VOLUME 41
NUMBER 2
MARCH 2020

ENERGY ECONOMICS EDUCATION FOUNDATION, INC.

ISSN 0195-6574
E-ISSN 1944-9089

THE ENERGY JOURNAL

EXECUTIVE SUMMARIES

IAEE
WWW.IAEE.ORG
INTERNATIONAL ASSOCIATION *for* ENERGY ECONOMICS

Optimal Storage, Investment and Management under Uncertainty: It is Costly to Avoid Outages!

Joachim Geske[a] *and Richard Green*[b]

Electricity storage facilities can arbitrage between periods of low and high prices, and can also substitute for conventional generation capacity. A storage unit will be a poor substitute if it does not hold enough energy when its output is actually needed, however. In an uncertain world, this implies holding a buffer of energy that will probably not be used, but many electricity models assume that the storage operator has perfect foresight and can fine-tune its discharges to the actual needs. Even models that represent uncertainty through a range of possible scenarios tend to assume perfect foresight within each scenario.

We present a model in which uncertainty is represented as a Markov Chain: given the demand (net of variable wind and solar generation) in one period, we know the probability with which it can take each possible level in the following period, and so on. These probabilities depend on the time of day, and could vary with the season. We have estimated these probabilities from five years of data for Germany, rounding each level of demand to the nearest 5 GW. Cost and generator output estimates derived from this Markov representation of the data are close to those from the original data.

Taking the level of storage and generation capacity as given, we can calculate the amount of charging or discharging that minimizes the expected cost of generation for each possible combination of demand, level of stored energy and time of day. It is optimal to aim to keep a large amount of energy in storage in order to minimize the risk that low storage levels coincide with high demands that cannot be met from generation alone. The amount of energy to be kept in this storage buffer is highest at the start of the daytime hours (when a sequence of high demands are expected to follow) and lowest in the evening (since overnight recharging can be expected).

The pattern of storage operations determines the duration curve for generation – the number of hours that each tranche of capacity can expect to operate for. Our algorithm selects the combination of power stations that would minimize expected costs, given this duration curve. The cost-minimizing combination can include allowing load to be lost in the event of high demand and a depleted store, as long as this does not happen too often. If this combination is different from the one against which operating decisions were made, the process is re-run until it converges.

We calibrated our model with the German load data and contemporary generation cost estimates. We found that 300 GWh of electricity storage (with a power capacity for charging and discharging of 30 GW) could replace 15 GW of generating capacity. There was an increase in base-load capacity and in the kind of mid-merit capacity that was optimal for a load factor of 50-70%, with reductions in peaking capacity and the types that had the lowest cost for load factors of around 80% or 30%. The expected total cost of generation fell by nearly 5%.

We found that this cost saving was not very sensitive to the amount of either energy or power capacity that storage had, at least over the range of values we considered. In other words, the first 150 GWh of storage energy capacity was worth €6.3/kWh per year, but the marginal value of

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a second 150 GWh was just €1.9/kWh per year, and that of a third tranche (taking the total energy capacity to 450 GWh, but keeping power capacity at 30 GW in each case) fell to €1.4/kWh per year. Reducing the power capacity to 10 GW, while holding energy capacity constant at 300 GWh, cut the average value of storage from €4.1/kWh per year to €3.7/kWh per year.

To estimate the impact of uncertainty, we ran the Markov process 100 times to give 5-year sequences of hourly demands, assumed that the system operator had perfect foresight, and found the optimal storage and generation decisions for each sequence. The cost saving from storage rose to just over 6%. The expected value of storage under uncertainty is 27% lower than this, suggesting that perfect foresight models give significant over-estimates. We are currently working to refine our model to take account of short-term forecasts and include seasonal variations in the pattern of demand.

Electricity markets need to give adequate incentives for storage operators to keep enough energy in reserve, if they are to be used to replace capacity at power stations. The "energy-only market" paradigm is based on the idea that the prospect of occasional high prices provides adequate incentives for rarely-used capacity. The "precautionary storage" that is optimal in our model, holding back energy despite profitable short-term arbitrage opportunities, can be seen as a kind of arbitrage against the extreme prices occasionally seen during shortages. An alternative is to include storage in a capacity market, as is already done in Great Britain. The British rules de-rate the unit's power capacity to take account of the risk that it will not have enough energy in storage when it is needed. A better solution might be to require the unit to keep its state of charge above a (time-varying) "threshold" level unless it obtains permission or is instructed to discharge.

