Factors Affecting Renters' Electricity Use: More Than Split Incentives

Rohan Best,[a] *Paul J. Burke,*[b] *and Shuhei Nishitateno*[c]

Understanding potential renter effects on electricity consumption is important for a number of reasons. Renters tend to be relatively disadvantaged from a socioeconomic perspective. If renters had improved access to more efficient appliances and installations, less electricity consumption and expenditure would be required to achieve any given level of utility, which would help to alleviate financial stress. Lower electricity consumption would also help to reduce emissions of carbon dioxide and other pollutants. Well-designed policy to pursue these objectives requires knowledge of the channels and magnitudes involved.

We quantify the relationship between renting and household electricity use in the United States (U.S.). We also consider the effects of particular channels through which renting may lead to excess electricity use. This includes split incentives relating to energy efficiency and consumption, and also factors related to household behavior and higher dependence on electrical heating among renters. The paper also quantifies the effect of renting on uptake of various types of electrical appliances and on some relevant behavioral variables. Data are from the nationally representative 2015 U.S. Residential Energy Consumption Survey.

The paper finds that a negative unconditional effect of renting on electricity use turns into a positive conditional effect when suitable control variables are included. Specifically, renting households on average consume around 9% more electricity per household than non-renters after controlling for a vast array of socioeconomic factors and for quantities of electrical appliances that are less prevalent among renters. This finding is larger than those from some earlier studies of U.S. household energy consumption that included fewer control variables. The paper also finds that none of the channels via which the renter effect operates are dominant. Contributors to the phenomenon include differences in energy efficiency, bill payment responsibility, behavior, natural gas usage, and appliance and equipment quantities.

This attempt to understand the channels leading to excess electricity use by renters can help policymakers have a better idea of how much of the effect relates to split incentives. Approaches to address split incentives such as seeking to move towards greater self-payment of electricity bills have some potential to reduce residential electricity use. Policy approaches may also be able to better target issues such as the undersupply of energy-efficient installations in rented properties. Policy plans would ideally be developed in a context-specific way and consider equity issues.

a Department of Economics, Macquarie University, NSW 2109, Australia. Email: rohan.best@mq.edu.au.

b Crawford School of Public Policy, Australian National University, ACT 2601, Australia.

c School of Policy Studies, Kwansei Gakuin University, Hyogo 669-1337, Japan.

Statistical Arbitrage and Information Flow in an Electricity Balancing Market

Derek W. Bunn[a] and Stefan O.E. Kermer[b]

In progressing towards more efficient competitive electricity markets, the liberalizing intent has generally been to replace central control with price signals and markets wherever possible. This is becoming the norm in forward, day ahead, and intraday trading, but in the provision of real-time balancing, progress in this direction has been more cautious. Market participants should be obliged to keep to these real-time nominations, either through central control or motivated to do so by the application of penalties on their imbalance volumes. However, it is an open question if further liberalization, involving a relaxation of this obligation in order to permit or even encourage a degree of participant imbalance would be beneficial, and if so, how might market participants manage their operations accordingly.

To motivate our analysis of the benefits or otherwise of statistical arbitrageurs operating in the balancing and settlements process, we firstly record a “natual experiment” in the progressively liberalized evolution of balancing arrangements in the British wholesale market. In 2015, the dual settlement system was changed to a single price, mainly to provide a clearer signal for the provision of flexible reserve capacity and innovative services. The system imbalance volumes for the “non-physical traders” in particular started to increase substantially. Furthermore these non physical traders achieved a profitability of about £10/MWh, or a profit margin of about 20% on the average power exchange prices at the time.

Motivated by this circumstantial evidence, the research in this paper seeks to analyse the potential effectiveness of this statistical arbitrage more formally. We specify optimal decision-making by physical and non-physical participants on the basis of realistic ex ante forecasts. By means of quantile regressions we predict the conditional distribution of the system imbalance and presume that these participants will take optimal expected value positions on deliberate imbalance spillage or shortage. We consider two different players, a physical part-loaded thermal player who has nominated a production schedule before gate closure and who is able to adapt production output and a non-physical player which is a trading company who is active on the wholesale power exchange (EPEX Spot) but does not physically control production or consumption after gate closure. To undertake a back-testing analysis and evaluate the system behaviour based on measured system imbalance data, out-of-sample simulations of the statistical arbitrage trading was caried out.

The standout results are that both the physical and non-physical agents make profits through opportunistic imbalancing. Whilst the actions of the physical player were beneficial in reducing total system costs and therefore welfare enhancing from both producer and consumer perspectives, the nonphysical player’s effects were more detrimental to the system. Furthermore, we find a tendency towards short positions for both the physical and nonphysical players, and this is despite the underlying market circumstances that more than 50% of the settlement periods were already short.

