdings are substitutes for one another. We approximate hedging opportunities by the fraction of firms which hedge electricity prices in a particular market region (ignoring the firm under consideration).

We find that firms that are located in regions with less liquid derivative markets increase cash holdings substantially if product price volatility is high. For the bottom third of firms with the lowest liquidity, a one-standard deviation increase in price volatility leads to a 1.3 percentage point increase in cash holdings, compared to a change very close to zero for firms in regions with the most liquid derivative markets. Since it is usually cheaper to hedge through the derivatives market than by holding cash, firms appear to rely on derivatives when markets for them exist and are liquid. This result highlights the way in which derivative markets are substitutes to liquidity management, and suggests that a benefit of having liquid derivative markets is that they allow firms to hold less cash on their balance sheets.

Our analysis extends the literature in a number of ways. First, we measure the extent to which energy utilities adjust their cash holdings in response to the risk they face from wholesale price movements. By isolating one particular source of risk and documenting firms' responses to this risk, we provide a particularly clean test on how product price risk affects corporate liquidity management. Our paper thus

[6] Two noticeable exceptions are the U.S. and Japan because privately-owned utilities played an important role before 1995 in both countries. Thus, we exclude them when we conduct this test. An example for a country in which political considerations had a huge impact on production assets of energy utilities is France. Their high number of power plants goes back to a plan of the former French Prime Minister Pierre Messmer to give priority to nuclear power plants (cf. Reinartz and Schmid, 2016, for more details).

adds to the growing literature on the determinants of corporate liquidity management (e.g. Almeida, Campello, and Weisbach, 2004, Bates, Kahle and Stulz, 2009, Lins, Servaes, and Tufano, 2010, Graham and Leary, 2017). By proposing a product price based explanation for cash holdings, we also contribute to the literature that analyzes how product markets affect corporate policies (e.g. Haushalter, Klasa, and Maxwell, 2007; Hoberg and Phillips, 2010, 2016; Hoberg, Phillips and, Prabhala, 2014).

Second, our detailed asset-level data on the methods of producing electricity used by different firms enables us to measure the way in which firms' reactions to price risk depends on the flexibility of their production process. This complements prior literature on operating flexibility and firm outcomes. Mauer and Triantis (1994), for instance, analyze theoretically how operating adjustment costs affect financing decisions. Empirical evidence in this context is provided by MacKay (2003) and Reinartz and Schmid (2016), who investigate how operating flexibility affects financial leverage. Furthermore, this paper provides some initial evidence that firms' cash holdings and derivative usage are substitutes for one another. It adds to prior literature on the financial consequences of hedging through derivatives (e.g., Perez-Gonzalez and Yun, 2013) and the interaction between operational and financial hedging (e.g., Hoberg and Moon, 2017; Giambona, Graham, Harvey, and Bodnar, 2018).

Third, we consider the way in which deregulation imposes risks on firms by exposing them to wholesale price movements. We document the way in which firms compensate for this additional risk by comparing the liquidity choices of firms before and after the introduction of a wholesale market for electricity. This adds to the literature on the consequences of deregulation. Fabrizio, Rose and Wolfram (2007), for instance, analyze how efficiency of energy utilities is affected by regulatory changes, and Ovtchinnikov (2009) investigates capital structure decisions after deregulation for multiple industries.

2. Wholesale Price Fluctuations and Liquidity Management

2.1. The Wholesale Market for Electricity

Competitive wholesale markets for electricity exist in many countries. In these markets, the prices for electricity adjust to reflect the supply and demand at a particular point in time. Consumers typically pay a pre-arranged rate to their retail company. These retail companies, however, typically purchase electricity they sell to consumers from the wholesale market at whatever the prevailing price happens to be. The suppliers of electricity on the wholesale markets are electricity-generating firms, many of which do not directly sell to final consumers. The Electricity Power Supply Association (EPSA) summarizes that “[i]n many cases, electricity is generated by a power company that ultimately will not deliver it to the end-use customer. A single megawatt […] is frequently bought and re-sold a number of times before finally being consumed. These transactions are considered "sales for re-sale," and make-up the wholesale electricity market.”[7]

Wholesale markets for electricity usually have a day-ahead market (DAM) in which market participants buy and sell electricity for delivery on the following day. Thus, this market is essentially a very short-term future market. The DAM typically features contracts for the delivery of electricity during individual hours of the following day. The price for electricity is formed independently for each contract and thus for every hour. Some wholesale markets also offer real-time markets in which electricity for delivery on the same day is traded. Because these markets are generally not very liquid, we focus on the DAM in which most of the trading takes place.

Wholesale electricity markets have developed in different regions of the world, with slightly different structures and regulations. In the U.S., the Federal Energy Regulatory Commission (FERC) order 2000, which was issued in February 2000, set the starting point for the creation of regional wholesale markets for electricity. Independent system operators (ISOs) and regional transmission organizations (RTOs) then formed market regions with day-ahead wholesale markets for electricity. Currently there are seven organized markets in the U.S. These are ISO New England, New York ISO, PJM, Midwest ISO, Southwest Power Pool, ERCOT, and California ISO. While some of those markets focus (approximately) on a single state (e.g., ERCOT covers most of Texas), others serve regions with multiple states (e.g., PJM covers all or part of 13 different states).[8] According to EPSA, two-thirds of the United States' economic

[7] https://www.epsa.org/industry/primer/?fa=wholesaleMarket
[8] For simplicity, we assume that a market exists in a state if it covers all or most of the state according to the FERC.

activity occurs within the boundaries of these markets. States outside these markets still do not have competitive markets for electricity; in these states, electricity is still supplied by regulated utilities.[9]

In Europe, the process of deregulating electricity markets and introducing wholesale markets for electricity was started in 1996 by the European Union Directive 96/92/EC. By the early 2000s, most E.U. markets were deregulated. European markets are generally organized as DAM, and most but not all wholesale markets in Europe cover one country. Nordpool, the largest electricity market in Europe, is an important exception and covers several northern European countries.

In Asia and Oceania, the deregulation process varied across countries. Australia was an early adopter and started introducing wholesale markets in the mid-1990s. It now has multiple markets, which generally cover single states. There are no markets for which we are able to obtain data during our sample period in South America and Africa.

We collect hourly electricity prices for 40 power markets located in 32 countries. We do not consider markets which were active for less than two years during our sample period, markets without day-ahead trading, and markets without hourly pricing.[10] Figure 1 illustrates the regions of the world in our sample that supply electricity competitively through wholesale markets. These regions cover a large portion of the developed economic world. However, while the basic structure of electricity markets is similar across the globe, the markets differ in a number of ways. Because it is difficult to control for all cross-regional differences econometrically, we focus on on time-series variation in the volatility of electricity prices in most of our empirical tests.

[9] Even some states located in regions with wholesale markets for electricity still maintain traditional rate regulation. We exclude firms located in these states from our sample. This affects most states in the Midwest ISO (see Cicala, 2017, for more details).

[10] For this reason, we do not include the Southwest Power Pool (starting in 2013), IBEX in Bulgaria (2014), EPIAS in Turkey (2015), and CROPEX in Croatia (2016). Furthermore, we ignore markets which do not feature a typical day-ahead market with hourly pricing (WESM, Philippines). Hourly electricity prices could not be obtained for the markets in Argentina, Brazil, Colombia, and Slovenia.

2.2. Price Risk facing Electricity Producers

Price risk faced by electricity producers should vary as a function of the electricity market. In some markets, demand for electricity is relatively stable and easy to forecast, leading wholesale prices to be relatively stable. However, in other markets, demand can fluctuate substantially and be difficult to predict accurately. For example, a heat wave in Texas in early August 2011 led to an electricity supply shortage and boosted prices peaks of more than 2,000 USD per MWh (the average price being around 35 USD per MWh).[11] In contrast, the electricity price went down to around *negative* 150 USD per MWh in Germany in May 2016.[12] The reason for this negative price was a combination of higher than expected production by wind turbines and the inflexibility of other power plants, which continued producing despite the negative price.

Since electricity producers sell their product in the wholesale market, their revenues will vary with the price they receive in the wholesale market. Fluctuating wholesale prices also impose adjustment costs on electricity producers, since they cannot store electricity easily if prices are low, and must pay setup costs to increase production if prices are high. Furthermore, because there is no way to dispose of electricity costlessly, these firms have to sell all the electricity they produce, even if the price is negative, meaning that the producer must pay a consumer to use the electricity they produce. Thus, wholesale price volatility creates a demand for liquidity from electricity producing companies, since unforeseen price fluctuations impose incremental costs on these firms.

Electricity producing firms differ from one another in terms of their exposure to price risk, because they face differences in regional demand fluctuations and also because their methods of producing electricity have different costs of adjusting output. Since electricity producers sell their product in the wholesale market, their revenues will vary with the price they receive in the wholesale market. Consumers' demand for electricity tends to be price inelastic, so a shock to demand can lead to large changes in

[11] https://www.eia.gov/todayinenergy/detail.php?id=3010
[12] http://www.independent.co.uk/environment/renewable-energy-germany-negative-prices-electricity-wind-solar-a7024716.html

wholesale prices. Supply curves of electricity producing firms, in contrast, can be relatively elastic, so changes in prices can lead firms to adjust quantities substantially. Therefore, the ability to adjust output quantities at relatively low cost in response to price movements can be valuable to electricity producers.

The cost to electricity producers of changing output varies dramatically with the method they use to produce electricity. Gas-fired power plants are very flexible, with run-up times of only several minutes and a low cost for starting the plant. Gas combined cycle power plants are also quite flexible, with run-up times of about 90 minutes. However, for other production technologies the time needed to stop and start the plants and the associated cost can be considerable. For example, lignite-fired plants need about six hours to start at a cost of about $43 per megawatt of production capacity, while coal-fired power plants need about three hours and have cost about $56 per megawatt.

The total cost associated with starting and stopping of plants to electricity producing firms can be sizable. As a rough measure of the magnitude of these costs, consider an average sized firm with 15 coal-fired plants. The average capacity of a coal-fired plant is 750 megawatts and the cost of cycling a coal plant (stopping and restarting it), is about $56 per megawatt, so each cycle costs about $42,000 per plant. If there are 50 cycles per year at each plant, the total cost is about $31.5 m annually per firm, which is more than 10% of the annual net income for a typical firm in our sample.[13]

The practical relevance of production flexibility for energy utilities is highlighted by the existence of negative electricity prices in many markets. In this context, the European Power Exchange states that: "[n]egative prices are not a theoretical concept. Buyers are actually getting money and electricity from sellers. However, you need to keep in mind that if a producer is willing to accept negative prices, this means it is less expensive for him to keep their power plants online than to shut them down and restart them

[13] These cost estimates are for "warm starts", which means that the plant is not totally shut down. Costs for "cold starts", in which the plant is completely shut down would be higher, but these events are much rarer. Estimates for the number of warm start-ups of coal-fired plants varies slightly between different sources, but 50 is an average estimate. For instance, the International Energy Agency estimates that a typical coal-fired plant has about 45 warm starts per year (Trueby, 2014, p. 19), whereas data from Aptech suggests more than 50 start-ups for coal-fired plants (Leyzerovich, 2007, p. 316).

later."[14] The fact that electricity prices are sometimes negative increases the value of being able to adjust output at low cost, as well as the downside risk that firms with inflexible production face from volatile prices.

Electricity producing firms also differ from one another in terms of their exposure to price risk, because they face differences in their ability to hedge the electricity price via derivatives. Derivatives can substitute for cash holdings because they transfer cash flows to the states of the world where they are most valuable (Froot, Scharfstein and Stein, 1993). However, derivatives are imperfect substitutes because they only allow firms to hedge risks for which appropriate markets exist, and the use of these markets for hedging is limited by their liquidity.