Time Commitments in LNG Shipping and Natural Gas Price Convergence

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Liquefied Natural Gas (LNG) is set to become an important part of global energy trade. Traded volume has been consistently growing over time, with 2018 being another record year. Despite its growing importance, there is still limited evidence that LNG has contributed significantly to improving cross-regional natural gas market integration.

The US shale gas revolution and the Fukushima incident have highlighted the compartmentalized nature of natural gas markets. These events have revealed how economic costs of LNG trade are positively related to the regional natural gas price spreads, which reduces profitable trade opportunities. One reason for this is lumpy and time-consuming investments in trade infrastructure (regasification, liquefaction, and shipping), which makes supply of LNG transportation capacity inelastic in the short run.

The purpose of this paper is to investigate the additional economic cost of LNG shipping that arises from time commitments in shipping. This cost element has, to the best of our knowledge, not previously been highlighted in the literature. We show how time commitments introduces an additional component to the economic shipping cost that is positively related to cross-market natural gas price spreads. The paper highlights how owning an LNG ship is equivalent to owning a recur-

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ring American call option on the price spread between destination and home market, with a strike price equal to the direct transportation cost. We then show how optimally exercising the option requires natural gas price spreads that exceeds direct transportation costs. This wedge contributes to weaken the ties between natural gas markets.

Empirically, we use a measure of LNG freight rates to show that while accounting for the direct freight cost improves measures of cross-regional natural gas prices convergence, the freight cost alone still leaves a considerable part of spreads unexplained. We then show that for the EU-US LNG route, a reasonable parameterization of time-commitment costs in LNG trade can produce an economically sizable additional time commitments cost.

The paper does not to present a full-fledged optimization model for LNG transportation, or a detailed technical model of the full cost of LNG shipping. Rather we highlight and investigate the additional economic cost due to time commitments. This does not exclude the importance of other cost elements. In addition, although the necessary time commitment in shipping will vary across routes and ships, a large time commitment is a general feature of the LNG shipping economy. A large part of the LNG freight is inter-continental and takes considerable time both to make the original voyage, and to re-position the vessel to make the next voyage.

The question of the economic cost of LNG trade is highly relevant to the future role of natural gas as a competitive part of the global energy supply. It is relevant to the question of reducing EU's reliance on Russian pipeline gas, and the potential impact of the US-China trade war on the competitiveness of US LNG in Asia. The time commitment cost proposed in this paper reduces competitiveness of long-haul LNG trade relative to natural gas pipeline supply. This is relevant to the question of how cheap US natural gas needs be to compete with Russian pipeline supply, and the impact of possible tariffs on US LNG imports to China. China is a growing LNG market, in 2018 it accounted for 16.7% of LNG imports. The results in this paper highlight that for LNG trade, shipping costs vary according to market conditions and time commitment cost can add to the economic shipping cost of LNG.

Spatial Effect of Wind Generation and Its Implication for Wind Farm Investment Decisions in New Zealand

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To achieve a low-emission economy transition, the New Zealand Government aims to lift the share of electricity generated from renewable resources from 80% to 90% by 2025. Electricity generation in New Zealand is hydro-dominated, with around 57% of electricity generated by hydro during 2011-2014. Since the future expansion of hydro capacity is limited and no solar resource is available to meet the peak demand in winter evenings, wind power could contribute as much as 20% of electricity if the government's target of 90% is to be achieved.

In this paper, we apply a spatial fixed effects bias-corrected Durbin Model (SDM) to estimate the merit-order effect (MOE) of wind penetration. By establishing the geographic location of wind farms we estimate the spatial impact of wind generated electricity at the grid injection point and neighbouring nodes, controlling for competing sources of electricity.