The flow of information is a key aspect of the microstructure and trading performance. Therefore, we also studied the effect of information time delays on the stability of the system with time lags between 15 and 120 minutes in contrast to the existing market rules for information flow. We observed that the detrimental system performance of the nonphysical player was due to its

a Corresponding author: London Business School, Regent’s Park, London NW1 4SA UK. dbunn@london.edu

b Energy Economics Group, Technical University, Vienna

longer information lag (60mins and more) and furthermore that if the lags can be shortened, it can provide even more system benefits than the physical player.

We conclude that market liberalisation to permit agent optimisation of imbalance positions with timely information below 30 minutes appears to be beneficial to the system as well as for the agents, whether physical or speculative. Furthermore, the case for more timely and transparent information on the state of the system is supported by our analysis.

The market design implication is that consideration should be given to reducing the extra information lags required for non-physical compared to physical players, as this would be highly beneficial. With a well-designed imbalance settlement price settlement process and timely information flows, agents can thus be incentivised to contribute to stabilizing the power-system, and speculation on the imbalance market should not be discouraged.

Emission Pathways towards a Low-Carbon Energy System for Europe: A Model-Based Analysis of Decarbonization Scenarios

Karlo Hainsch,[a] Thorsten Burandt,[b] Konstantin Löffler,[c] Claudia Kemfert,[d] Pao-Yu Oei,[c] and Christian von Hirschhausen[c]

Overview and Motivation

The European Union (EU) has declared several climate goal targets, which should lead to an energy system with almost no greenhouse gas (GHG) emissions until 2050 (European Comission 2018). While the focus of the scientific community in recent years was heavily set on decarbonizing the electricity sector (Gerbaulet et al. 2019; Child et al. 2019), an integrated approach of including all energy sectors (power, heat, and transportation) offers the benefit of capturing interdependencies between them. Therefore, the European Commission (2018) uses the PRIMES framework, an energy system model, to analyze possible pathways for the European energy system. However, the framework shows a substantial lack of transparency with respect to model setup and data, which impedes further analyses and verification. Our work aims to bridge that gap, providing insights from the Global Energy System Model (GENeSYS-MOD) about the European energy system under different climate scenarios.

Methods

This paper presents different scenarios based on the regional distribution of the available CO_2-budget to keep the global mean temperature well below 2° Celsius. To analyze these scenarios, the "Global Energy System Model" (GENeSYS-MOD) by Löffler et al. (2017) is used. GENeSYS-MOD is a full-fledged energy system, originally based on the existing "Open Source Energy Modelling System" (OSeMOSYS) created by Howells et al. (2011). The model uses a system of linear

a Corresponding author. Workgroup for Infrastructure Policy, Technische Universität Berlin. Send correspondence to Workgroup for Infrastructure Policy, Secretariat H33, Straße des 17. Juni 135, 10629 Berlin, Germany. E-mail: kh@wip.tu-berlin.de.

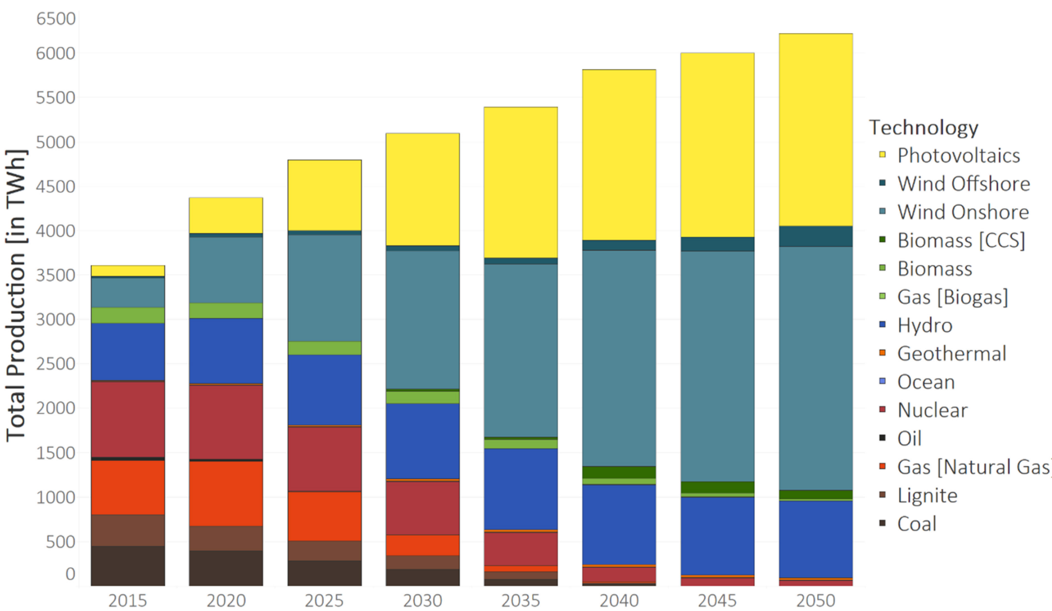
b Workgroup for Infrastructure Policy, Technische Universität Berlin, Department of Energy, Transport, Environment, German Institute for Economic Research (DIW Berlin), and Department of Industrial Economics and Technology Management (IØT), Norwegian University of Science and Technology (NTNU).

