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# MIT CEEPR Newsletter

MIT Center for Energy and Environmental Policy Research



MASSACHUSETTS INSTITUTE OF TECHNOLOGY



# Editorial

Change and disruption have remained a familiar constant in the energy sector since our last newsletter. Fueled by the renewed onset of destructive forest fires in California – some of which may again have been triggered by faulty utility equipment, despite preemptive outages – resilience of energy infrastructure has quickly risen to the forefront of the energy debate. But environmental risk is not the only setting where resilience has witnessed a surge in attention – a recent malware attack against India's largest nuclear power plant served as a pointed reminder of the continued need for improved cybersecurity.

Such uncontrolled threats join the more predictable, yet no less disruptive forces of politically agreed decarbonization commitments, with new mandates continuously expanding the already remarkable cohort of national and subnational net-zero-emissions targets and accelerated deployment roadmaps for carbon-free energy. So far, the resulting transformation has been fastest in the electricity sector, where decarbonization options are more readily available. Even so, the challenges have proven substantial, heralding even greater obstacles as we gradually

transform other sectors, such as industry, heating, and transportation.

For communities that lack all access to modern forms of energy, these challenges may seem abstract and remote. And while that may change as climate impacts worsen on these same communities, the recent launch – facilitated by MIT – of the Global Commission to End Energy Poverty pays tribute to the sometimes overlooked human dimension of energy. Another new groundbreaking initiative at MIT, the Roosevelt Project, will address this human dimension closer to home by offering a platform for innovative solutions to the disruptions that rapid change to the energy landscape will bring to workers and communities across the United States.

CEEPR will be closely involved in these efforts, and the research it facilitates will continue to address the full range of issues faced in a rapidly evolving energy landscape. As always, you can find a sample of our recent activities described in this newsletter.

—Michael Mehling

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# Optimal Commodity Taxation with a Non-Renewable Resource

*by: Julien Daubanes and Pierre Lasserre*



When governments need to raise public revenues, they should tax nonrenewable resources more than regular commodities according to a dynamic rule. For carbon resources, that means augmenting the carbon tax in a way that further reduces their development and slows down their exploitation, which goes further in the direction of resolving the climate problem.

How should a government that needs to collect tax revenues distribute the burden of commodity taxation across sectors? The textbook answer to this question is the famous static inverse elasticity rule due to Ramsey (1927), which says that under simplifying conditions, the tax rate applied on each good should be proportional to the reciprocal of the price elasticity of its demand.

On the one hand, Ramsey's original analysis does not seem sufficient to explain the special tax treatment received by the flow of most energy nonrenewable resource commodities. For example, high levels of taxes on the use of energy resources are often rationalized by the fact that energy demand is relatively price inelastic. However, it is the peculiarity of their supply that makes nonrenewable resources special: The supply of a nonrenewable resource consists in

extracting production from limited reserves over time. This peculiarity of nonrenewable resources has several important implications for optimal taxation. First, reserve limitations generate economic rents. Second, the non-renewability of a natural resource makes economic distortions intertemporal.

On the other hand, apart from the peculiarity of resource supply, Ramsey's original framework fits particularly well with the characteristics of actual nonrenewable resource tax systems. Despite economists' recommendations, the use of direct rent taxation proved limited in nonrenewable resource sectors, leaving large rents untaxed. Recent World Bank data suggest that, for instance, economic profits—including rents—from oil extraction worldwide exceeded \$609 billion in 2015. In this context, Ramsey commodity taxes are particularly useful, as they allow

governments to indirectly tap such untaxed rents (Stiglitz, 2015); for instance, royalties and other indirect linear commodity taxes are dominant forms of resource taxation (Daniel, Keen, and McPherson, 2010).

In a new MIT CEEPR working paper<sup>1</sup>, Daubanes and Lasserre (2019) reexamine the problem of optimum commodity taxation in the presence of natural nonrenewable resources, and obtain a formula for how these resources should be taxed when governments need to collect commodity tax revenues. This new Ramsey resource tax formula is



Julien Daubanes



Pierre Lasserre

an augmented, dynamic version of the standard rule, and requires a novel analysis of the tax incidence to nonrenewable resource extraction and reserve development.

First, Daubanes and Lasserre's tax rule accounts for the variety of observed resource tax systems, ranging from systems in which firms finance reserve production and are paid back by future after-tax extraction rents to the extreme case of nationalized industries.