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The paper's main contribution follows from the application of the spatial Durbin (SDM) model to estimate the spatial spill-over and temporal effects of wind penetration on nodal prices. We find a negative and significant relationship between nodal prices and wind penetration. Ignoring spatial spill-overs leads to an underestimation of the impact of wind generation on nodal prices. Increased wind-generated electricity injected into the grid lowers nodal price. Furthermore, surplus wind-generated electricity can be exported to neighbourhood nodes, which reduces the nodal price. The total effects of a 10% point increase in wind penetration on nodal prices are a reduction of $0.92 per MWh at 4am, and $3.55 per MWh at 6pm. These effects are statistically significant. Based on estimates from the SDM model, we further find that CNI2 is the best wind site for expanding wind capacity, offering a net savings of $8 million per MW wind generation installed. Development at TIW is the worst option because it results in a net loss of $0.7 million.

Our findings have policy implications for electricity system design and wind deployment. Adding more intermittent wind generation into the electricity system will create challenges for the system operator and market participants. Adding more intermittent wind generation will increase the volatility of nodal prices. Closure of the Huntly thermal power station will increase the risk of supply disruption. The addition of more wind generation could lead to a need for more flexible peaking plants. Because those peaking plants only generate for a short period and maintaining those plants are expensive, this may lead to the debate on the need for a capacity market. Battery storage, hydro development, increased uptake of solar and demand response could contribute to balancing supply and demand. From the perspective of commercial investment in wind farm development significant negative spill-over effects indicate that scalability would be a big advantage. However, in an electricity market that receives no subsidies private investment must be financially variable. The findings provide valuable financial information when evaluating the location of development options. The ability of spatial econometric models to provide quantitative estimates of spill-over magnitudes and to allow statistical testing for the significance of these represents a valuable contribution of spatial models to understanding and forecasting regional electricity prices, and locating financially feasible wind sites. This methodology will be applicable to analysing the cross-border effects in any electricity system that has opportunities to export or import electricity from neighbouring countries, such as Switzerland or Germany.

Renewable and Nonrenewable Energy Consumption, Economic Growth, and Emissions: International Evidence

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The growing threat of global warming, concentration of greenhouse gas emissions in the atmosphere, and climate change is a topic of global importance. In particular, it is important to find ways to mitigate their effects while finding alternative ways to meet rapidly growing energy demand worldwide. In this context, sustainable development and use of renewable energy resources has been at the forefront of energy policy in many countries that hope to contribute toward the global goal of reducing greenhouse gas emissions.

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While there is a large empirical literature on the energy-growth nexus and the relationships between emissions, energy and growth, there are no studies that employ a global sample and very few studies that separately examine the effects of renewable and nonrenewable energy sources. The lack of global studies and separate consideration of renewable and non-renewable energy in the energy-emissions-economic growth literature is partly due to the lack of data on renewable energy resources for a significant number of countries. Furthermore, many studies ignore key structural factors underlying the relationship between emissions, energy, and income. These factors can hinder the ability of a government to tackle environmental degradation. Such institutional factors include bureaucratic inefficiency, the influence of special-interest groups, and the resistance of state-owned enterprises.

Against the above background, this study sets three objectives. First, it examines how renewable and nonrenewable energy sources influenced the level of economic development in a global sample of countries of varying income levels. Second, this study investigates how renewable and nonrenewable energy sources impact the level of greenhouse gas emissions in the global sample, controlling for income and other factors. Third, this study analyzes whether the level of economic development affects the effect of renewable and nonrenewable energy sources on the level of greenhouse gas emissions. To do so, the global sample is separated into subsamples of countries at different levels of development using a panel approach. This study employs a panel data of a global sample consisting of 102 countries, from 1996 to 2012.

In our baseline model, we take into account the impact of country-specific institutional quality, measured by the national economic freedom index. While a handful of studies have documented the critical relationship between economic freedom and renewable energy deployment as well as environmental quality, this variable has not received adequate attention in empirical studies on renewable energy and pollutant emissions. For emissions, total greenhouse gas emissions are used as the main proxy. For completeness and robustness check, this study also employs two other proxies - nitrous oxide (N_2O) emissions and carbon dioxide (CO_2) emissions since these gases are the major sources of greenhouse gas emissions at the global level.