c Workgroup for Infrastructure Policy, Technische Universität Berlin and Department of Energy, Transport, Environment, German Institute for Economic Research (DIW Berlin).

d Energy Economics and Sustainability, Hertie School of Governance, Department of Energy, Transport, Environment, German Institute for Economic Research (DIW Berlin), and German Advisory Council on Environment(SRU).

equations of the energy system to search for lowest-cost solutions for a secure energy supply, given externally defined constraints on GHG emissions. In particular, it takes into account increasing interdependencies between traditionally segregated sectors, e.g., electricity, transportation, and heating. For our approach, we aggregated European countries into 17 geographic regions, calculating energy- and resource-flows to meet power, heat, and transport demands. The installed capacities in 2015 serve as a starting point for further investment, production, trade, and salvage decisions which are calculated by the model. Several European limits of emitting CO_2 corresponding to common emission pathways (1.5°C, 2°C, BAU) are analyzed. The BAU case assumes a carbon price, while the climate goal scenarios set carbon budget constraints in line with the respective goal. In these latter cases, we also apply different distribution mechanisms of said budgets to the modeled regions based on economic indicators (free distribution, by GDP, by population, and by current emissions).

Figure 1: Development of European power generation in the base scenario (2°C without national budgets); Source: Own illustration



Results

As a result, in the base scenario, we were able to model a possible path towards a renewable and almost climate-neutral European energy system in 2050 which would be in line to keep global mean temperature below 2° C. This implies the phase-out of fossil fuels, which happens at different rates for the power, heating, and transportation sectors. The power sector is leading the change to renewables since the electrification of the other sectors is only beneficiary if the required electricity is produced through clean technologies. A significant reduction of fossil-fuel based power generation is required within the next ten years. Both the heating and transportation sectors experience a slower rate of change, depending on the regional configuration of the power sector. 90% of the remaining available emissions are emitted until the year 2035, after which the difficult to decarbonize processes in the high-temperature heating, as well as means of transportation, are tackled. As expected, a stricter carbon budget in line with a 1.5° C target results in a quicker decarbonization of the electricity sector. In contrast, a BAU pathway still shows conventional technologies in 2050, especially in the high-temperature heating sector. While limiting global warming to less than 1.5° C results in a cost increase of roughly 25% compared to 2° C, the BAU scenario barely outperforms said 2° C scenario by 3%, even though the assumed carbon price is rather conservative.

Conclusions

The paper provides two major contributions: model-based calculations indicate that decarbonization of the European energy system in line with climate goal targets can be economically and technologically feasible. Second, by contributing a significant piece of modeling to the community, open-access with fully transparent code, data, and results, we contribute to the scientific debate and the transparency of analysis, thus strengthening the political debate with scientific substance.

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Financial Stress and Basis in Energy Markets

Niaz Bashiri Behmiri,[a] *Maryam Ahmadi,*[b] *Juha-Pekka Junttila,*[c] *Matteo Manera*[d]

Increased financialization of commodity markets developed the association between financial and commodity markets. Therefore, besides the physical inventories, the changes in financial market conditions became an important influential factor on commodity futures prices. In this study, we suspect that the conventional inventory-based models, only measuring the relationship between the commodities basis and inventory under the theory of storage, are not sufficient to explain and predict the changes in the spread between spot and futures prices, the so-called basis. The goal of this study is to understand the relationship between physical inventory, the US financial stress and the basis in the crude oil, heating oil and natural gas markets before and after increasing commodity financialization.

We examine the role of stress in the US financial markets on the energy commodities interest-adjusted basis during the time span from 1994 to 2018. We find that, only after the 2008 financial crisis, there are evidences for a positive effect from the increasing level of financial stress on the energy market commodities interest-adjusted bases. The effect of inventory remains positive during the whole time period; however, this positive effect gradually declines over time. Hence, after the 2008 collapse, the conventional inventory based models do not fully explain the energy market com-

a Corresponding author. University of Stavanger, UiS Business School, Norway. E-mail: bashiri.niaz@gmail.com.

b University of Milan-Bicocca, Italy.

c University of Jyväskylä School of Business and Economics, Finland.

d University of Milan-Bicocca and Fondazione Eni Enrico Mattei (FEEM), Italy.

modities bases. These results can be due to higher participation of financial investors, specifically hedge funds in commodity futures markets. Moreover, the association between the energy commodities interest-adjusted bases with the changes in financial stress is nonlinear, as the bases reactions to the financial stress are higher in the high financial stress periods. This is more profound in crude oil market than heating oil and natural gas. Moreover, the reactions of the energy commodities interest-adjusted bases to the changes in the level of inventory is nonlinear, as the reactions is lower when the level of inventory is high confirming the theory of storage. Finally, there is an interaction effect between inventory and financial stress, which shows that the strength of the effect of inventory (financial stress) on the energy commodities adjusted-basis depends on the level of financial stress (inventory).