2.3. Empirical Implications

Price uncertainty combined with production inflexibility and imperfect hedging opportunities creates price risk for electricity producers. If the wholesale price changes substantially, then the optimal response of the suppliers would be to move along the supply curve and adjust output accordingly. However, it takes time to change output, e.g., by shutting down a power plant, especially for firms producing electricity with inflexible technologies. For this reason, after a price shock, an inflexible producer will be left producing a suboptimal quantity for a period of time. Because of the cost of changing output, inflexible suppliers sometimes choose to produce a suboptimal quantity for limited periods of time rather than pay the costs of stopping and restarting the plant. Regardless of whether a firm pays to shut down a plant temporarily or continues to operate at a loss, the firm can suffer a cash flow shock when there are declines in the wholesale price.

The potential of such cash flow shocks provides a reason why electricity producers should use liquidity management. Almeida, Campello, Cunha, and Weisbach (2014) formally model a problem similar to the one faced by electricity producers. In this model, the firm faces an uncertain cash flow requirement

[14] https://www.epexspot.com/en/company-info/basics_of_the_power_market/negative_prices

to continue a valuable investment, leading the firm to hold cash in anticipation of the potential cash flow shock. A clear implication of this model is that when the magnitude of a potential cash flow shock increases, a firm should hold more cash. This effect is lessened when a firm has better access to capital markets or can hedge the cash flow shocks in other ways, such as through a derivatives market.

For electricity producers, the potential cash flow shock arises from the risk coming from uncertainty about the wholesale price of electricity when there is inflexibility in their production process. When price uncertainty is low and/or production flexibility is high, such price risk is relatively unimportant. However, when price uncertainty is high *and* the cost of adjusting production is high, price risk is substantial, increasing the probability of negative cash flow shocks. Consequently, firms with high costs of adjusting production are expected to hedge such price risk ex ante by holding more liquidity.

In addition, we expect this hedging via liquidity effect to be larger when firms do not have access to derivative markets that can be used to hedge cash flow shocks directly because an alternative to holding cash as liquidity is to hedge directly using derivatives. In the case of electricity markets, the relevant markets are the futures or forwards markets in which firms can sell part of their output in advance. Although futures and forward prices typically follow spot prices, using these instruments at least partly protects firms from fluctuations in the day-ahead spot market in the short-run.[15] However, hedging opportunities vary substantially across power markets: some markets have very liquid electricity derivatives trading, while it is difficult to hedge price risk in other markets. For instance, a report by the Economic Consulting Associates (2015) on European electricity forward markets and hedging products "found weaknesses in liquidity in many forward energy markets with only Austria, Germany and the Nordic area exhibiting high levels of churn" (p. VII). Consequently, we expect firms to hedge price risk by holding more liquidity especially in regions where it is more difficult to hedge the electricity price.

[15] In the long-run, higher spot price uncertainty also creates higher uncertainty about the price for which futures or forwards can be entered in the future.

3. Data Description

3.1. Sample of Electricity-Producing Utilities

To construct a sample of energy utilities from all over the world, we start by combining lists of active and inactive utility companies from *Thomson Reuters*. We focus on publicly-traded utilities in the 2000 to 2014 period. We perform several steps to clean the sample. First, we eliminate all firms without a primary security classified as equity. Second, we wish to consider only companies that focus on the generation of electricity. To ensure that other companies are not included, we rely on firms' SIC and ICB codes, the business description obtained from *Capital IQ*, and additionally conduct manual research on the companies' business lines. We obtain data on their power plants for this sample form the Platts WEPP database (see Section 3.3). After eliminating firms with only renewable generation assets (i.e., solar, wind, or geothermal) because they receive preferential rates in several countries, we end up with a sample of 398 unique electricity-generating firms. For most of the analysis, we focus on the subsample of the 194 firms that are located in regions that have wholesale markets for electricity during some portion of our sample period. These firms are located in 34 different electricity markets and operate a total of about 45,000 unique power plants.

Table 1 provides a detailed overview of the composition of the sample over time. The number of sample firms increases significantly over time. The main reason for this increase is that many regions deregulated their electricity markets and created wholesale markets during our sample period.

3.2. Wholesale Electricity Price Data

To measure the degree of electricity price volatility, we use hourly data on electricity prices in each market. These data are available for 40 regional markets from 32 countries. Most countries have their own national market but some markets cover more than one country (e.g., Nordpool, which covers several Northern European countries) and some countries have more than one market (i.e., Australia, Canada, and the U.S.). We obtain the price data from the websites of the power exchanges, direct contact with those exchanges, or from *Thomson Reuters*. To make the prices comparable across countries, all prices are converted into U.S. dollars using daily exchange rates.

To illustrate that there are considerable differences with regard to price fluctuations across markets, we present time series plots of electricity price times for in three selected markets in Figure 2: the German market, Nordpool, and the state of New York. The full time series for all three markets is shown in the first subfigure. In the following subfigures, we show an exemplary year, month, and week for those markets. The German market consistently has higher price volatility than the New York market, which is in turn higher than the volatility in the Nordpool market. This figure also illustrates that there is considerable variation of the electricity price within a year, month, and day. For example, the price for electricity in the German market fluctuated between around minus 50 US$ per MWh and 100 US$ per MWh in January 2012. The fact that wholesale market buyers had to pay between 50 US$ per MWh and nearly 100 US$ per MWh on January 15 illustrates the intra-day fluctuations of the electricity price. Part of these price variations are related to (predictable) seasonal factors, which is another reasons why we mainly focus on changes of electricity price volatility over time within a particular market in our empirical analyses. By using this approach we ensure that our results are not affected by time-constant seasonal factors in a market.

Since our goal is to evaluate the way in which product price risk affects firms' liquidity management, we calculate different measures of the wholesale price fluctuations in a particular market. To do so, we first match all sample firms to electricity markets based on their geographical location. We then calculate a measure we refer to as *VOLATILITY*, which equals the standard deviation of hourly electricity prices in during a firm's fiscal year, normalized by the average electricity price in that market.[16] For most of the analysis, we focus on the natural logarithm of *VOLATILITY* as our main measure of product price

[16] Hourly prices are used to calculate volatility because daily prices, which are simply aggregations of hourly prices, are less precise than hourly prices for our purpose. For example, assume a daily price of 100 USD. If the price was 100 USD for all hourly contracts, it would have been optimal to run coal-fired plants in all hours. However, if the price was zero for 12 hours and 200 for the other 12 hours, switching on and off the plant would have been the optimal strategy. These two cases cannot be distinguished when using daily prices. Nevertheless, we perform a robustness test with daily prices and find similar, but slightly weaker results.

risk. To ensure that this measure is comparable over time, we only calculate it if at least 8,000 hourly electricity price observations are available in a market-year.

Besides our main measure of product price risk, we calculate several alternative volatility measures. First, we calculate the standard deviation of hourly electricity prices without scaling it by the average electricity price in that market. The second alternative definition is based on the standard deviation of hourly electricity price changes. Third, volatility is defined as the standard deviation of hourly electricity price changes, normalized by a market's average electricity price level.

3.3. Power Plant Data

Our measures for production flexibility are based on the generation technologies of the sample firms' power plants. Data on the production technologies for single power plants is obtained from the annual versions of the *Platts World Electric Power Plant* database. This comprehensive database contains information on power plants and their technologies around the globe. It includes information on single power plant units, including their production technologies, capacities, geographic locations, start dates of commercial operation, and their owners/operators.[17]

We obtain this database for all years between 2000 and 2014 and manually match each power plant in this database to the energy utilities sample. We use yearly versions of this database because each issue only includes the current owner/operator. About 50% of the plants match to our sample firms; the remainder are, for instance, owned by large utilities that are not publicly listed and are excluded from our sample for this reason. These data on production assets allow us to calculate the degree of operating flexibility for each firm in each year using the production technologies of single power plants. We define *FLEXIBILITY* as the generation capacity of flexible power plants, scaled by a firm's total generation capacity. Flexible plants are gas and oil-fired power plants because they have the fastest run-up time and the lowest ramp-up cost (see Reinartz and Schmid (2016) for more details about the flexibility of individual production

[17] A detailed description of the database is provided by Platts' Data Base Description and Research Methodology (www.platts.com/IM.Platts.Content/downloads/udi/wepp/descmeth.pdf).

technologies). Wind, solar, and hydro are not actively dispatched and thus not considered as flexible plants. Examples for other generation technologies that are not flexible include coal, lignite, nuclear, or waste.

3.4. Financial Variables

Our measure of cash holdings is calculated as total cash holdings of the firm divided by book value of assets. Control variables included in all models are size (measured as the natural logarithm of total assets), cash flow (earnings before interest, taxes, depreciation, and amortization scaled by total assets), leverage (total debt divided by the sum of total debt and book value of equity), and GDP (the natural logarithm of the GDP per capita).[18] In additional tests, we also control for several other possible determinants of cash holdings, such the market-to-book ratio (market capitalization divided by the book value of equity), capital expenditures (scaled by total assets), dividend payments (a dummy variable which equals one if a divided is paid), and the inflation rate. Fiscal years that end between January and June are allocated to the previous year; only complete fiscal years are considered. To restrict the impact of outliers, all financial variables are winsorized at the 1% and 99% levels.

3.5. Descriptive Statistics

Panel A of Table 2 shows the descriptive statistics for our sample firms, averaged for the whole sample period. On average, energy utilities have cash holdings equal to seven percent of their total assets. This is comparable to values reported for multi-industry samples (see Almeida, Campello, Cunha, and Weisbach (2014)). Furthermore, there is considerable variation in the cash ratio with an inter-quartile range of seven percentage points. The average value of *VOLATILITY* is 0.65, with a standard deviation of 0.96. The average value of *FLEXIBILITY* is 0.35, with a standard deviation of 0.30. Our sample firms operate an average of 313 different power plants, with a median value of 116. The average firm in our sample has total

[18] All financial variables are measured in U.S. dollars. Both the measure of cash holdings and the control variables have become standard in the literature on cash holdings since Opler, Pinkowitz, Stulz and Williamson (1999).

assets of around 22 billion USD (median: 5 billion USD). Panel B of Table 2 presents a correlation matrix for the different volatility measures, and indicates that all measures are highly correlated.

4. Estimating the Impact of Price Risk on Utilities' Liquidity

4.1. Empirical Specification

To measure the impact of price risk on utilities' liquidity management decisions, we estimate the extent to which utilities' cash holdings are affected by price risk coming from wholesale price uncertainty.[19] Firms do, of course, have other ways managing liquidity; for example, they can acquire lines of credit, build debt capacity, or hedge through derivatives markets. We focus on cash holdings for two main reasons. First, cash is straightforward to measure and has been the focus of the prior empirical literature. Second, there are theoretical reasons why cash is the preferred way of managing liquidity. Lines of credit and debt capacity can disappear during poor financial conditions when they are most needed, effectively being used to fund overinvestments in good times rather than efficient investments in poor times (see Acharya, Almeida and Campello (2007) or Almeida, Campello, Cunha, and Weisbach (2014)). Hedging price risk by pre-selling electricity in the derivatives market is common in many regions; we address this possibility and analyze how it affects our findings below in Section 5.4.

We estimate equations predicting an energy utility's cash holdings. We use measures of product price risk a firm faces in a particular year as our primary independent variable. Because of cross-sectional differences caused by firm-level, country-level, and market-level factors, we present specifications using year-specific, country-specific and, in most cases, firm-specific fixed effects. In addition, we include the firm's log (assets), its cash flow (normalized by assets), its leverage (total debt scaled by total debt plus book value of equity), and the log of GDP per capital (in 2010 USD) in each equation. All these control variables are measured in year t-1. The reported t-statistics are based on cluster-robust Huber/White standard errors (White, 1980), clustered by countries.

[19] As emphasized by Duchin, Gilbert, Harford and Hrdlicka (2017), the cash holdings variable we rely on includes holdings of a number of securities, some of which are risky.