The study's three main findings are as follows. First, the consumption of both renewable and no-renewable energy appears to promote economic growth for both developed and developing economies. Second, the use of non-renewable energy consumption significantly raises the level of emissions across different income groups of countries. Meanwhile, renewable energy appears to help developed countries contain carbon emissions. In other words, renewable energy has been effective for controlling carbon emissions in developed countries. Third, developing countries have not been successful in containing carbon emissions through renewable energy. Our findings are relatively robust to different estimation methodologies, different measures of renewables, and different types of pollutant emissions.

This study also finds that while governance appears to effectively curtail the level of emissions in developed countries, it seems to have insignificant effects on reducing emissions in middle- and low-income countries. This implies that developing and emerging countries have relatively weak environmental policies that need to be strengthened.

The findings of this study have several implications. First, promoting renewable energy would also benefit economic development. The renewable energy industry indeed generates significant economic benefits. For example, local governments can collect property and income taxes and other payments from renewable energy projects. These revenues can be used to support vital public services, particularly in rural communities where such projects are often located. Increasing the supply of renewable energy has the potential of creating more jobs and other positive economic ripple

effects. Compared with fossil fuel technologies, which tend to be mechanized and capital intensive, the renewable energy industry is more labor-intensive. This implies that, on average, relative to fossil fuels, more jobs are created for each unit of renewable sources supplied and consumed. Second, this study finds that the use of renewable energy sources in developed countries appears to tackle emissions successfully while developing countries are still struggling with addressing emissions through renewable energy sources. The success of developed countries in promoting renewable energy sources and controlling emissions implies substantial scope for policy improvements in this area for developing countries.

Equilibrium Analysis of a Tax on Carbon Emissions with Pass-through Restrictions and Side-payment Rules

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Chile was the first country in Latin America to impose a tax on carbon-emitting electricity generators. However, the current regulation does not allow firms to include emission charges as costs for the dispatch and pricing of electricity in real time. The regulation also includes side-payment rules to reduce the economic losses of some carbon-emitting generating units. These rules state that the portion of the carbon tax that generation firms that face the tax and that cannot cover their full costs from spot prices should receive a side payment that is financed by all units operating at a given hour, including inframarginal generators that do not use fossil fuels. Clearly, the current implementation of the carbon tax in Chile has no effect on carbon emissions in the short term due to the existing pass-through restriction. However, the policy does change investment incentives in the long term since firms are forced to absorb an administrative definition of carbon emission costs every year.

In this paper, we develop an equilibrium model with endogenous investments in generation capacity to quantify the long-run economic inefficiencies of an emissions policy with such features in a competitive setting. We benchmark this policy against a standard tax on carbon emissions and a cap-and-trade program using a Base Case and two additional case studies to show the potential counterintuitive effects of the policy. Our main conclusion from the Base Case, which tries to replicate the generation technologies available for development in Chile, is that pass-through restrictions and side-payment rules provide distorted price signals in the short term that lead to inefficient entry and operation of generating resources. In terms of carbon emissions, we find that for a tax rate of 15 $/tCO2 a standard carbon tax yields 38% less annual carbon emissions than the same policy with administrative restrictions. Rising the tax rate to 30 $/tCO2 increases this difference to 61%. We also find that the regulator might face an incentive problem to migrate the present policy to a standard carbon tax or cap-and-trade program if the current tax was solely implemented for fiscal purposes. Our results indicate that tax revenues under the policy with administrative restrictions can be much higher than under a standard carbon tax. Furthermore, we find that removing the side-payment rule but maintaining the pass-through restriction does result in some improvement of the policy in terms

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of incentives for carbon emissions reductions. However, price signals and, consequently, the generation mix, remain distorted with respect to the first-best design of a standard carbon tax.

We also employ two additional case studies to show that, counterintuitively, the policy with administrative restrictions could increase carbon emissions in a system or result in even lower carbon emissions, but higher social cost, than a standard carbon tax. These findings highlight the critical importance of promoting short-run efficiency by pricing carbon emissions in the spot market in order to incentivize efficient investments in generating capacity in the long run.