Therefore, after the 2008 crisis, inventories have not been the only driver behind the changes in energy commodities markets bases, as with the growing financial liberalization of commodities, financial market conditions have become an important factor in explaining the behavior of bases in energy markets. This is more evident during higher turbulence in the financial markets. Therefore, variations of the spread between spot and futures prices are not only a signal of scarcity or abundance of the commodities in question. These results are useful for all the energy markets participants, the financial market traders, refiners and other energy users who consider the energy bases variations when making their decisions. In addition, the results are important to policy makers for the part of financial market related shock effects on the real economy, i.e., the energy commodity markets in this case.

National Climate Policies and Corporate Internal Carbon Pricing

Nuno Bento,[a] Gianfranco Gianfrate,[b] and Joseph E. Aldy[c]

While national governments pledged to reduce their greenhouse gas emissions under the Paris Agreement, delivering on these aims will require significant changes in the activities of major sources of emissions such as companies. To drive such changes, companies will need to consider carbon emissions as a cost of production and many companies have begun doing so through internal carbon pricing. We evaluate how national carbon pricing policies influence firm-level internal carbon pricing and corporate emission targets. The goal of this study is to investigate how firms respond to the implementation of a national carbon-pricing regime with respect to the carbon prices they set internally for their decision-making.

We empirically investigate the adoption of internal carbon pricing by major companies reporting to the Carbon Disclosure Project (CDP). A matching estimator enables an appraisement of the effect that climate change policies have in the decision of companies to set their internal carbon prices.

We find that firm-level internal carbon prices are significantly higher in countries explicitly pricing carbon through tax and/or cap-and-trade programs. In particular, we reveal a causal relationship between the national carbon policies in place and the level of internal carbon prices. The treatment effect of having a national carbon pricing policy in place is economically (27 USD per ton) and statistically significant.

a Instituto Universitário de Lisboa (ISCTE-IUL), DINAMIA'CET, 1649-026 Lisboa, Portugal. nuno.bento@iscte-iul.pt (Corresponding author)

b EDHEC Business School, 06202 Nice, France

c Harvard Kennedy School, Cambridge, MA 02138, USA, Resources for the Future, National Bureau of Economic Research, Center for Strategic and International Studies

We further estimate a ''dose-response function'' (DRF) which provides more information regarding the effectiveness of national carbon policies by uncovering heterogeneities in the effects of exposure to various levels of national prices. This model was applied to the case of European countries that are rather consistent from economic, institutional, and cultural perspectives. We observe a general positive relationship, increasing with the treatment between national carbon prices and the adopted ICPs. Considering that there are European carbon regulations in practice like a trading system, this result suggests that international carbon prices can have an impact on the decision of companies to price carbon internally. However, more research is needed on the interplay of national and international carbon pricing in the future.

These findings shed light on how companies are factoring climate change in their decision making and on the drivers that can contribute to the generalization of climate pricing in the economy. Specifically, our findings support the view that national carbon pricing mechanisms lead companies to the adoption of higher internal carbon prices.

Navigating the Oil Bubble: A Non-linear Heterogeneous-agent Dynamic Model of Futures Oil Pricing.

Giulio Cifarelli[a] *and Paolo Paesani*[b]

Focusing on the 2003–2019 period, our paper combines the LPPL methodology to test for the presence of speculative bubbles with the Heterogeneous Agent Model approach to modelling oil prices. In particular, we focus on the bubble-like dynamics, which characterizes the 2007–2009 years according to a large body of recent literature. In view of this aim, our modelling choice may be justified as follows. Under normal conditions, chartists tend to destabilize the market, whereas fundamentalists and hedgers have the opposite effect. This reflects in the presence of constant oscillations in log-differenced prices typical of martingale processes. These oscillations are larger and more persistent if chartists prevail over fundamentalists and hedgers. On rare occasions, however, a different pattern may emerge, with prices moving along explosive trajectories. In our view, this can be related to incorrect interpretation of market signals (or to the inability of trading against the market), especially by fundamentalist speculators, combined with imitation across different categories of heterogeneous agents. When this occurs, positive feedback reactions emerge along with self-reinforced herding of the kind best detected by the LPPL methodology. Based on these considerations, our paper obtains two main results. First, between 2003 and 2019 we detect only one period consistent with the presence of a speculative bubble, between 2007 and 2008. Second, this bubble is set off by fundamentalist speculators who seem to lose confidence in market signals and in their ability to stop the bubble. This reaction reinforces the standard price destabilizing effect caused by chartists over the entire sample period, which hedgers are unable to offset. Our analysis, which controls also for exchange rate and equity market risk perception, confirms that speculation plays a clear-cut destabilizing role over the entire sample period, due to the joint reaction of chartists and fundamentalists. Our results are thus in line with Zhang et al. (2017) and Zhang and Wu (2019) among others.

a Corresponding author. DISEI, University of Florence. Send correspondence to Department of Science of Economics, Via delle Pandette, 9 - 50127 Firenze (FI). E-mail: giulio.cifarelli@unifi.it.

b DEF, University of Rome Tor Vergata. E-mail paolo.paesani@uniroma2.it.