4.2. Estimates of the Impact of Price Volatility on Cash Holdings

We present estimates of this specification in Table 3. We first present estimates that include country-fixed effects but no firm-fixed effects in Column (1), and in Column (2), we add control variables, which are measured one year before cash holdings. These estimates suggest that, consistent with theoretical predictions, higher wholesale price volatility is associated with higher cash holdings. According to the estimates presented in Column (2), a one-standard deviation increase in volatility leads to a 1.4 percentage-point increase of the cash ratio. Since the average cash ratio in our sample is 0.07, this increase represents approximately a 20 percent change. In Columns (3) and (4), we include firm-fixed effects. The inclusion of firm-fixed effects lowers the predicted impact of a one standard deviation increase in volatility to a 0.7 percentage-point increase in cash holdings, which represents a 10 percent increase. These calculations indicate that when product price risk is higher, firms tend to increase their cash holdings, presumably as a way of managing their liquidity.

4.3. Identifying the Equation Using Weather Uncertainty as an Instrument for Price Volatility

The estimates in Columns (3) and (4) of Table 3 include firm-fixed effects and thus are based on variation in wholesale price volatility over time rather than across firms. There are at least two reasons why volatility could potentially be correlated with the residual in the equations reported in Table 3. First, in some circumstances firms are not price takers and do have an impact on the prices they pay. Second, it is conceivable that electricity price volatility in a market could be correlated with other time-variant country factors, such as economic growth expectations. If these factors also affect firms' liquidity management, they could lead to a nonzero correlation between volatility and the residuals in the estimated equations.

To address such concerns and to identify the impact of product price risk on firms' liquidity policies more cleanly, we exploit the fact that electricity prices are heavily influenced by an exogenous factor – the weather. Electricity capacity is fixed in the short-run and the ability of utilities to adjust the supply of electricity is limited by the required time to start or stop production. Electricity demand varies considerably over time, with weather being a major factor influencing demand. In addition, electricity is non-storable in an economically meaningful way and its demand tends to be price inelastic. As a consequence, the price of electricity fluctuates considerably over time because of demand volatility, and one important driver of this volatility is the weather. Thus, higher fluctuations in temperatures increase the volatility of electricity demand, which in turn leads to a higher volatility of electricity prices.

Using this logic, we construct an instrument for electricity price volatility based on the volatility of daily temperatures in a power market and year. Similar to our main analyses, we focus on time-series variation in the volatilities of temperatures and electricity prices within on power market because there are likely to be many unobservable factors that influence both temperatures and prices in the cross section. We obtain data on daily temperatures from Global Historical Climatology Network (see Menne et al., 2012, for a detailed description of this dataset). These daily temperatures are measured on the weather-station level, so we match all weather stations to electricity markets. We only use data from weather stations for which we have information on the daily temperatures for all sample years.[20] Overall, we use about 27 million daily temperature observations from 4,604 weather stations. On average, there are 115 weather stations and 682,000 daily temperature observations in each electricity market. We calculate the daily average temperature in a power market as the mean over weather stations in that market and *WEATHER VOLATILITY* as the standard deviation of daily temperatures during a firm's fiscal year.

For *WEATHER VOLATILITY* to be a valid instrument for electricity price volatility, it must be unrelated to the residuals in the equations predicting firms' cash holdings but correlated with electricity price volatility. This condition is clearly satisfied since the weather is an exogenous to any firm-level decisions.[21]

To evaluate whether *WEATHER VOLATILITY* is related to electricity price volatility, we estimate a first stage regression, in which we predict electricity price volatility as a function of *WEATHER VOLATILITY*. Estimates of this equation, reported in Column (1) of Table 4, indicate that *WEATHER VOLATILITY* clearly predicts movements in electricity price volatility (with K-P rk Wald F statistics of

[20] More precisely, we require 183 daily temperature observation per year in all sample years.
[21] Except possibly those involving the firm's CO_2 emissions.

around 10). Therefore, because *WEATHER VOLATILITY* is exogenous but correlated with electricity price volatility, it appears to be a valid instrument.

In Column (2) of Table 4, we analyze the impact of volatility on cash holdings using the instrumented values for volatility. As in the specifications reported in Table 3, we find a strong and positive impact of variations in the electricity price on firm liquidity. The estimates imply that a one-standard deviation increase in the instrumented electricity price volatility leads to an increase of cash holdings of about 1.2 percentage-points, which represents a 17 percent increase. The magnitude is between the models with and without firm-fixed effects in Table 3, for which the corresponding numbers are an increase of 0.7 percentage-points and 1.4 percentage-points. A potential concern with these results could be that weather affects not only wholesale price volatility, but also the production process of solar and wind power plants. To mitigate such concerns, we repeat the previous analysis but restrict the sample to firms for which solar and wind plants account for less than ten percent of their overall capacity. The estimates in Columns (3) and (4) are similar to those reported above. Overall, these findings suggest that changes in electricity price volatility occurring because of weather fluctuations causally affect liquidity management decisions of firms.

4.4. Robustness

We have argued that electricity-producing utilities face product price risk coming from uncertain wholesale prices they receive for their electricity. This price risk can lead to negative cash flow shocks, so firms hold more liquidity in response to this risk. We have presented statistical tests suggesting that firms do adjust their liquidity in this fashion. We now present a series of tests designed to ensure that these results are robust to the volatility of input prices, definitions of variables, concerns about market power, alternative specifications, and other choices we have made in designing our empirical tests.

4.4.1. Input Price Volatility

In the electricity industry, input prices account for more than 80% of total production cost for plants using fossil fuel (cf. Brown and Kodaka, 2014). Natural gas prices tend to be volatile, while coal prices are usually stable. Since, electricity prices tend to be correlated with natural gas prices, a possible concern is that a correlation between input and electricity prices biases our findings.

To analyze the way in which input price volatility affects our findings, we collect data on gas and coal prices. For natural gas, we focus on the price of gas for industrial customers (in US$ per MWh). Monthly gas prices are obtained from the Energy Information Administration (EIA) for U.S. states, and quarterly price data for other countries comes from the International Energy Agency (IEA). For coal, we focus on the price of steam coal for industrial customers in US$ per ton. The frequency of this data, which comes again from the EIA for U.S. states and IEA for other countries, is quarterly. Based on these data, we calculate the annual standard deviation of gas and coal prices as a measure of input price volatility. Unfortunately, gas and coal prices are not available for all countries, so the sample we use for this test is smaller. The results are reported in Table 5. None of the measures for input price volatile has a significant impact on cash holdings, and the estimated effect of product price risk is similar to those reported in Table 3. This test suggests that input price volatility does is not the reason why we find a relation between wholesale price volatility and the utilities' cash holdings.

4.4.2. Measurement of Volatility

The main measure we use for product price risk is the log of the volatility of hourly electricity prices during a firm's fiscal year, scaled by the average electricity price. We report estimates of equations using alternative definitions of volatility in Panel A of Table 6. The alternative definitions we examine are the non-logged version of the main measure, the standard deviation of hourly electricity prices (non-scaled), the standard deviation of hourly electricity price changes (in US$), and the standard deviation of hourly electricity price changes (in US$) scaled by the average electricity price. Using each of these alternative definitions of price volatility, we find that higher product price volatility leads firms to have higher cash holdings.

Another issue in designing our specification is the frequency of the data used to calculate volatility. All results reported to this point are based on volatility measures computed using hourly electricity prices.

We focus on volatility using hourly rather than daily prices (the average of a firm's hourly prices) because daily prices ignore variation within a particular day, which can be a very important factor for start/stop decisions of power plants. Nonetheless, as a robustness test, we reestimate our equation using daily prices in Panel B, Column 1. In addition, we also present estimates volatility calculated based on weekly and monthly prices in Columns 2 and 3. These data have the advantage of providing a more long-term perspective on price volatility. Finally, all these measures of volatility can reflect both upward and downside risk. Because downside risk rather than upside risk should be the driver behind higher cash holdings, we recalculate the hourly volatility measure in Column 4 of Panel A ignoring positive price changes between two hours. This measure is defined as the standard deviation of negative hourly electricity price changes (in US$) scaled by the average electricity price. Even though each specification uses a different way to calculate price volatility, the results are nonetheless similar. Consequently, it does not appear that our inference that price volatility affects firms' cash holding decisions does not depend on the approach we use to measure electricity price volatility.

4.4.3. The Role of Market Power

Another possible concern is that if firms have a large market share, they could be able to affect wholesale prices and not be price takers. To mitigate such concerns, we restrict the sample to firms that account for less than 10% or 5% of a market's total capacity in a given year and reestimate the equation on this subsample. In addition, we reestimate our equation only on firms that operate in power markets with more than 50 or 100 different power plant operators with a production capacity of at least 100 megawatts.[22] The results are reported in Panel C of Table 6. None of these alternative specifications changes the results meaningfully.

[22] For the calculation of the number of power plant operators in a market, we rely on data from the *Platts World Electric Power Plant Database*, which includes both publicly traded and private firms.

4.4.4. Alternative Control Variables

In the estimates reported above, we control for the (lagged) firm size, cash flow, leverage, and GDP per capita. To evaluate whether other observable characteristics of energy utilities affect our findings, we estimate equations including the *MARKET-TO-BOOK* ratio, which is defined as the market value of equity divided by its book value, *CAPEX*, which is defined as capital expenditures scaled by total assets, *DIVIDEND*, which is a dummy variable that equals one if the firm pays a dividend, and *INFLATION*, which is the yearly inflation rate in a country. The results are reported in Panel D of Table 6. None of these control variables has a material effect on the impact of product price risk on cash holdings.

4.5. Deregulation as a Source of Risk

The results we have presented suggest that electricity producing firms' cash holdings change with the volatility in wholesale electricity prices. Volatility in wholesale electricity prices increases producing firms' cash flow volatility. These firms compensate for this increased cash flow volatility by holding more cash, as predicted by the precautionary theory of cash holdings. Holding cash is costly since it is tax disadvantaged in most countries and creates potential agency problems. The cost of holding the incremental cash can be thought of as a cost of deregulation, since under deregulation, electricity-producing firms sell in the wholesale market, and must bear price risk they do not have to bear in a regulated environment. This risk leads electricity producing firms to add liquidity to their balance sheets, the cost of which should be considered when making regulatory decisions.

An implication of this view is that producing firms that operate in deregulated markets should face more risk, and consequently hold more cash, than otherwise similar firms who operate in regulated markets. This prediction can be tested in our sample, which includes 398 electricity-producing firms operating in both regulated and deregulated markets. For the 349 firms for which all necessary data is available, 75 change from regulated to deregulated markets during our sample period, and the remaining 274 are in regulated or deregulated markets for the entire sample period.[23] Using this sample of both regulated and deregulated firms, we estimate how the existence of a market affects firms' cash holdings. We include a dummy variable *Market* equal to 1 if the firm sells its electricity in a wholesale market in a particular year, and 0 otherwise. In addition, we estimate equations using our main electricity price volatile measure and set it to zero for regions without wholesale markets.

We present estimates of this equation in Table 7. In Column (1), we present the basic specification without country fixed effects and in Column (2), we include firm fixed effects. With firm fixed effects, *Market* is perfectly correlated with the fixed effects when firms are either deregulated or regulated throughout the entire sample period. Consequently, in this specification, *Market* is identified from the firms that switch from being regulated to deregulated in our sample period. The estimated coefficient on *Market* is positive across both specifications, with a magnitude between .012 and .0.19. This coefficient implies that having to sell electricity through a wholesale market leads firms to increase cash holdings by 1.2 to 1.9 percentage points. Since the mean cash holdings (normalized by total assets) is .07, this equation implies that deregulation leads to about a 20 to 25 percent relative increase in firms' cash holdings. In Columns (3) and (4), we include our main measure for electricity price volatility, which is now set to zero for non-market regions. The advantage of this measure is that it considers that level of price risk in deregulated markets. The findings are similar to those in Columns (1) and (2) using the dummy variable for the existence of a market. Overall, this analysis suggests that deregulation leads to higher cash holdings in the energy utilities industry, especially when in markets where wholesale prices are more volatile. The holding cost of this additional cash can be thought of an additional cost of deregulation.