Identifying Strategic Traders in China's Pilot Carbon Emissions Trading Scheme

Lei Zhu,[a] Xu Wang,[b] and Dayong Zhang[c]

In response to the global coalition to cope with global warming and climate change caused by greenhouse gases (GHGs) emissions, China has made a critical move to establish seven pilot emission trading schemes (ETS). A nationwide ETS was also launched in late 2017, which covers only the power generation sector in its first stage of operation though. China's ETS platform to a large extent follows the European Union emissions trading system (EU ETS) to create a market for trading emissions rights or permits. Despite the challenges and difficulties since the inception of these pilot programs, important progress has been made. By the end of 2018, the total trading volume reached 105.1 million tons, and there were totally 3,051 firms involved in the trading scheme. As a newly launched ETS market, it inevitably faces many challenges. To adapt to the on-going evolution of the market conditions and to promote market efficiency and governance, substantial improvement in the market setup and continuing regulatory updates are well expected.

Price plays an important signaling role in every market. Classic finance theories argue that price should reflect information and market fundamentals in an efficient market. When looking at the permit price data from the early years of operation, considerable variations are observed, both over time and across pilot markets. Though it is understandable that a market in its infancy stage may experience a certain level of inefficiency, excess volatilities can cause non-negligible negative impacts on the long-term development of the ETS market. One noticeable reason in extant literature on ETS is that participants with market power can manipulate prices through strategic trading behavior to gain themselves economic benefits. Such strategic trading behavior can potentially induce significant price distortions and undermine the signaling role of carbon price in a market. It is therefore an important and urgent task for regulators to monitor and curb such trading behavior in the carbon market. This concern is more pronounced in the case of China's pilot schemes. Existing evidence shows that the China market is dominated by a few major players, among a relatively small group of participants. In this situation, the main issue is how to identify strategic traders, which is never a simple task.

Based on the theoretical contributions by a number of researchers, we find that the "full market model" proposed by Godal (2005) and several following researches provide very useful

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guidance in distinguishing strategic traders from price-takers. The model improves previous works by allowing all agents in the market to be strategic traders (thus forming a full market), and identifying them via the comparison between the equilibrium permit price and their final marginal abatement costs. Based on this simple but effective strategy, we set up a four-step procedure to identify strategic traders. A sample of 1,867 firms from the pilot ETS in China is used to conduct an empirical case study.

Results show that the empirical strategy works well. It outperforms the traditional approaches and generates much more stable results. There is clear evidence of the presence of strategic traders (both buyers and sellers) in all pilot programs. The distribution of these traders, however, differs significantly across those pilot markets. While strategic buyers are more powerful in Shanghai and Tianjin markets, leading to lower equilibrium permit prices, other markets show the opposite. There are also sectoral patterns shown in these markets. Strategic traders are mainly found in highly energy-intensive sectors, such as in electricity suppliers and metal industries.

Our findings also show that not only price, but also total compliance costs and trading volumes in the market are affected by strategic trading behavior. This information further urges the regulators to react promptly, especially when a unified national market is on the move. Other implications from the results should also be considered useful for policy makers. For example, large price variations across markets are reflections of regional imbalances, which should pose a serious challenge to the development of a unified market. Our research also raises some future research questions. Statistical analysis of the determinants of carbon prices in China is needed to enable the inference on how much different factors contribute to price distortion. More firm-level information, such as government ownership, should also be considered when investigating firms' trading behaviors. With limited data availability, however, this dimension is not incorporated in our study. We hope that our research provides an interesting way of studying the ETS market that can be extended to studying other markets.

Carbon Tax and Energy Intensity: Assessing the Channels of Impact using UK Microdata Attitudes

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While the negative relationship between carbon taxes and energy intensity is well-established in the literature, existing studies are unable to shed much light on the channels through which a moderate carbon tax leads to reductions in energy intensity. Thus, important open questions remain about the behavioral components that dominate firm energy intensity reductions: how do firms achieve reductions in their energy intensity when they are faced by a moderate carbon tax liability? Are the tax-induced changes in firm behavior consistent with predicted policy outcomes?