Effects of Carbon Mitigation on Co-pollutants at Industrial Facilities in Europe

Klara Zwickl,[a] Simon Sturn,[b] and James K. Boyce[c]

The combustion of fossil fuels simultaneously releases carbon dioxide (CO_2) and air pollutants such as sulfur oxides (SO_X), nitrogen oxides (NO_X), and particulate matter (PM). More stringent climate policies therefore may generate air quality co-benefits, increasing the overall benefits from carbon mitigation. So far, however, little is known about the relationship between CO_2 and co-pollutant emissions at the point-source level.

Using European data on large industrial point sources from the European Pollutant Release and Transfer Register (E-PRTR), we estimate how changes in carbon dioxide emissions affect emissions of the three co-pollutants SO_X, NO_X, and PM_{10}. Our sample includes between 630 and 2,400 facilities for the years 2007 to 2015. We find substantial and statistically significant co-pollutant elasticities of about 1.0 for SO_X, 0.9 for NO_X, and 0.7 for PM_{10}. The energy sector is characterized by relatively high co-pollutant elasticities of 1.6 for SO_X, and 1.0 for NO_X and PM_{10}.

Identifying climate policy-induced changes in CO_2 emissions based on changes in regulatory stringency, we estimate co-pollutant elasticities in the electricity sector of 1.2 to 1.8 for SO_X, 1.1 to 1.5 for NO_X, and 0.8 for PM_{10}. Combining these results with co-pollutant damage costs obtained from the European Environmental Agency, we calculate the value of air quality co-benefits arising from one ton of CO_2 reduction in the energy sector. The monetized co-benefits (in 2005 EUR) range from 33 to 98 EUR/tCO_2 for SO_X, 9 to 24 EUR/tCO_2 for NO_X, and 4 to 10 EUR/tCO_2 for PM_{10}, with a joint magnitude of 46 to 132 EUR/tCO_2 for the three co-pollutants together. These air quality co-benefits are significantly higher than the European Environmental Agency's estimated climate damage costs of 10 to 38 EUR/tCO_2. These findings would justify substantially higher carbon prices based on co-benefits alone, independent of their climate benefits.

The Impact of Electric Vehicle Density on Local Grid Costs: Empirical Evidence from Norway

Paal Brevik Wangsness,[def] and Askill Harkjerr Halse[g]

We observe a rapid rise in the number of battery electric vehicles (BEVs) in Norway, and there exists a literature that warns that BEV charging will cause substantial future costs to the local grid, unless measures are put in place. If indeed the aggregate uncoordinated charging by BEV owners does induce higher costs to Distribution System Operators (DSOs), then Norwegian data would be the first place to investigate. Detailed data of all Norwegian DSOs and all registered BEVs during the last ten years give a unique opportunity to analyze this relationship. To our knowledge, such an

a Department of Socioeconomics, Vienna University of Economics and Business, klara.zwickl@wu.ac.at

b Department of Socioeconomics, Vienna University of Economics and Business, simon.sturn@wu.ac.at. Also affiliated with: Department of Economics, University of Massachusetts Amherst.

c Department of Economics and Political Economy Research Institute, University of Massachusetts Amherst, boyce@econs.umass.edu

d Institute of Transport Economics – Norwegian Centre for Transport Research, Gaustadalleen 21, 0349 Oslo

e Norwegian University of Life Sciences, Ås, Norway

f Corresponding author. Institute of Transport Economics – Norwegian Centre for Transport Research, Gaustadalleen 21, 0349 Oslo, Norway. Tel.: +47 91699070. E-mail address: pbw@toi.no

g Institute of Transport Economics – Norwegian Centre for Transport Research, Gaustadalleen 21, 0349 Oslo

empirical analysis has not been done before on real data in a country-wide analysis. It will therefore push the knowledge frontier on a debated, but relatively unexplored topic empirically. Findings may have implications for how to regulate DSOs, how to price household power usage and how to assess the net social cost of achieving emission reduction targets through promoting BEVs.

By merging together data from NVE on annual costs of DSOs applied for regulation, their operational area, and data on registered cars at municipal level, we get a unique panel dataset for such analysis. Our data set of 107 Norwegian DSOs outputs, costs and registered BEVs in their operational area between 2008 and 2017 allows us to investigate how BEVs affect DSO costs. Exploiting local differences in the growth of the BEV fleet over time, we investigate how an increase in the number of BEVs affects the costs of the local DSO, using fixed-effects estimation that account for time-invariant characteristics of the DSO. We also control for growth in output indicators that could be correlated with growth in the BEV fleet. We look at both total costs and individual cost components.