[23] The number of firms that change from being regulated to deregulated is significantly smaller as our sample of deregulated firms used in the main tests because many countries introduced electricity markets in the late 1990s.

5. The Role of Operating Flexibility and Hedging Opportunities

5.1. Operating Flexibility

Electricity producing firms differ from one another in their exposure to product price risk, because they face differences in regional demand fluctuations and also because their methods of producing electricity differ in "flexibility", the cost of adjusting output quantity. The cost to electricity producers of changing output varies dramatically with the method they use to produce electricity. Gas-fired power plants are very flexible, with run-up times of only several minutes and a low cost for starting the plant. Gas combined cycle power plants are also quite flexible, with run-up times of about 90 minutes. However, for other production technologies the time needed to stop and start the plants and the associated cost can be considerable. For example, lignite-fired plants need about six hours to start at a cost of about $43 per megawatt of production capacity, while coal-fired power plants need about three hours and have cost about $56 per megawatt.[24]

For this reason, after a price shock, an inflexible producer will be left producing a suboptimal quantity for a period of time. Because of the cost of changing output, inflexible suppliers sometimes choose to produce a suboptimal quantity for limited periods of time rather than pay the costs of stopping and restarting the plant. Regardless of whether a firm pays to shut down a plant temporarily or continues to operate at a loss, the firm can suffer a cash flow shock when there are declines in the wholesale price. The risk that firms face a loss when product prices decline is a particular concern for firms with low levels of operating flexibility. On the other hand, energy utilities with high levels of operating flexibility should be at least partially protected from volatile product prices because they can adjust their production quickly and at low cost.

[24] The practical relevance of operating flexibility for energy utilities is highlighted by the existence of negative electricity prices in many markets. In this context, the European Power Exchange states that: "[n]egative prices are not a theoretical concept. Buyers are actually getting money and electricity from sellers. However, you need to keep in mind that if a producer is willing to accept negative prices, this means it is less expensive for him to keep their power plants online than to shut them down and restart them later." (https://www.epexspot.com/en/company-info/basics_of_the_power_market/negative_prices)

We evaluate whether the method of production used by our sample firms affects their response to changes in price volatility. To do so, we construct a measure of operating flexibility, called *FLEXIBILITY*, which is defined as the capacity of a firm's gas and oil-fired power plants, scaled by its total electricity-generation capacity.[25] To assess whether operating flexibility affects the way in which firms react to product price risk, we start by adding *FLEXIBILITY* as an additional control variable in Column (1) of Table 8. The estimates indicate that, everything else being equal, firms with higher levels of operating flexibility hold less cash. Next, we split the sample in three subsamples based on the flexibility of the production process used. In Columns (2), (3), and (4), we present estimates this equation for terciles of the sample based on firms' level of *FLEXIBILITY*. The results suggest that the impact of price volatility on cash holdings comes primarily from the sample of firms with relatively inflexible production technologies. For the least flexible firms, the coefficient on volatility is highest, with a value of 0.014. This estimate implies that a one-standard deviation increase of electricity price volatile would lead to a 1.1 percentage point increase in cash, which corresponds to a 15 percent increase. For firms with medium and low levels of operating flexibility, the coefficients are 0.006 and 0.004, each of which is not statistically significantly different from zero. In Column (5), we use a specification with an interaction term between operation flexibility and product price risk, and the results are similar.

The positive impact of volatility on cash holdings appears to be driven by firms with inflexible production technologies. In contrast to flexible firms, these energy utilities cannot easily adjust their production in case of adverse price shocks. Because of the possibility of an unexpected cash flow shock, these firms build up liquidity buffers if the electricity price is highly volatile. Operating flexibility and cash holdings appear to be substitutes for one another in their effect on firms' ability to hedge potential cash flow shocks.

[25] Reinartz and Schmid (2016) provide technology-specific values for different production technologies.

5.2. Robustness of Operating Flexibility: Sensitivity to Particular Technologies

One potential concern is that the differences we observe across production technologies do not reflect differences in operating flexibility, but instead occur because of one or two particular technologies that are different for some other reason. For example, nuclear power is likely to contain risks not present with other technologies that could lead firms using nuclear power to have more liquid balance sheets, although it is not clear why those risks would lead to a relation between cash holdings and price volatility. Furthermore, the cost structures of nuclear power plants are opaque because cost for the final deposition of nuclear waste are often unclear and difficult to consider.

In Panel A of Table 9, we reestimate our equation excluding individual technologies to ensure that the results are general and are not driven by the idiosyncrasies associated with any particular technology. In Columns (1) to (3), we exclude all firm years that have at least one plant with the following technologies: nuclear, coal, and hydro. Another possible concern is that certain types of power plants are not actively switched dispatched (i.e., switched on and off). In particular, wind and solar plants produce electricity whenever there is wind or sun with little active dispatching of such power plants. To a smaller extent, this concern also applies to hydro power plants. To analyze whether such not actively dispatched power plants bias our results, we exclude all firm-years of utilities operating wind or solar plants in Column (4). The results are similar to those in the main specification in Table 8. Thus, it does not appear that the use of any particular technology is driving our results. Regardless of which firms are included into the equation, their liquidity decisions appear to be a function of both the price volatility and their operating flexibility.

5.3. Robustness of Operating Flexibility: Endogeneity of Production Assets

So far, we have addressed the potential endogeneity of electricity price volatility, but assumed that production flexibility is exogenous. However, it is possible that firm-level factors like cash holdings could affect firm's investment decisions in different types of power plants, which in turn would affect their levels of flexibility.[26] To address the potential concern that this endogeneity of production could affect our results, we exploit the deregulation of electricity markets and the wave of privatizations in the late 1990s and early 2000s. Before the late 1990s, most electricity markets around the globe were regulated, and energy utilities were usually state-owned.[27] Power plants that were planned before deregulation and privatization were more likely affected by political considerations rather than factors relating to finance that could lead to reverse causality (Peltzman and Winston, 2000). Furthermore, state-owned firms are unlikely to have any financial constraints that could influence their decisions which power plants to construct.

Empirically, we use production asset data as of 1995 instead of contemporaneous values to estimate a firm's flexibility. We rely on the earliest available version of the *PLATTS WEPP* database and exclude all plants that were not yet operating in 1995 to approximate firms' production assets in 1995. We then recalculate the *FLEXIBILITY* measure based on power plants that were active in 1995. We report estimates of this equation in Panel B of Table 9. Similar to before, we find that the impact of product price risk on cash holdings is concentrated in firms with low levels of operating flexibility. For firms with medium and high levels of operating flexibility, the coefficients on electricity price volatility are also positive, but smaller and statistically insignificant. Using an interaction term between flexibility and price risk in Column (4) also leads to the conclusion that operating flexibility reduces the impact of product price risk on cash holdings.

5.4. Hedging through Derivatives Markets

An alternative to holding cash as liquidity is to hedge directly using derivatives. In a number of regions of the world, electricity utilities can sell part of their production in advance in futures or forwards markets. Such hedging protects firms from fluctuations in the day-ahead spot market in the short-run. We

[26] To investigate whether observable differences between firms with different types of power plants affect the results, we interact our proxy for flexibility with the control variables in an unreported robustness test. However, none of the coefficients of the interaction terms is statistically significant, and the coefficients of our main variables of interest are similar to those in the main specification.
[27] The U.S. and Japan are exceptions in this context because privately owned electricity-generating firms were common in both countries long before that time. Thus, we exclude them from this test.

next evaluate the extent to which the possibility of hedging price risk is a substitute for holding cash as a way to manage liquidity.

To do so, we exploit the fact that the opportunities to hedge electricity price risk vary substantially across power markets. We construct a measure of firms' abilities to hedge in a particular market called *HEDGEABILITY* as the fraction of firms that hedge in a particular power market. We first calculate the fraction of firms other the firm in question that use derivative to hedge the electricity price in a particular electricity market in each year, using hand-collected data on the hedging behavior of energy utilities from Lievenbrück and Schmid (2014).[28] We average these fractions across all years in a power market. We only consider years with at least five observations and markets with at least three years of non-missing data.

We divide the sample into terciles based on *HEDGEABILITY* and evaluate the extent to which the existence of a liquid derivatives market affects the relation between price volatility and cash holdings in each subsample. We present estimates of these equations in Table 10. We find that volatility affects cash holdings much more when firms have poor hedging opportunities. The coefficient for electricity price volatility is 0.017 in the sub-sample of firms with the worst hedging opportunities. This coefficient implies that a one-standard deviation increase of product price risk leads to a 1.3 percentage-point increase in cash holdings, which corresponds to an 18 percent increase in this sub-sample. For firms with average hedging opportunities, the coefficient for electricity price volatility is positive, but not statistically significantly different from zero. In the sub-sample of firms with the best hedging opportunities, the coefficient is very close to zero.

These results suggest that when liquid derivative markets exist, firms can more easily sell their electricity in advance and hedge the risk coming from price fluctuations. However, if derivative markets do not exist or if they are not sufficiently liquid, then firms change their cash holdings in response to volatility changes. This finding provides direct evidence that hedging through derivatives markets is a substitute for holding cash.

[28] The last year for which hedging data for individual firms is available is 2010.

6. Conclusion

One of the most important decisions financial managers make concerns the liquidity of the firm's balance sheet. Holding cash is costly for tax and other reasons, while at the same time insulating the firm from the obligation to raise external capital should there be an unexpected cash shortfall. We evaluate firms' decisions to hold cash by isolating one specific source of risk faced by firms in one industry: the risk faced by electricity producing firms when electricity wholesale prices are volatile and their production is inflexible.

Our estimates imply that firms' cash holdings are positively related to electricity price fluctuations. This pattern is consistent with the view that firms' liquidity choices reflect the expected costs of price risk. To isolate the channel through which wholesale electricity price volatility affects producing firms' liquidity choices, we rely on the fact that movements in electricity prices often occur because of weather-induced demand shocks. Using an instrument based on the volatility of a region's weather, we find the same pattern as when we use our baseline firm-fixed effects models for estimation: price volatility leads to changes in cash holdings, with this relation much stronger for firms using methods of production for which it is more difficult and costly to change output quantities. This pattern suggests that price risk causally affects firms' cash policy in the manner suggested by the precautionary theory of liquidity.

Wholesale price volatility appears to increase the risk faced by electricity producers, who compensate by holding more cash on their balance sheets. This additional risk faced by electricity producers is a consequence of the deregulatory environment. As a test of this idea, we compare the cash holdings of firms operating in regulated markets to those operating in deregulated ones. Consistent with the notion that deregulation increases the risk faced by electricity producers, our results suggest that firms selling on wholesale markets hold about 20% more cash than otherwise identical firms in regulated markets.

When we analyze the role of firms' operating flexibility, we find that firms with more inflexible production technologies for which altering output is costly tend to hold more cash in markets with more volatile electricity prices. In contrast, electricity price uncertainty has little impact on firms' cash holdings if their production flexibility is high. In addition, the ability of firms to hedge price risk through derivative markets by selling a portion of their electricity in advance varies across markets. Being able to hedge in this manner is potentially a substitute for holding liquidity. Empirically, we find that, consistent with this argument, the existence of a more liquid derivative market in electricity reduces the impact of price risk on firms' liquidity choices. The liquidity of capital markets and of balance sheets appear to be substitutes for one another.

Overall, our findings suggest that in the electricity producing industry, price volatility can be an important factor affecting firms' liquidity choices. The flexibility of the production process is a major factor affecting this risk. The electricity producing industry provides a useful laboratory for studying liquidity management issues, since we can observe the production assets and high-frequency output prices. However, it is likely that price risk affects liquidity management choices in a similar manner in other industries as well.