Second, all such optimal combinations of extraction taxes with reserve development subsidies imply extraction taxes at least as high as the tax on other goods. Moreover, they cause a distortion to the nonrenewable resource sector that takes the form not only of slower extraction at a given level of remaining

reserves, but also of lower induced reserves.

Last, but not least, Daubanes and Lasserre's formula can be directly used to indicate how carbon taxation should be augmented to take into account governments' revenue needs. The Ramsey resource tax causes a distortion to the extraction of carbon resources that goes further than the Pigovian tax in the direction prescribed for the resolution of carbon externalities.

In the numerical application presented below for the case of oil, the Ramsey resource tax is imposed on top of a carbon tax. The carbon tax is taken from Nordhaus (2014). When the cost of public funds—i.e., the cost in terms of economic surplus of levying \$1 of revenues through taxes—is  $\lambda = \$1.1$ , the

Ramsey tax on oil is set at \$13 and the induced extraction rate is 30 BB. The yield of the carbon tax is lower than in the absence of a Ramsey tax, and the more so the higher  $\lambda$ . Nevertheless, the joint yield of the two taxes is higher than if either of them were alone. Oil discoveries are also lower than if either of the two taxes were present in isolation. Clearly, both contribute to the objectives of increasing revenue and protecting the climate. To sum up, public financial hardness does not need to obscure or delay environmental decisions; on the contrary, it calls for policies that go even further than correcting externalities. ■

<sup>1</sup> Julien Daubanes and Pierre Lasserre (2019), "Optimal Commodity Taxation with a Nonrenewable Resource", CEEPR WP-2019-008, MIT, May 2019.

## Decentralized Economic Dispatch for Radial Electric Distribution Systems

by: *Sruthi Davuluri*

Imagine a neighborhood where the households own a variety of distributed energy resources (DERs) and have different consumption habits. For example, some households own rooftop solar, others own electric vehicles, some have a home storage unit, while other neighbors simply use the house as a vacation home. The diverse customers across the neighborhood will inevitably consume electricity at different times of the day and inject surplus energy at various magnitudes. Assuming that all of the customers belong to the same flat-rate tariff structure, all of the neighbors will be charged the same price regardless of their impact on congestion or contribution to peak loads. While consumers are becoming increasingly motivated to practice sustainable energy consumption habits, it remains challenging when most consumers do

not receive the proper price signals.

Under net metering laws, consumers that have surplus energy will reduce their electricity bill and will only be charged for the net load that they consume, after considering the amount of excess energy that they inject back into the grid. However, this does not account for the congestion that the surplus energy contributes to the physical system. On the contrary, customers with rooftop solar could be compensated appropriately for providing surplus energy during peak hours. Although DERs at one household may have a negligible impact on the entire system, the net impact could increase as more residential consumers invest in DERs in the coming decades, which could potentially threaten the quality of service for the entire network.

In addition to the physical impacts, there are a number of economic inefficiencies associated with a flat-rate tariff structure — such as some customers over-consuming or under-consuming during different time periods. While it is clear that there are technical and economic inefficiencies associated with treating every diverse customer identically, it is unclear how the industry could account for heterogeneity across many end-users. With the current techniques, is not computationally feasible for a centralized system operator to account for a high level of granularity across residential electricity consumers.

An alternative approach is introduced in this paper<sup>1</sup> which accounts for diverse customer preferences and utilizes local communication.

There are several different geometries of





The distributed economic dispatch algorithm enables small end-users to aggregate themselves such that they can communicate their diverse preferences to the local substation. Unlike other approaches proposed in the literature, the distributed algorithm introduced in this paper converges to the same solution as a centralized operator with perfect information, and does so with only two sweeps across the system.