In this paper, we evaluate the components of energy intensity reductions arising from the UK carbon tax, using a panel of 493 manufacturing firms over the period 2001-2006. In practice, there exists a range of firm responses to a moderate tax on carbon. Firms may adjust the input mix within their production technologies in response to changes in the relative price of energy. Second,

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they might install new lower energy-using capital. Third, firms may pursue low carbon innovation efforts through R&D investments that deliver efficiency improvements in existing production technologies. Finally, some firms may choose to exploit scale economies to absorb the energy price shocks due to the carbon tax.

In the first stage of our research design, we propose an energy intensity gain (EIG) decomposition based on a stochastic energy cost frontier. The EIG components include allocative efficiency change (AEC), scale efficiency change (SEC), other input change (OIC), the rate of technological change (TC) and economic efficiency change (EEFC). In the second stage, we estimate the impact of the carbon tax on these components using an instrumental variable approach that addresses the endogeneity of the UK climate change levy (CCL) rules.

We find that manufacturing firms in our sample responded to the CCL through factor substitution (OIC) and improvements in energy technology (TC). On the other hand, the limited contribution of energy efficiency (EEFC) to EIG runs contrary to the popular energy policy approach aimed at reducing energy intensity via energy efficiency improvements. Nevertheless, this finding is very much consistent with the emerging efficiency literature suggesting that improvements in energy efficiency are not necessarily equivalent to falling energy intensity. In sum, our findings underscore the challenge arising from the overreliance on singular energy policy objective such as efficiency improvement. Broader policy measures aimed at improving overall firm resource allocation might be more appropriate.

Solar Bait: How U.S. States Attract Solar Investments from Large Corporations

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Past solar adoption literature has focused primarily on households without significant attention to the potential of commercial properties as sites for solar generation. However, in recent years more firms have entered the energy market as producers of renewable solar-based electricity. Still, the current level of commercial solar adoption represents a very small fraction of potential adoption. For example, Walmart, the largest corporate solar adopter, generates solar power at only 7% of its facilities. We examine firms' decisions to install solar panels on their properties using state- and firm-level data from the USA. We are particularly interested in the effects of state-level characteristics, including policies and regulations, on firms' decisions regarding solar investments.

We perform an exploratory empirical analysis using data from the Solar Energy Industries Association (SEIA) "Solar Means Business" reports. The effects of state solar policies, such as net metering, renewable portfolio standards with solar carve-outs, and tax incentives, are compared to the effects of state characteristics such as solar intensity, energy market indicators, and variables representing the environmentalism of a state's population including electric vehicle adoption rates. The effects of these factors are assessed in relation to the annual total commercial solar capacity in-

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stalled and number of installations, and in relation to a multi-state firm's decision of where and when to install solar – a conceptualization of the problem that is novel to the solar adoption literature.

We find that state characteristics that influence the return-on-investment from solar installations, most notably solar intensity, are important for commercial adoption decisions. Further, the results suggest that certain state level policies, including solar carve-outs in renewable portfolio standards, financing programs and tax breaks, can incentivize firms to install solar panels. Across different model specifications, we observe that firm installation decisions are correlated with personal electric vehicle ownership rates. This may indicate a 'green' business marketing strategy, whereby firms install solar to improve their social responsibility image.

Our work is relevant to corporations interested in solar adoption, firms in the solar sector, and to state policymakers. Private sector readers will better understand the decision-making process of larger firms in assessing a potential solar investment. Policymakers will note the effectiveness, or lack thereof, of certain state policies. The study provides evidence of correlation between firms' decisions pertaining to solar adoption and pro-environmental behavior of the populace in the state where solar panel installation is contemplated.

Impact of Intensity Standards on Alternative Fuel Adoption: Renewable Natural Gas and California's Low Carbon Fuel Standard

Daniel Scheitrum[a]

Transportation emissions make up over one quarter of all greenhouse gas (GHG) emissions in the United States. The transportation sector has been the target of various pieces of regulation aimed at reducing the carbon footprint of the sector, but remains a substantial source of GHGs. California has undertaken a state-level approach to reduce transportation emissions, the California Low Carbon Fuel Standard. This paper details the mechanism by which the intensity standard achieves emissions reductions with particular attention to an emerging alternative transportation fuel, renewable natural gas (RNG). Natural gas presents a real possibility for near-term reductions in transportation emissions through the employment of RNG. RNG is considered to be an extremely low-carbon fuel because it is produced via the recovery of methane that would otherwise emit into the atmosphere and its consumption displaces the consumption of fossil natural gas and other high-carbon fuels.