We find that increases in the BEV fleet are associated with positive and statistically significant increases in costs when controlling for other DSO outputs and year dummies. The point estimates also imply that the effect is economically significant, with a preferred model giving a cost elasticity of 0.018 from increases in the local BEV stock. This finding is robust to the addition of several controls and removal of outliers. We also find the strongest impact through operational costs, and not capital costs. Although we find significant effects in the national sample, there is a lot of heterogeneity in these results, with the marginal cost estimates being a lot higher for small DSOs in rural areas, and a lot lower for larger DSOs. This heterogeneity also indicates that the BEV-induced costs is not a major problem that has affected a large number of consumers. The half of the sample with the largest DSOs, where the estimated cost elasticity from BEVs was close to zero, serve over 93 % of the customers in the entire sample.

Finding that increased BEV ownership is associated with higher DSO costs, implies that the case for a well-specified peak-pricing system for grid tariffs is strengthened, so that efficient load-shifting is properly incentivized. Many BEV owners would probably respond by installing smart charging systems, which would ease the household cost minimization and ensure more efficient grid capacity utilization, even with small hour-to-hour price differences.

Towards Use of Cleaner Fuel in Urban and Rural Households in Colombia: Empirical Evidence from 2010 to 2016.

Jhon Pérez,[a] Efrain Bernal,[b] and Patricia. Rodríguez-Sánchez[c]

Colombia has close of 6.5 million people or 13% of the population still use traditional solid fuels for cooking. The goal of this paper is to determine the main socioeconomic factors that conducting the cooking fuel preferences of Colombian households during the years 2010 to 2016. We developed a theoretical framework based on cooking fuel preferences of households in Colombia according to consumer's utility function. With this structure, we use a Multinomial Logit Regression (MLR) model using categorical variables to identify socioeconomic aspects. For empirical analysis from the Colombia Living Standard Survey (CLSS) conducted in the years 2010 and 2016. There-

a Corresponding author. Faculty of Engineering. La Salle University, Block C, Floor 7th, Bogotá D.C.- Colombia. E-mail: jjperez@unisalle.edu.co.

b Faculty of Engineering. Block C, Floor 7th, Bogotá D.C.- Colombia. La Salle University.

c Business Administration Program. Bogotá D.C.- Colombia. Universidad Militar Nueva Granada.

fore, was necessary to develop several maps related to the evolution of cooking fuel usage in rural, intermediate cities, and urban areas.

We checked the patterns of cooking fuel choice in Colombia by using CLSSs conducted in the years 2010 and 2016 and their relationship with the evolution of usage and selection of cooking fuels and were identified various socioeconomically significant variables such as type of household (mainly apartment and room); household property rights (mainly own and paying); household income and educational level of household head (all categories). At last the paper presents a discussion related to energy policy implemented in Colombia for substitution of fuels for cooking in rural areas, intermediate cities and urban areas. Further we explained the energy policy applied in Colombia in rural, urban and rural households in relationship to the energy transition. Reducing the use of solid fuels by modern fuels.

This paper contributes with the literature specially due there are few works in the literature related to the selection of cooking fuel, especially in the Andean countries (Colombia, Venezuela, Peru and Bolivia). Therefore, in the application of energy policies in developing countries regarding to substitution and fuel massification of cleaner fuels and its implications in socioeconomic factors. The results reveal that an increase in the level of education multiplies the odds of choosing NG over any other cooking fuel. Policy makers need to address the problem of investment in the implementation of renewable energies, which they are higher than traditional ones.

Market Design Considerations for Scarcity Pricing: A Stochastic Equilibrium Framework

Anthony Papavasiliou,[a] Yves Smeers,[b] and Gauthier de Maere d'Aertrycke[c]

Motivation. Scarcity pricing is currently being discussed in Europe as an alternative or complement of capacity mechanisms for supporting the provision of reserve services from flexible resources. This is reflected in various policy documents published by the European Commission and European Parliament, including the Clean Energy Package and the European Balancing Guideline. However, the implementation of scarcity pricing in the form of Operating Reserve Demand Curves (ORDC) in European electricity markets requires a careful consideration of the difference in fundamental principles between U.S. and E.U. market designs, and specifically (i) the role of balancing as a service, (ii) the role of virtual trading, and (iii) the co-optimization of energy and reserves. These differences in E.U. and U.S. market design principles affect the ability of scarcity prices based on ORDC to back-propagate to day-ahead and other forward markets, and thereby provide a robust investment signal for flexible resources. The present paper presents a stochastic equilibrium framework for describing a spectrum of market design options between the current E.U. market design and an ideal U.S.-style two-settlement system. These models are used for conducting a numerical analysis of the Belgian electricity market. This analysis provides the basis for a concrete proposal of market design changes in the Belgian electricity market that aim at ensuring that scarcity pricing can back-propagate to forward markets and appropriately signal investment in flexible capacity.