Our analysis highlights the fact that the liquidity of firms' balance sheets is an endogenous choice, and that economy or industry level factors affect this choice. In doing so, these factors can affect firms in ways that have not been fully appreciated. First, deregulating the electricity industry led producers to face price risk, and to compensate for this risk by holding more cash than they otherwise would. The cost firms face from having to adjust their balance sheets is a real effect of deregulation that has not been fully understood. Second, more active derivative markets mean firms can hold less liquid balance sheets. Again, since it is costly for firms to hold liquidity, this effect of liquid derivative markets on firms' balance sheets is a social benefit of having liquid derivative markets.

References

Acharya, Viral V., Heitor Almeida and Murillo Campello (2007) "Is Cash Negative Debt? A Hedging Perspective on Corporate Financial Policies," *Journal of Financial Intermediation*, 16, 515–554.

Almeida, Heitor, Murillo Campello, Igor Cunha, and Michael S. Weisbach (2014) "Corporate Liquidity Management: A Conceptual Framework and Survey," *Annual Review of Financial Economics*, 6, 135–162.

Almeida, Heitor, Murillo Campello, and Michael S. Weisbach (2004) "The Cash Flow Sensitivity of Cash," *Journal of Finance*, 59, 1777–1804.

Bates, Thomas W., Kathleen M. Kahle, and René M. Stulz (2009) "Why do U.S. firms hold so much more cash than they used to?" *Journal of Finance*, 64, 1985–2021.

Becher, David A., Harold J. Mulherin, and Ralph A. Walkling (2012) "Sources of gains in corporate mergers: Refined tests from a neglected industry," *Journal of Financial and Quantitative Analysis*, 47, 57–89.

Boldt, Jenny; Hankel, Lisa; Laurisch, Lilian Charlotte; Lutterbeck, Felix; Oei, Pao-Yu; Sander, Aram; Schroeder, Andreas; Schweter, Helena; Sommer, Philipp; Sulerz, Jasmin (2012) "Renewables in the grid. Modeling the German power market of the year 2030," *Working Paper*.

Brown, Jason P. and Andreas Kodaka (2014) "U.S. Electricity Prices in the Wake of Growing Natural Gas Production," *The Main Street Economist* (Federal Reserve Bank of Kansas City), 2, 1–8.

Campello, Murillo, Erasmo Giambona, John R. Graham, and Campbell R. Harvey (2011) "Liquidity management and corporate investment during a financial crisis," *Review of Financial Studies*, 24, 1944–1979.

Cicala, Steve (2017) "Imperfect Markets versus Imperfect Regulation in U.S. Electricity Generation," *NBER Working Paper*.

Duchin, Ran, Thomas Gilbert, Jarrad Harford and Christopher Hrdlicka (2017) "Precautionary Savings with Risky Assets: When Cash is not Cash," *Journal of Finance*, 72, 793–852.

Economic Consulting Associates (2015) "European Electricity Forward Markets and Hedging Products – State of Play and Elements for Monitoring," *Final Report*.

Epstein, Larry (1978) "Production Flexibility and the Behaviour of the Competitive Firm under Price Uncertainty," *Review of Economic Studies*, 45, 251-261.

Erel, Isil, Yeejin Jang, Bernadette A. Minton, and Michael S. Weisbach (2017) "Corporate Liquidity, Acquisitions, and Macroeconomic Conditions," *NBER Working Paper.*

Fabrizio, Kira R., Nancy L. Rose, and Catherine D. Wolfram (2007) "Do markets reduce costs? Assessing the impact of regulatory restructuring on US electric generation efficiency," *American Economic Review*, 97, 1250–77.

Faulkender, Michael W., Kristine W. Hankins, and Mitchell Petersen (2017) "Understanding Precautionary Cash at Home and Abroad," *NBER Working Paper*.

Federal Energy Regulatory Commission (2015) "Energy Primer: A Handbook of Energy Market Basics."

Froot, Kenneth A., David S. Scharfstein, and Jeremy C. Stein (1993) "Risk Management: Coordinating Investment and Financing Policies," *Journal of Finance*, 48, 1629–1658.

Giambona, Erasmo, John R. Graham, Campbell Harvey, and Gordon Bodnar (2018) "The Theory and Practice of Corporate Risk Management: Evidence from the Field," *Financial Management*, forthcoming.

Graham, John R. and Mark T. Leary (2017) "The Evolution of Corporate Cash," *NBER Working Paper*.

Haushalter, David, Sandy Klasa and William F. Maxwell (2007) "The Influence of Product Market Dynamics on a Firm's Cash Holdings and Hedging Behavior", *Journal of Financial Economics*, 84, 797–825.

Hoberg, Gerard and Gordon Phillips (2010) "Product Market Synergies in Mergers and Acquisitions: A Text Based Analysis, *Review of Financial Studies*, 23, 3773–3811.

Hoberg, Gerard, Gordon Phillips, and Nagpurnanand Prabhala (2014) "Product market threats, payouts, and financial flexibility," *Journal of Finance*, 69, 293–324.

Hoberg, Gerard and Gordon Phillips (2016) "Text-Based Network Industries and Endogenous Product Differentiation", *Journal of Political Economy* 124, 1423-1465.

Hoberg, Gerad and Katie S. Moon (2017) "Offshore activities and financial vs operational hedging," *Journal of Financial Economics*, 125, 217–244.

Keynes, John M. (1936), "The General Theory of Employment, Interest and Money," McMillan, London.

Kulatilaka, Nalin and Marks, Stephen G. (1988), "The Strategic Value of Flexibility: Reducing the Ability to Compromise," *American Economic Review*, 78, 574–580.

Leyzerovich, Alexander S. (2007) "Steam Turbines for Modern Fossil-Fuel Power Plants", CRC Press Inc., Tylor & Francis Group.

Liang, Jiaqi and Ronald G. Harley (2010) "Pumped storage hydro-plant models for system transient and long-term dynamic studies," *Power and Energy Society General Meeting, 2010 IEEE*.

Lievenbrück, Martin and Thomas Schmid (2014) "Why do firms (not) hedge? — Novel evidence on cultural influence," *Journal of Corporate Finance*, 25, 92-106.

Lin, Chen, Thomas Schmid, and Michael S. Weisbach (2017) "The Real Effect of Climate Change: Evidence from New Investments in Power Plants," *Working Paper*.

Lins, Karl V., Henri Servaes, and Peter Tufano (2010) "What drives corporate liquidity? An international survey of cash holdings and lines of credit," *Journal of Financial Economics*, 98, 160–176.

MacKay, Peter (2003) "Real Flexibility and Financial Structure: An Empirical Analysis," *Review of Financial Studies*, 16, 1131–1165.

Mauer, David C. and Triantis, Alexander J. (1994) "Interactions of Corporate Financing and Investment Decisions: A Dynamic Framework," *Journal of Finance*, 49, 1253–1277.

Menne, Matthew J., Imke Durre, Russell S. Vose, Byron E. Gleason, and Tamara G. Houston (2012) "An Overview of the Global Historical Climatology Network-Daily Database," *Journal of Atmospheric and Oceanic Technology*, 29, 897–910.

Moody's Investor Service (2016) "Australian utilities' operational flexibility is key to their ability to manage power price volatility," report summary available at https://www.moodys.com/research/Moodys-Australian-utilities-operational-flexibility-is-key-to-their-ability--PR_354068

Morellec, Erwan, Boris Nikolov, and Francesca Zucchi (2014) "Competition, cash holdings, and financing decisions," *Working Paper*, Swiss Finance Institute.

Opler, Tim, Lee Pinkowitz, Rene M. Stulz, and Rohan Williamson (1999), "The Determinants and Implications of Corporate Cash Holdings," *Journal of Financial Economics*, 52, 3–46.

Ovtchinnikov, Alexei V. (2010) "Capital Structure Decisions: Evidence from Deregulated Industries," *Journal of Financial Economics*, 95, 249-274.

Peltzmann, Sam and Winston, Clifford (2000) "Deregulation of network industries - What's next?" AEIBrookings Joint Center for Regulatory Studies, Washington, DC.

Pérez González, Francisco and Yun, Hayong (2013) "Risk Management and Firm Value: Evidence from Weather Derivatives", *Journal of Finance*, 68, 2143–2176.

Reinartz, Sebastian J. and Thomas Schmid (2016) "Production Flexibility, Product Markets, and Capital Structure Decisions," *Review of Financial Studies*, 29, 1501–1548.

Rettl, Daniel A., Alex Stomper, and Josef Zechner (2016) "The Stability of Dividends and Wages: Effects of Competitor Inflexibility," *Working Paper*.

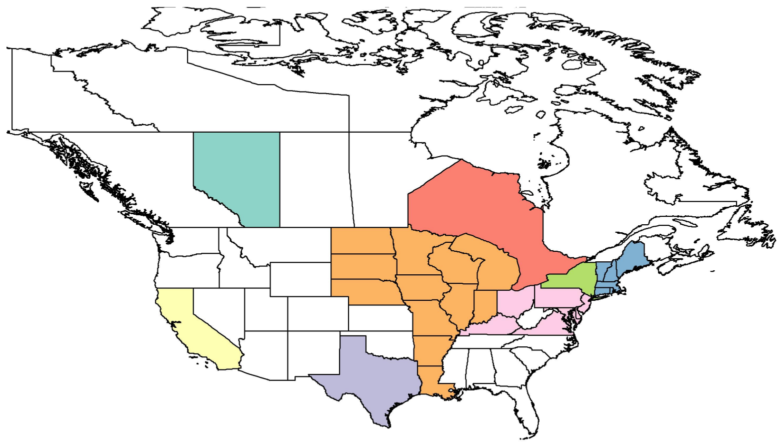
Sandmo, Agnar (1971) "On the Theory of the Competitive Firm Under Price Uncertainty," *American Economic Review*, 61, 65–73.

Swider, Derk J. (2006) "Handel an Regelenergie- und Spotmärkten", Springer, Wiesbaden.

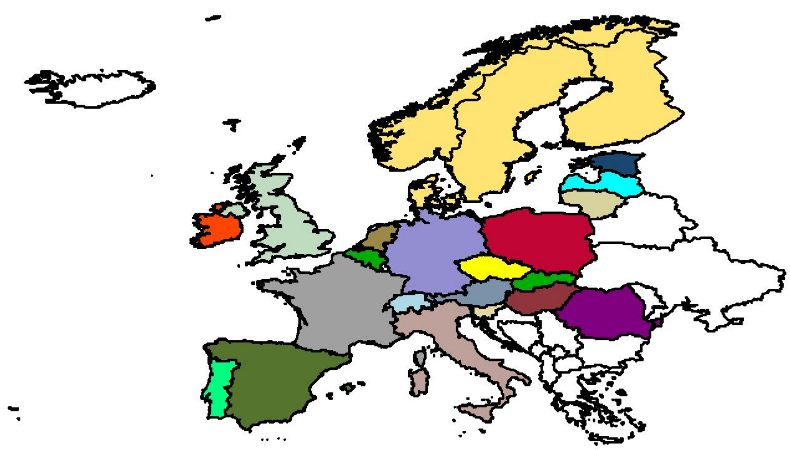
Trueby, Johannes (2014) "Thermal Power Plants Economics and Variable Renewables Energies", *International Energy Agency Insight Series*.

Turnovsky, Stephen J. (1973) "Production Flexibility, Price Uncertainty and the Behavior of the Competitive Firm," *International Economic Review*, 14, 395-413.

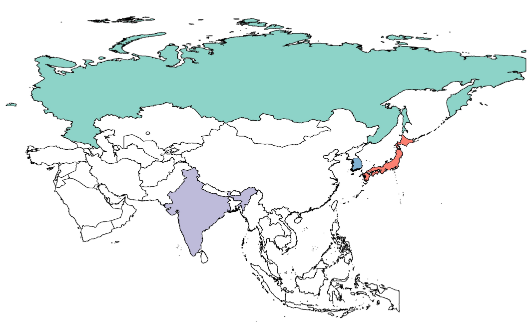
White, Halbert (1980) "A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity," *Econometrica*, 48, 817-838.