This paper relies on RNG supply estimates form earlier work and evaluates the manner in which the LCFS program can incentivize RNG production as well as examining how RNG use in transportation fuel facilitates achieving the policy goals of the LCFS. This model employs a numerical simulation to evaluate the consumption response of gasoline, ethanol, diesel, biodiesel, fossil natural gas and RNG under a complete range of LCFS intensity targets. This simulation revels that there is a narrow range of intensity targets within which credit prices can respond. Outside this narrow range, credit prices will either bind at zero or the credit price maximum.

Further the LCFS program is compared to a hypothetical carbon tax and surplus analysis evaluate the economic cost in terms of deadweight loss per unit of GHG avoided. While the LCFS

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is less efficient at achieving emissions reductions when compared to a carbon tax, the efficiency of the LCFS approaches that of a carbon tax as the LCFS policy becomes more stringent.

Reforming the Operation Mechanism of Chinese Electricity System: Benefits, Challenges and Possible Solutions

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A new wave of electricity market reform was launched by the Chinese government in March 2015. One of the major objectives was to reform the power operation mechanism to be more efficient. However, this is a complex task and has widespread impacts, the equal share approach still dominates the power system operation in most areas of China since the launch of reform four years ago, little changes have been made to implement the economic dispatch. To provide decision-making support for the on-going electricity market reform, this study employs an integrated approach to analyze the benefits, challenges and possible solutions of reforming the power operation mechanism in China. A benefits estimation model is first established to quantify the gains from implementing the economic dispatch, from the perspectives of coal savings, carbon emission reductions and operation cost reductions. Then, an identification model for the political economy challenges is constructed to explore the conflicts among involved stakeholders, which are caused by uneven benefits reallocations. At last, several market and regulatory solutions are proposed to address the identified challenges.

The major findings of this study show that economic dispatch could decrease the total operation cost by approximately 3.10%. The share seems small but the absolute value (66.44 billion yuan) is larger than the other sub-reforms, such as the transmission and distribution reform (48 billion yuan) and the government electricity funding reform (35 billion yuan). Moreover, the total potential decreases in coal consumption and carbon emissions achieved by the economic dispatch scheme are estimated as 80.93 Mtce and 263.39 million tons, respectively. The North China Grid and Northwest China Grid are the biggest winners from economic dispatch implementation, and these regions could be selected as pilot areas to implement the economic dispatch mechanism. In addition, three major challenges have been identified for the implementing the operation mechanism reform, including inadequate compensation for ancillary services, local protectionism and the no-incentive business models of grid companies. The conclusions and implications from this study can provide decision-making support for the on-going electricity market reform, they can also be served as great references for other countries in the future.

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Effects of Privatization on Price and Labor Efficiency: The Swedish Electricity Distribution Sector

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When a network industry is privatized, a fundamental controversy lies in the potential increase in productive efficiency due to increased incentives to minimize costs, vs. distortions in allocative efficiency and a subsequent redistribution from consumers to producers due to market power. The electricity distribution sector is particularly well suited for firm performance comparisons since electricity distribution is a homogenous good, and since data on the technical characteristics of the networks as well as accounting data is standardized and reported to a central regulator. At the same time, since the market is regulated, the possibility to extrapolate results to other markets requires care.

In this study, I examine the effects of private acquisitions of publicly owned networks in the Swedish electricity distribution sector. Specifically, I study the performance of 34 municipality owned networks that were acquired by private firms around the turn of century. I focus on two outcome variables: price and labor efficiency. I find evidence of an increase in labor efficiency in the acquired networks by 8-18 percent compared to the control group depending on model specification, while no acquisition effect is found on price. Thus, the evidence suggests economically meaningful efficiency gains but that these are not fed through to consumer prices. All acquisitions examined in the study were conducted by two firms, E.ON and Fortum. The qualitative effects on both outcome variables are similar across firms, although the increase in labor efficiency is both statistically and economically more significant in the networks acquired by Fortum.