Performed Research. We develop a stochastic equilibrium framework for analyzing two types of arbitrage that allow scarcity pricing to remunerate flexible resources for reserve services: the arbitrage between energy and reserve capacity, and the arbitrage between real-time prices and

a Corresponding author. Center for Operations Research and Econometrics, Univeristé catholique de Louvain, Belgium. Email: anthony.papavasiliou@uclouvain.be.

b Center for Operations Research and Econometrics, Univeristé catholique de Louvain, Belgium.

c Center for Economic Expertise, Modelling, and Studies, Tractebel/ENGIE.

day-ahead prices. This stochastic equilibrium framework relies on coherent risk measures, and is sufficiently flexible to capture a wide range of differences in market design principles that exist between U.S. and E.U. markets. The motivating question for our analysis is the following: "can we introduce scarcity pricing, which is inspired by a U.S. design, to E.U. markets, or do we require additional changes in the E.U. design in order for scarcity pricing to be effective"? We use our stochastic equilibrium framework in order to make this motivating question more specific: In order for scarcity pricing to be effective: (i) Do we need to trade reserve capacity in European real-time markets? (ii) Do we need to introduce virtual trading in Europe? (iii) Do we need to co-optimize energy and reserve in European day-ahead markets?

We apply our stochastic equilibrium framework in order to represent these increasingly disruptive reforms of the European market. We apply our model to a case study of the Belgian market for the time interval from September 2015 until March 2016. Due to the large size of the model, we present our analysis in a risk-neutral setting, which can be solved equivalently as a stochastic program. We focus our analysis on the back-propagation of scarcity prices to the day-ahead market, and the resulting effect of scarcity pricing on flexible generators (specifically 8 CCGT units in Belgium) and flexible consumers.

Conclusions. Our analysis produces the following observations: (i) The introduction of a real-time market for reserve capacity, which is the least disruptive measure towards implementing scarcity pricing in Europe, restores the financial viability for CCGT units in Belgium, and creates opportunities for loads to offset the increase in energy prices that results from the introduction of scarcity pricing. (ii) Virtual trading and the co-optimization of energy and reserve in day-ahead market clearing have a lesser effect on reserve and energy prices once a real-time market for reserve capacity has been put in place. These measures are also fairly disruptive interventions to E.U. market design. On the basis of these observations, our analysis produces a concrete policy recommendation: (iii) The introduction of a real-time market for reserve capacity in Belgium is a pragmatic no-regret measure towards setting up a European real-time market that can value reserve services accurately, and has been recommended for implementation to the Belgian regulator.

Potential Benefits, Applications, and Policy Implications. The modeling framework that has been developed in the present paper is a novel application of stochastic equilibrium beyond long-term models of investment to short-term models of electricity market clearing. The framework has been shown to be highly agile, and useful in providing guidance regarding the design of short-term (day-ahead and real-time) electricity markets. Our modeling framework allows us to highlight the challenge of properly remunerating flexibility as a result of the fact that real-time markets for reserve capacity are absent in Europe. Steps towards the implementation of scarcity pricing in Belgium that have resulted from the analysis include: (i) the issuing of a report on behalf of the Belgian transmission system operator that back-calculates ORDC adders for 2017, as they would have occurred based on telemetry measurements of the Belgian Available Reserve Capacity; (ii) the publication of scarcity pricing adders by the Belgian transmission system operator, effective October 2019; and (iii) the launch of a public consultation by the Belgian transmission system operator regarding the market design proposal of the present paper.

The Profitability of Energy Storage in European Electricity Markets

Petr Spodniak,[a] *Valentin Bertsch,*[b] *and Mel Devine*[c]

Variable renewable energy sources (vRES) have been rapidly penetrating the markets and increasing the volatility of the residual load, which intuitively suggests that energy storage requirements in the system increase. We therefore study the profitability of energy storage exploiting the temporal price variations in three European electricity day-ahead markets in the period 2006–2016, a period during which significant investments in vRES took place across Europe. More precisely, we disentangle the main drivers of profitability (contribution margins) and operation (operating hours) of differently sized energy storages (1–13 MWh/MW) and focus on the effects of wind and solar generation, electricity demand, carbon emission prices and the price differential between coal and gas commodities. We analyse both operational storage profits and storage operating hours since operating hours are a good indicator for the system's storage capacity requirements, whereas the operational profits are a good indicator revealing whether the markets as they exist today reward storage capacity. Studying both together allows for identifying potential misalignments between system needs and market design.

Our methodological approach combines optimisation and econometrics. We are therefore able to abstract from restrictive technological and cost assumptions associated with specific storage technologies. In our analysis, we focus on (i) the evolution of the contribution margins of energy storages with different storage volumes (the different storage volumes mimic the real-world technologies, such as batteries or pumped hydro, serving different purposes in the energy systems). Subsequently, we carry out an econometric analysis to understand the main fundamental drivers behind the evolution of (ii) the contribution margins and (iii) the operating hours of the considered storages.