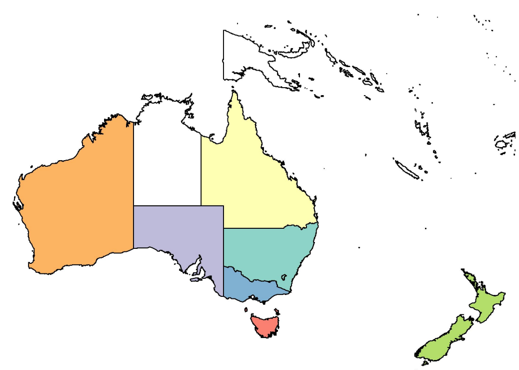
(a) North America



(b) Europe

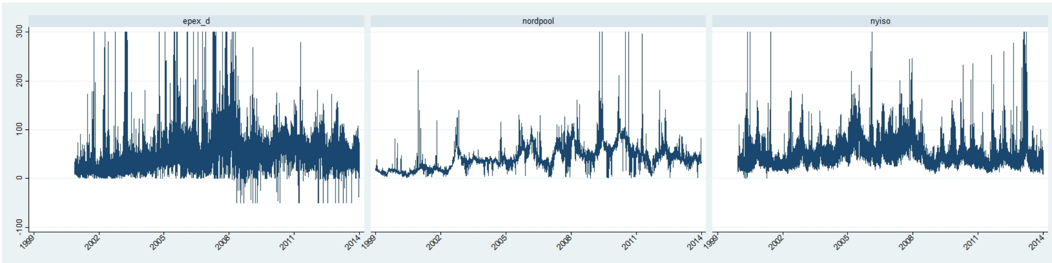


(c) Asia

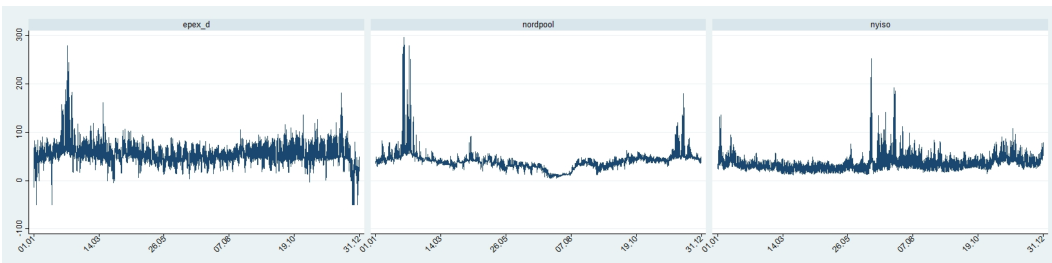


(d) Oceania

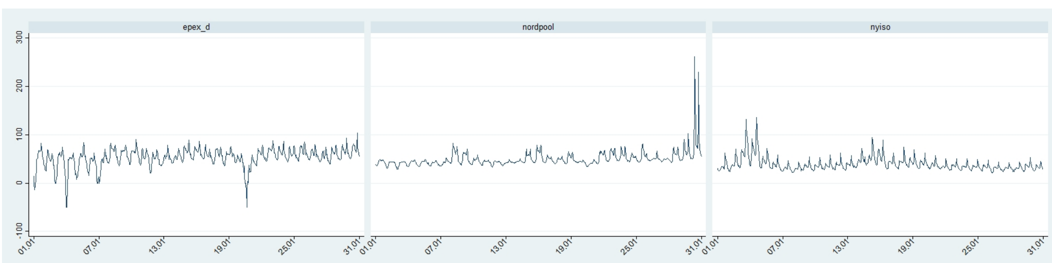
Figure 1: This figure shows the different regions which have competitive wholesale markets for electricity and are included in our sample.



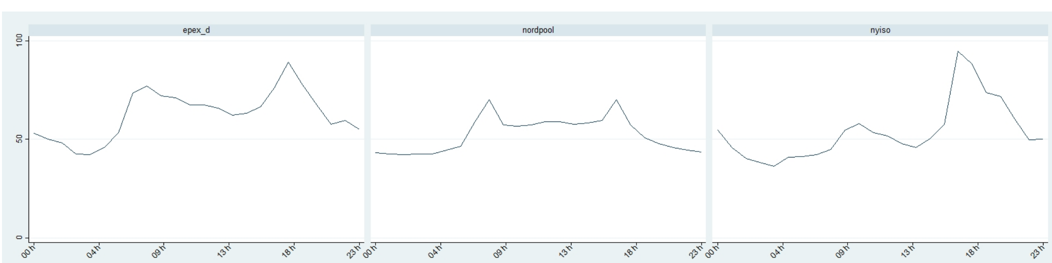
(a) Electricity price over time



(b) An exemplary year: 2012



(c) An exemplary month: January 2012



(d) An exemplary day: January 15, 2012

Figure 2: This figure shows hourly electricity prices in US$ per MWh for three selected market: EPEX_D (Germany), Nordpool (Northern Europe), and NYISO (state of New York). The whole time series is shown in Figure (a). The prices for an exemplary year (2012), month (January 2012) and day (January 15, 2012) are shown in Subfigures (b), (c), and (d). For this illustration, prices are capped at minus 50 and 300 US$ per MWh. An overview on all included markets can be found in Appendix B.

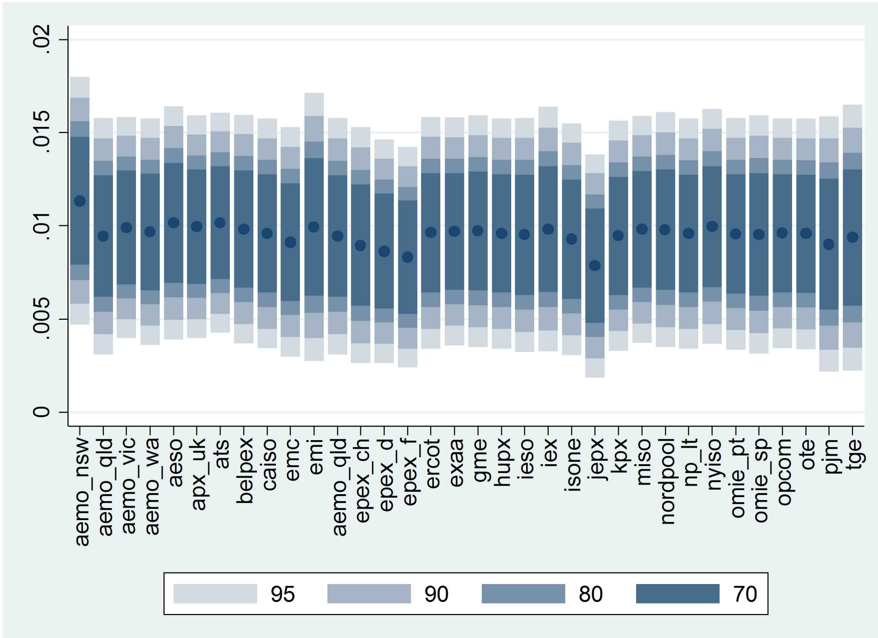


Figure 3: This figure shows the coefficient estimates for log(volatility) and their confidence intervals when we subsequently exclude the indicated markets. The baseline model for this analysis is equivalent to Column 4 of Table 3.

Table 1: Sample Overview

	Full sample			Firms located in market regions		
Year	**#Firms**	**#Plants**	**#Markets**	**#Firms**	**#Plants**	**#Markets**
2000	167	12,076	13	37	2,916	11
2001	173	14,685	15	43	4,566	14
2002	189	18,536	17	49	7,385	16
2003	214	20,758	20	64	9,280	19
2004	222	20,087	21	67	9,792	20
2005	263	24,093	24	91	13,796	21
2006	278	24,906	26	98	14,916	25
2007	298	25,993	29	106	15,757	27
2008	269	26,439	31	109	16,902	29
2009	311	28,349	32	149	18,884	30
2010	305	30,916	37	150	20,754	32
2011	299	31,758	38	149	21,363	33
2012	288	32,233	39	141	21,733	34
2013	286	33,219	40	141	22,171	34
2014	271	33,891	40	131	22,938	34
Total	3,833	377,939	422	1,525	223,153	379
Unique	398	67,180	40	194	45,135	34

This table presents an overview on the sample firms, their power plant units, and the number of electricity markets for each sample year. Full sample refers to all firms and all markets (independent of whether any sample firms is located in this market). The last three columns refer to firms which are located in regions with competitive wholesale markets for which hourly electricity price data is available (cf. Appendix B for an overview on the different markets).

Table 2: Descriptive Statistics

Panel A: Firm-level Descriptives

Variable	N	mean	p25	p50	p75	SD
Cash	1,525	0.07	0.02	0.04	0.09	0.09
Volatility	1,525	0.65	0.28	0.40	0.61	0.96
Log(Volatility)	1,525	-0.83	-1.27	-0.92	-0.50	0.75
Weather volatility	1,508	7.91	6.07	7.90	9.47	2.82
Flexibility	1,524	0.35	0.08	0.32	0.54	0.30
#Plant Units	1,524	313	36	116	380	556
Assets (mio USD)	1,525	21,662	1,202	5,117	23,835	42,290
Assets (log)	1,525	15.32	14.00	15.45	16.99	2.06
Cash flow	1,505	0.09	0.07	0.09	0.12	0.07
Leverage	1,524	0.47	0.34	0.51	0.64	0.22
GDP (US$ per capita)	1,525	37,380	31,867	42,224	48,374	16,786
Log(GDP per capita)	1,525	10.28	10.37	10.65	10.79	0.93
MtB	1,365	1.65	0.89	1.35	1.91	1.44
Capex	1,482	0.08	0.04	0.06	0.09	0.09
Dividend (dummy)	1,502	0.76	1.00	1.00	1.00	0.42
Inflation	1,525	3.00	1.46	2.30	3.38	2.80

Panel B: Correlation of Volatility Measures

	A	B	C	D	E
A: Log(Volatility)	1.00				
B: Volatility	0.82	1.00			
C: Log($\text{Volatility}_{\text{price}}$)	0.89	0.68	1.00		
D: Log($\text{Volatility}_{\text{diff}}$)	0.87	0.71	0.94	1.00	
E: Log($\text{Volatility}_{\text{std. diff}}$)	0.85	0.92	0.71	0.82	1.00

Panel A presents descriptive statistics for all sample firms located in regions with competitive wholesale markets for which hourly electricity price data is available. Reported are the number of observations (N), mean value, 25% percentile, median, 75% percentile, and standard deviation (SD). Panel B shows the correlation between the different measures for electricity price volatility. A detailed description of all variables can be found in Appendix A.

Table 3: Explaining Cash Holdings as a Function of Wholesale Price Volatility

Column	1	2	3	4
Log(Volatility$_t$)	**0.016*** **	**0.019*** **	**0.0100*** **	**0.0096*** **
	(4.50)	**(4.27)**	**(3.40)**	**(3.20)**
Log(assets)$_{t-1}$		-0.0061*		-0.011
		(-1.85)		(-1.11)
Cash flow$_{t-1}$		-0.074		0.0088
		(-1.17)		(0.20)
Leverage$_{t-1}$		-0.084**		-0.019
		(-2.27)		(-0.84)
Log(GDP per capita$_{t-1}$)		-0.0051		-0.064**
		(-0.14)		(-2.52)
Year-FE	yes	yes	yes	yes
Country-FE	yes	yes	n/a	n/a
Firm-FE	no	no	yes	yes
Observations	1,525	1,473	1,515	1,464
Adj. R^2	0.17	0.24	0.65	0.69

The dependent variable is cash holdings [wc02001] normalized by total assets [wc02999]. Volatility is defined as the standard deviation of hourly electricity prices during a firm's fiscal year, normalized by a market's average electricity price level. Estimation models are pooled OLS or firm-fixed effects regressions. Control variables are lagged by one year. T-statistics based on Huber/White robust standard errors clustered by countries are presented in parentheses. ***, ** and * indicate significance on the 1%-, 5%- and 10%-levels, respectively. A detailed description of all variables can be found in Appendix A.