To identify the effects of the acquisitions, I employ a synthetic control method. To the best of my knowledge, this is the first study to use this method to evaluate firm performance in the electricity distribution sector. For each acquired network, I create a synthetic control network from a weighted average of the control networks. The synthetic control network is constructed to have the same technical characteristics and pre-acquisition trend of the outcome variable as the acquired network. The effect of the acquisition is then estimated by comparing the factual post-acquisition trend of the outcome variable to that of its synthetic analogue. Conceptually, it is a generalization of the more commonly used difference-in-differences (DiD) estimator, and is particularly well suited to estimate the effect of an intervention when the number of potential control firms is large. Robustness tests using a conventional DiD estimator largely confirms the results from the synthetic control method, although the estimated efficiency gains are either less pronounced, or comparable to, the results using the synthetic control method. Further, the precisions of the estimates are comparatively low under both methods for several of the specifications. Therefore, results should be interpreted with care.

Although it is beyond the scope of this study to identify the specific mechanisms driving the efficiency gains, one plausible explanation is returns to scale, since each of acquisitions involved bordering networks that were previously operated by each respective municipality. For example, the same administrative staff may be used for several networks, and the use of equipment may be optimized by transporting it across regions. It is also likely that some publicly owned firms prefer to offer higher wages relative to private firms *ceteris paribus*, in which case variations in labor efficiency also reflects how revenues are distributed between workers and owners. Another contributing

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explanation could be returns to scope between various stages in the supply chain. This should provide E.ON and Fortum with a cost advantage compared to municipality owned control networks that generally do not engage in generation or regional transmission, limiting the possibility to generalize results to other markets.

The Role of the Financial Sector in EU Emissions Trading: Insights from the EU Transaction Log and Interviews

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In this paper we investigate empirically the role of the financial sector in the EU Emissions Trading Scheme (EU ETS). This topic is of particular interest, since non-regulated entities were responsible for the largest overall trading volume and have played important roles for liable companies in providing services related to trading. We employ a mixed-method approach using regression analysis on data from the EU Transaction Log (EUTL), as well as interview techniques, which allow us to extend and confirm the insights gained from the quantitative analysis.

Our regression analysis shows that different types of liable companies choose to interact with financial actors to differing degrees. While larger companies with trading experience are more likely to have a trading strategy interacting with many different financial actors, in particular banks or exchanges, smaller, less professionalised companies are more likely to follow a singular trading strategy and interact with brokers (in particular for selling allowances).

We are particularly interested in the roles of banks, since they have been pulling out of EU emissions trading, due to various reasons including new regulations, such as Markets in Financial Instruments Directive (MiFID I), the successor of which (MiFID II) will come into force in January 2018. Semi-structured interviews conducted with experts from banks active on the market for EU emissions permits and their clients confirm that banks have played multiple roles in the EU carbon market including acting as an intermediary, service provider and particularly as hedging partner for larger companies in the electricity sector.

We therefore expect an impact of banks pulling out of the market in particular on large firms and those in the electricity sector. However, this effect is expected to be mitigated by the fact that an increasing amount of allowances is available at auction and that the rising share of renewables in electricity markets reduces hedging demand.

Many emissions trading schemes operating today have allowed more or less unfettered participation in trading with a view to increasing liquidity of the market. However, regulation such as MiFID I (aimed at derivative markets) and MiFID II (at spot markets) are important in creating more transparency and accountability, especially considering the large-scale VAT fraud that took place on the spot market for EUAs and generated 5 billion in estimated tax losses to European governments. It may be more of a concern that not all financial players active on the EU emissions market are covered by MiFID and that banks have started outsourcing activities related to trading to smaller subsidiaries not falling under MiFID. It may therefore be necessary to further strengthen other measures, such as stricter checks on the identity and previous records of participants in EU emissions trading and a more effective market oversight.

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