Our main findings can be summarised as follows:

1. We empirically show that the operational profits expressed as contribution margins declined over the studied period 2006–2016 in Germany and the UK and exhibit high intra- and inter-annual variability in the Nordics;
2. Under today's market conditions, only the smallest considered storages would be needed, which mainly balance hourly variations and also that these would only become profitable in the studied wholesale markets if storage costs can be decreased strongly;
3. Electricity demand is a significant positive driver of profits across the studied markets and storage sizes, which is also the case for the gas-coal spread in Germany and the UK;
4. Wind generation is associated with increasing profits and number of operating hours in Germany, which we argue is due to its innate nature of variability and lower predictability;
5. Solar power generation in Germany is associated with a positive effect on the number of storage operating hours but, particularly for the larger storage sizes, with a negative effect on profits, i.e. despite the greater number of storage operating hours, storage

a Corresponding author: Economic and Social Research Institute (ESRI) & Trinity College Dublin (TCD). Dublin, Ireland. E-mail: petr.spodniak@gmail.com

b Economic and Social Research Institute (ESRI); Department of Energy Systems Analysis, German Aerospace Center (DLR); Chair of Energy Systems and Energy Economics, Ruhr-Universität Bochum.

c UCD Energy Institute, College of Business & School of Electrical and Electronic Engineering, University College Dublin (UCD).

operators gain lower profits in Germany as solar PV generation increases. This finding underpins the necessity to explicitly consider both profits and operating hours in our analysis.

Our findings may be of use for policy makers, investors or storage technology developers in a number of ways. In general, the declining operational profits of energy storages should point out to the fact that the markets do not send any investment signals, suggesting that there is no additional requirement for energy storages so far and that the current power markets are sufficiently flexible. At the same time, however, the finding that solar PV generation has a positive effect on storage operating hours in Germany implies that the storage requirements in the system increase. Together, these two findings indicate a potential misalignment between system requirements and market rewards. Policy makers need to monitor the development of the existing electricity markets to be able to identify needs for modification in due time. For storage technology developers our sensitivity analysis on storage costs is a useful basis to derive a target invest. Overall, our analysis shows the uncertainty potential investors are confronted with and what drivers are most relevant.

Transmission Integration and the Market for Congestion Revenue Rights: The Case of the Texas Electricity Market

Gaurav Doshi,[a] and Xiaodong Du[b]

This paper looks at the effect of transmission expansion on the market of Congestion Revenue Rights (CRR) in the Texas electricity market. CRRs are financial contracts that enable the holders (e.g., generating companies and retailers) to hedge the risk due to transmission congestion costs in the Day Ahead Market (DAM). CRRs also serve as a financial instrument used for speculative purposes by various market players such as financial traders. Our paper answers the question about how the addition of electricity transmission lines affects the prices of CRR? We also measure how this effect varies across different times of the day and spatial locations? We provide empirical evidence by analyzing the effect of transmission expansion due to Competitive Renewable Energy Zones (CREZ) on the CRR prices at different Times of Use (ToU) and spatial locations.

A brief overview of the analysis and main findings is as follows:

- We conduct a spatial heterogeneity analysis by estimating the effect of transmission expansion for CRRs across different spatial locations. We find that the CREZ induced drop in prices is most pronounced for CRRs associated with West zone. This effect is consistent across Peak Weekday, Peak Weekend, and Off Peak.
- We also find evidence of distributional heterogeneity in the effect of transmission expansion. The decline in prices is primarily driven by CRRs that were historically (prior to CREZ) at third and fourth quintile of CRR price distribution.
- We also discern the differential effects of CREZ on CRR prices across different firm types: generating firms, retailers, and financial traders. Analysis reveals that the drop in prices is largest in magnitude for generators followed by retailers and then by traders. These effects are due to different incentives and strategies adopted by various firms in the Texas electricity market.

a Corresponding author. Department of Agriculture and Applied Economics, University of Wisconsin Madison, 427 Lorch St., Madison, WI 53706, United States of America. E-mail: gdoshi2@wisc.edu.

b Department of Agriculture and Applied Economics, and Renk Agribusiness Institute, University of Wisconsin Madison. E-mail: xdu23@wisc.edu.

- Finally, we find convergence in prices for CRRs between West and other zones which is indicative of increase in efficiency of the CRR market.

The results on price convergence and heterogeneity in the effects of transmission integration are informative about the efficiency of wholesale electricity market. Convergence of CRR prices across different locations limit the ability of market participants to accrue profits from speculative behavior in the CRR market. Several years since CREZ, congestion continues to increase across different zones in the Texas electricity market. Recognizing this, ERCOT has been investing in transmission lines across the state. Our findings shed light on how these investments in transmission capacity would affect the CRR market as well as the strategic behavior of different market participants.