Table 4: Instrumenting Wholesale Price Volatility using Weather Volatility

Column	1	2	3	4
Sample	all		weather-affected capa < 10%	
Model	IV first	IV second	IV first	IV second
Weather volatility$_t$	**0.19*** **		**0.21*** **	
	(3.08)		**(3.53)**	
Log(Volatility$_t$)$_{instr}$		**0.016** **		**0.018** **
		(2.04)		**(2.57)**
Log(assets)$_{t-1}$	-0.095	-0.0098	-0.091	-0.0025
	(-0.89)	(-1.01)	(-0.64)	(-0.24)
Cash flow$_{t-1}$	-0.027	0.0048	-0.0056	0.043
	(-0.15)	(0.11)	(-0.029)	(0.96)
Leverage$_{t-1}$	0.0032	-0.022	-0.013	-0.031
	(0.017)	(-0.97)	(-0.056)	(-1.44)
Log(GDP per capita$_{t-1}$)	-1.70	-0.063**	-1.50	-0.088**
	(-0.87)	(-2.17)	(-0.74)	(-2.41)
Year-FE	yes	yes	yes	yes
Firm-FE	yes	yes	yes	yes
Observations	1,449	1,449	1,252	1,252
K-P rk Wald F	9.46		12.45	

This table shows instrumental variable regressions which use weather volatility as an instrument for electricity price volatility. Weather volatility is defined as the standard deviation of daily average temperatures during a firm's fiscal year. Electricity price volatility is defined as the standard deviation of hourly electricity prices during a firm's fiscal year, normalized by a market's average electricity price level. The sample for this analysis consists of all firms in Columns 1 and 2. In Columns 3 and 4, only firms with less than ten percent weather-affected generation capacity (i.e., solar, wind, and geothermal) are considered. First-stage instrumental variable regressions are reported in Columns 1 and 3. In those specifications, the dependent variable is log(volatility). Columns 2 and 4 show second-stage instrumental variable regressions with cash holdings [wc02001] normalized by total assets [wc02999] as dependent variables. K-P rk Wald F stands for Kleibergen-Paap rk Wald F statistic. T-statistics based on Huber/White robust standard errors clustered by countries are presented in parentheses. ***, ** and * indicate significance on the 1%-, 5%- and 10%-levels, respectively. A detailed description of all variables can be found in Appendix A.

Table 5: How does Input Price Volatility Affect Cash Holdings?

Column	1	2	3	4
Log(Volatility$_t$)	**0.0099****	**0.010****	**0.0067****	**0.0063****
	(2.52)	**(2.47)**	**(2.28)**	**(2.36)**
Volatility [gas price]$_t$	-0.00082			
	(-0.82)			
Log(Volatility [gas price]$_t$)		-0.00037		
		(-0.10)		
Volatility [coal price]$_t$			0.00070	
			(0.69)	
Log(Volatility [coal price]$_t$)				0.0045
				(0.55)
Controls	yes	yes	yes	yes
Year-FE	yes	yes	yes	yes
Firm-FE	yes	yes	yes	yes
Observations	914	914	737	737
Adj. R^2	0.78	0.78	0.60	0.60

The dependent variable is cash holdings [wc02001] normalized by total assets [wc02999]. Volatility is defined as the standard deviation of hourly electricity prices during a firm's fiscal year, normalized by a market's average electricity price level. The frequency of gas prices is monthly for the U.S. and quarterly for other countries. The frequency of coal prices is quarterly for all countries. The unreported control variables are identical to those in Table 3. All models are firm fixed effects regressions. Control variables are lagged by one year. T-statistics based on Huber/White robust standard errors clustered by countries are presented in parentheses. ***, ** and * indicate significance on the 1%-, 5%- and 10%-levels, respectively. A detailed description of all variables can be found in Appendix A.

Table 6: Robustness of Cash Predictive Models to Alternative Specifications

Panel A: Alternative Volatility Definitions				
Column	1	2	3	4
Volatility_t	0.0044***			
	(2.96)			
$\text{Log}(\text{Volatility}_{\text{price},t})$		0.0093***		
		(3.01)		
$\text{Log}(\text{Volatility}_{\text{diff},t})$			0.0083**	
			(2.40)	
$\text{Log}(\text{Volatility}_{\text{std.diff},t})$				0.0078**
				(2.21)
Controls	yes	yes	yes	yes
Year-FE	yes	yes	yes	yes
Firm-FE	yes	yes	yes	yes
Observations	1,464	1,464	1,464	1,464
Adj. R^2	0.69	0.69	0.69	0.69

Panel B: Measurement of Volatility				
Column	1	2	3	4
	measurement frequency			downside risk
	daily	weekly	monthly	only < 0
$\text{Log}(\text{Volatility}_t)$	**0.0089*** **	**0.0088*** **	**0.0084*** **	
	(3.07)	**(3.17)**	**(3.09)**	
$\text{Log}(\text{Volatility}_{\text{std.diff},t})$				**0.021*** **
				(2.84)
Controls	yes	yes	yes	yes
Year-FE	yes	yes	yes	yes
Firm-FE	yes	yes	yes	yes
Observations	1,464	1,464	1,464	1,464
Adj. R^2	0.69	0.69	0.69	0.69

continued on next page

Table 6 continued

Panel C: The Role of Market Power				
Column	1	2	3	4
	<10% capa	<5% capa	>50 firms	>100 firms
Log(Volatility$_t$)	**0.010****	**0.012****	**0.012****	**0.012****
	(2.66)	**(2.27)**	**(2.38)**	**(2.26)**
Controls	yes	yes	yes	yes
Year-FE	yes	yes	yes	yes
Firm-FE	yes	yes	yes	yes
Observations	1,064	867	906	829
Adj. R^2	0.70	0.70	0.68	0.69

Panel D: Alternative Control Variables				
Column	1	2	3	4
Log(Volatility$_t$)	**0.0093*****	**0.0089*****	**0.0091*****	**0.0094*****
	(3.12)	**(3.14)**	**(3.07)**	**(3.24)**
Log(assets)$_{t-1}$	-0.012	-0.0086	-0.0087	-0.0088
	(-1.04)	(-0.70)	(-0.71)	(-0.72)
Cash flow$_{t-1}$	-0.0066	0.042	0.048	0.052
	(-0.13)	(0.81)	(0.94)	(1.01)
Leverage$_{t-1}$	-0.018	-0.026	-0.029	-0.027
	(-0.60)	(-0.91)	(-0.96)	(-0.92)
Log(GDP per capita)$_{t-1}$	-0.074**	-0.10**	-0.11**	-0.11***
	(-2.11)	(-2.68)	(-2.71)	(-2.97)
Market-to-book$_{t-1}$	0.0013	0.0010	0.00096	0.00094
	(0.26)	(0.24)	(0.23)	(0.23)
Capex$_{t-1}$		0.0044	0.0033	0.0031
		(0.21)	(0.15)	(0.14)
Dividend (dummy)$_{t-1}$			-0.0037	-0.0024
			(-0.42)	(-0.28)
Inflation$_{t-1}$				0.0024
				(1.42)
Year-FE	yes	yes	yes	yes
Firm-FE	yes	yes	yes	yes
Observations	1,311	1,283	1,275	1,275
Adj. R^2	0.69	0.69	0.69	0.69

continued on next page

Table 6 continued

The base specification is as follows: the dependent variable is cash holdings [wc02001] normalized by total assets [wc02999], and volatility is defined as the standard deviation of hourly electricity prices, normalized by a market's average electricity price level. The unreported control variables in Panels A to C are identical to those in Table 3.

Alternative definitions of volatility are reported in *Panel A*. In the first column, we use our main volatility measure, but do not take the natural logarithm. In Column 2, we use the unscaled standard deviation of hourly electricity prices. The third alternative definition is based on the standard deviation of hourly electricity price changes (in US$). In the last column, volatility is defined as the standard deviation of hourly electricity price changes (in US$), normalized by a market's average electricity price level. In *Panel B*, volatility is calculated as the standard deviation of daily prices in Column 1, weekly prices in Column 2, and monthly prices in Column 3, all normalized by a market's average electricity price level. In the last column, we calculate a volatility measure that only considers downside risk. For this measure, we use the standard deviation of hourly electricity price changes (in US$), normalized by a market's average electricity price level, but only consider negative price changes. In *Panel C*, only firms which account for less than 10% (Column 1) or 5% (Column 2) of the total production capacity in an electricity market and year are considered. In Columns 3 and 4, we only consider electricity markets and years with at least 50 or 100 firms that have an electricity production capacity of more than 100 megawatt (according to the full Platts WEPP database, not only our sample). In *Panel D*, we present models with additional control variables.

All models are firm fixed effects regressions. Control variables are lagged by one year. T-statistics based on Huber/White robust standard errors clustered by countries are presented in parentheses. ***, ** and * indicate significance on the 1%-, 5%- and 10%-levels, respectively. A detailed description of all variables can be found in Appendix A.

Table 7: The Introduction of Wholesale Markets and Cash Holdings

Column	1	2	3	4
Market (dummy)$_t$	**0.012****	**0.019****		
	(2.15)	**(2.56)**		
Log(Volatility$_{\mathbf{zero},t}$ + 1)			**0.021***	**0.027*****
			(1.99)	**(3.06)**
Log(assets)$_{t-1}$	-0.0048**	-0.012*	-0.0042*	-0.013
	(-2.06)	(-1.73)	(-1.78)	(-1.67)
Cash flow$_{t-1}$	0.061	0.12*	0.021	0.11
	(0.89)	(1.97)	(0.31)	(1.62)
Leverage$_{t-1}$	-0.066***	-0.026	-0.079***	-0.034*
	(-2.94)	(-1.41)	(-3.43)	(-1.77)
Log(GDP per capita$_{t-1}$)	-0.030**	-0.023	-0.031***	-0.025
	(-2.49)	(-1.60)	(-2.82)	(-1.50)
Year-FE	yes	yes	yes	yes
Country-FE	yes	n/a	yes	n/a
Firm-FE	no	yes	no	yes
Observations	3,338	3,320	3,010	2,995
Adj. R^2	0.23	0.60	0.24	0.62

The dependent variable is cash holdings [wc02001] normalized by total assets [wc02999]. Market is a dummy variable which equals one if a wholesale market for electricity exists in a region and year. Volatility$_{zero}$ is defined as the standard deviation of hourly electricity prices, normalized by a market's average electricity price level; for regions without a wholesale market for electricity, this variable is set to zero. The year in which a market is introduced is excluded in all analyses. Models are pooled OLS or firm fixed effects regressions. Control variables are lagged by one year. T-statistics based on Huber/White robust standard errors clustered by countries are presented in parentheses. ***, ** and * indicate significance on the 1%-, 5%- and 10%-levels, respectively. A detailed description of all variables can be found in Appendix A.

Table 8: Does Operating Flexibility Mitigate the Impact of Price Risk on Cash Holdings?

Column	1	2	3	4	5
Sample	all	low flex	medium flex	high flex	all
Log(Volatility$_t$)	**0.010*** **	**0.014*** **	**0.0060**	**0.0044**	0.017***
	(3.30)	**(3.22)**	**(1.09)**	**(0.76)**	(3.93)
Flexibility$_t$	-0.037*				-0.033*
	(-2.03)				(-1.83)
Log(Volatility$_t$) x flex$_t$					**-0.019** **
					(-2.29)
Log(assets)$_{t-1}$	-0.010	-0.026*	0.0088	0.0043	-0.011
	(-1.21)	(-1.95)	(0.46)	(0.35)	(-1.28)
Cash flow$_{t-1}$	0.0025	0.023	-0.0055	0.024	**0.0016**
	(0.056)	(0.23)	(-0.13)	(0.34)	**(0.036)**
Leverage$_{t-1}$	-0.027	-0.067*	0.017	-0.025	-0.025
	(-1.30)	(-1.85)	(0.58)	(-0.64)	(-1.23)
Log(GDP per capita$_{t-1}$)	-0.067***	-0.057*	-0.14	-0.13	-0.061**
	(-2.80)	(-1.83)	(-1.23)	(-1.03)	(-2.76)
Year-FE	yes	yes	yes	yes	yes
Firm-FE	yes	yes	yes	yes	yes
Observations	1,463	475	484	481	1,463
Adj. R^2	0.69	0.61	0.85	0.66	0.69

The dependent variable is cash holdings [wc02001] normalized by total assets [wc02999]. Volatility is defined as the standard deviation of hourly electricity prices, normalized by a market's average electricity price level. Flexibility is defined as the generation capacity of gas and oil-fired power plants, scaled by total capacity. Firms are split into low / medium / high flex in Columns 2 to 4 based on their flexible generation capacity. All models are firm fixed effects regressions. Control variables are lagged by one year. T-statistics based on Huber/White robust standard errors clustered by countries are presented in parentheses. ***, ** and * indicate significance on the 1%-, 5%- and 10%-levels, respectively. A detailed description of all variables can be found in Appendix A.

Table 9: Robustness of Operating Flexibility Models to Alternative Specifications

Panel A: Exclusion of Firms with a Particular Technology				
Column	1	2	3	4
Exclude	Nuclear	Coal	Hydro	Solar/Wind
Log(Volatility$_t$)	0.017***	0.025***	0.027**	0.019**
	(3.47)	(5.41)	(2.89)	(2.42)
Flexibility$_t$	-0.032	-0.015	-0.039	-0.00029
	(-1.64)	(-0.80)	(-1.30)	(-0.010)
Log(Volatility$_t$) x flex$_t$	**-0.022****	**-0.031*****	**-0.031****	**-0.026****
	(-2.41)	**(-4.16)**	**(-2.45)**	**(-2.17)**
Controls	yes	yes	yes	yes
Year-FE	yes	yes	yes	yes
Firm-FE	yes	yes	yes	yes
Observations	1,066	534	490	667
Adj. R^2	0.70	0.73	0.60	0.74

Panel B: Production Assets before Deregulation/Privatization				
Column	1	2	3	4
Sample	low flex$_{1995}$	medium flex$_{1995}$	high flex$_{1995}$	all
Log(Volatility$_t$)	**0.014*****	**0.0086**	**0.0069**	0.014***
	(4.27)	**(1.03)**	**(1.63)**	(2.86)
Flexibility$_{1995}$				n/a
Log(Volatility$_t$) x flex$_{1995}$				**-0.036***
				(-2.02)
Controls	yes	yes	yes	yes
Year-FE	yes	yes	yes	yes
Firm-FE	yes	yes	yes	yes
Observations	242	242	241	736
Adj. R^2	0.62	0.53	0.59	0.59

continued on next page

Table 9 continued

The dependent variable is cash holdings [wc02001] normalized by total assets [wc02999]. Volatility is defined as the standard deviation of hourly electricity prices, normalized by a market's average electricity price level. The unreported control variables are identical to those in Table 3.

In *Panel A*, we only consider utilities that do not operate any power plant using the technology specified in each column. In *Panel B*, we replace the contemporaneous values of flexibility with those of 1995. In most countries, electric utilities were state-owned and electricity markets were heavily regulated at that point of time. The U.S. and Japan are different in the context because investor-owned utilities were common in these countries even before 1995. Thus, we exclude firms located in these two countries for this test. $\text{Flexibility}_{1995}$ is time-constant and thus absorbed in the firm-fixed effects regressions.

All models are firm fixed effects regressions. Control variables are lagged by one year. T-statistics based on Huber/White robust standard errors clustered by countries are presented in parentheses. ***, ** and * indicate significance on the 1%-, 5%- and 10%-levels, respectively. A detailed description of all variables can be found in Appendix A.

Table 10: Do Hedging Opportunities Mitigate the Impact of Price Risk on Cash Holdings?

Column	1	2	3	4
Sample	low hedg.	medium hedg.	high hedg.	all
Log(Volatility$_t$)	**0.017****	**0.0052**	**-0.0016**	0.025***
	(2.18)	**(0.64)**	**(-0.41)**	(3.76)
Hedgability$_{avg}$				-
Log(Volatility$_t$) x hedgability$_{avg}$				**-0.041*****
				(-2.99)
Log(assets)$_{t-1}$	-0.023**	-0.0073	0.017	-0.0051
	(-2.47)	(-0.47)	(0.97)	(-0.43)
Cash flow$_{t-1}$	-0.084	0.035	0.12	0.027
	(-1.50)	(0.41)	(1.50)	(0.42)
Leverage$_{t-1}$	-0.020	-0.019	-0.017	-0.017
	(-0.69)	(-0.50)	(-0.51)	(-0.83)
Log(GDP per capita)$_{t-1}$	-0.15	0.083	-0.57	-0.12
	(-1.15)	(0.61)	(-1.40)	(-1.54)
Year-FE	yes	yes	yes	yes
Firm-FE	yes	yes	yes	yes
Observations	400	391	348	1,139
Adj. R^2	0.53	0.75	0.54	0.71

The dependent variable is cash holdings [wc02001] normalized by total assets [wc02999]. Volatility is defined as the standard deviation of hourly electricity price changes, normalized by a market's average electricity price level. Hedgability is the fraction of firms in an electricity market that hedge, averaged across all years between 2000 and 2010. The firm under consideration is ignored for its calculation, and only market-years with at least five observations and markets with at least three years of data are considered. Hedgability is time-constant and thus absorbed in the firm-fixed effects regressions. All models are firm-fixed effects regressions. Control variables are lagged by one year. T-statistics based on Huber/White robust standard errors are presented in parentheses. We cluster standard errors by firms for the sub-sample regressions in Columns 1 to 3 because the number of countries in each group is too small. Standard errors are clustered by countries in Column 4. ***, ** and * indicate significance on the 1%-, 5%- and 10%-levels, respectively. A detailed description of all variables can be found in Appendix A.

Appendix

Appendix A: Definition of Variables

Variable	Description
Main Variables	
Cash	Cash & short term investments [wc02001] scaled by total assets [wc02999].
Volatility	Standard deviation of hourly electricity prices during the firm's fiscal year, normalized by a market's average electricity price level. Electricity prices are in megawatt per US$. Local electricity prices are converted to US$ using daily exchange rates. In most models, the natural logarithm of volatility is used. Source: Own calculations based on hourly electricity prices.
Weather volatility	Standard deviation of daily temperatures during the firm's fiscal year. Daily temperatures are calculated as the average across all weather stations within an electricity market. Only stations with at least 183 annual observations in all sample years are considered. Source: Own calculations based on data from the daily global historical climatology network (cf. Menne et al., 2012).
Market (dummy)	Dummy variable which equals one if a wholesale market for electricity exists in a region and year and zero otherwise. Source: hand-collected.
Flexibility	Generation capacity of gas and oil-fired power plants, scaled by total capacity. Source: Own calculations based on WEPP database.
Hedgability	Defined as the fraction of firms in an electricity market that hedge, averaged across all years between 2000 and 2010. The firm under consideration is ignored for its calculation, and only market-years with at least five observations and markets with at least three years of data are considered. Source: Own calculations based on Lievenbrück and Schmid (2014).
Control Variables	
Assets	Total assets [wc02999] in US$. Source: Worldscope.
Cash flow	Earnings before interest, taxes, depreciation, and amortization [wc18198] / total assets [wc02999].
Leverage	Total debt [wc03255] / (Total debt plus book value of equity [wc03501]).
GDP per capita	GDP per capita (in 2010 US$) in a country and year. Source: Worldbank.
Market-to-book	Market capitalization [wc08001] / book value of common equity [wc03501].
Capex	Capital expenditures [wc04601] / total assets [wc02999] at the beginning of the respective year.
Dividend (dummy)	Dummy variable which equals one if the firm pays a dividend [wc05376].
Inflation	Yearly inflation rate in a country. Source: Worldbank.
Volatility [gas price]	Standard deviation of gas prices during a calender year. Gas prices refer to the prices for industrial customers in US$ per MWh. The frequency of prices is monthly for U.S. states and quarterly for other countries. Source: EIA for U.S. states and IEA for other countries.
Volatility [coal price]	Standard deviation of coal prices during a calender year. Coal prices refer to the prices of steam coal for industrial customers in US$ per ton. The frequency of prices is quarterly. Source: EIA for U.S. states and IEA for other countries.

Definition of Variables - continued

Variable	Description
Alternative Volatility Measures	
$\text{Volatility}_{\text{zero}}$	Standard deviation of hourly electricity prices, normalized by a market's average electricity price level; for regions without a wholesale market for electricity, this variable is set to zero. Source: Own calculations based on hourly electricity prices.
$\text{Volatility}_{\text{price}}$	Standard deviation of hourly electricity prices. Source: Own calculations based on hourly electricity prices.
$\text{Volatility}_{\text{diff}}$	Standard deviation of hourly electricity price changes. Source: Own calculations based on hourly electricity prices.
$\text{Volatility}_{\text{std.diff}}$	Standard deviation of hourly electricity price changes, normalized by a market's average electricity price level. Source: Own calculations based on hourly electricity prices.

Appendix B: Sample Composition: Electricity Markets

Country	**market**	**first year**	**N**
Australia	AEMO_NSW	1999	140,252
Australia	AEMO_QLD	1999	140,252
Australia	AEMO_SA	1999	140,252
Australia	AEMO_TAS	2005	84,395
Australia	AEMO_VIC	1999	140,252
Australia	AEMO_WA	2007	72,456
Austria	EXAA	2002	112,382
Belgium	BELPEX	2007	70,024
Canada	AESO	2000	131,136
Canada	IESO	2002	111,072
Czech Rep.	OTE	2010	43,819
Denmark	Nordpool	1999	139,756
Estonia	NP_EE	2010	41,680
Finland	Nordpool	1999	139,756
France	EPEX_F	2001	114,636
Germany	EPEX_D	2000	127,507
Hungary	HUPX	2010	38,975
India	IEX	2008	56,548
Ireland	SEMO	2008	61,259
Italy	GME	2004	94,238
Japan	JEPX	2005	85,464
Korea	KPX	2001	119,832
Latvia	NP_LV	2013	13,895
Lithuania	NP_LT	2012	22,270
Netherlands	APX_NL	1999	132,971
New Zealand	EMI	1999	139,584
Norway	Nordpool	1999	139,756
Poland	TGE	2000	127,123
Portugal	OMIE_PT	2007	65,777
Romania	OPCOM	2005	83,247
Russia	ATS	2009	53,135
Singapore	EMC	2003	105,192
Slovakia	OKTE	2010	43,824
Spain	OMIE_SP	1999	140,249
Sweden	Nordpool	1999	139,756
Switzerland	EPEX_CH	2006	70,624
U.K.	APX_UK	2003	103,535
United States	CAISO	2010	43,825
United States	ERCOT	2011	35,064
United States	ISONE	2003	103,776
United States	MISO	2006	78,335
United States	NYISO	2000	131,385
United States	PJM	1999	140,256
Total/Avg.		2004	4,119,522

continued on next page

Table Appendix B continued

This table presents an overview on the electricity markets. Reported are the first year for which data is available (the start year for the data collection is 1999), and the number of observations (N) in a market. The last year for which data is available is 2014 for all markets.