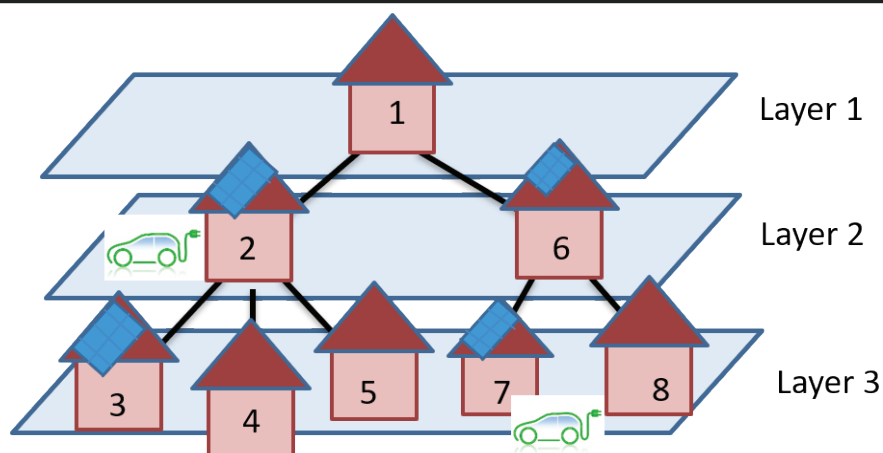
how distribution systems could be designed. For residential purposes, the distribution system often has a radial, or tree-like, structure, as displayed in the figure below. While radial structures are not as reliable as a meshed grid geometry, it is of considerably lower cost and typically used in suburban neighborhoods. Meanwhile, meshed grids are typically used in dense, urban centers, and the wires are often underground, which increase the upfront costs.

By taking advantage of the radial structure, the algorithm allows for local information exchange in order to enable

computationally feasible energy exchange. The use of local data exchange provides an opportunity for diverse consumer preferences to be cumulatively communicated to a system operator in a bottom-up manner without expecting a single centralized system operator to have knowledge on the entire system. Thus, market operations at the transmission and distribution level could continue with business as usual.

The algorithm is tested on a 46-Bus proof-of-concept example using real data. The power dispatched is compared between the distributed algorithm and

the centralized OPF for various levels of DERs. The cost savings are calculated in order to quantify the economic benefits of using a bottom-up, decentralized perspective. The economic analysis implies that the decentralized algorithm would improve welfare for customers with higher demand elasticity, such as customers with flexible load. Overall, the use of the decentralized algorithm to dispatch power for a radial electricity system could lead to cost savings between approximately \$35,000 and \$400,000 per year. These cost savings could be attributed to the decentralized algorithm accounting for the cost of distributed energy resources and the demand elasticity of consumers. ■



In a radial distribution system, power is diverted through serial splits and layers as it is delivered to end-use consumers, resulting in a tree-like structure.

<sup>1</sup> Sruthi Davuluri (2019), "Decentralized Economic Dispatch for Radial Electric Distribution Systems", CEEPR WP-2019-010, MIT, July 2019.



Sruthi Davuluri



# Spatial and Temporal Variation in the Value of Solar Power across United States Electricity Markets

by: *Patrick R. Brown and Francis M. O'Sullivan*

While the cost of solar photovoltaics (PV) has fallen rapidly over the past decade, the U.S. electric power system has simultaneously undergone rapid changes. The deployment of variable renewable energy (VRE) capacity at large scale has begun to push down wholesale electricity prices, decreasing the market revenues of new VRE generators. At the same time, the adoption of emissions-control technologies at coal generators has reduced the marginal emissions rate of air pollutants—delivering a clear public health benefit, but decreasing the relative public health benefits of PV deployment.

What do these simultaneous reductions in the cost and value of PV imply for the net benefits of PV across the United States today? In this Working Paper<sup>1</sup>, we address this question by simulating the performance of new utility-scale PV generators at the sites of ~10,000 pricing nodes across the continental U.S. over

2010–2017. Our analysis covers six U.S. Independent System Operators: California ISO (CAISO), the Electric Reliability Council of Texas (ERCOT), Midwest ISO (MISO), the Pennsylvania-New Jersey-Maryland Interconnection (PJM), New York ISO (NYISO), and ISO-New England (ISONE). We combine historical satellite-derived weather data with nodal electricity prices, capacity market prices, and marginal particulate matter and CO<sub>2</sub> emissions rates from grid electricity to assess the wholesale energy value, capacity value, public health benefits, and climate benefits of new PV generators.

The energy value of PV—assessed at the level of hourly nodal day-ahead locational marginal electricity prices (LMPs)—is found to vary significantly with location, even within the territory of a given ISO. Particularly along the east coast, transmission congestion results in nodal “hotspots” where in some years the wholesale market revenue of a PV

generator is up to twice that at the median node across the system as a whole. In general, LMPs are found to vary more widely than PV capacity factors, such that a PV generator is more likely to maximize its revenues by selecting a high-LMP location than a high-capacity-factor location.

PV capacity revenues are typically 5-20% of energy revenues, but in some congested zones along the east coast (particularly around Boston and New York City) the capacity revenue can rise to 40-80% of the energy revenue. Both energy and capacity revenues have declined in California between 2010-2017 as PV penetration grew from ~2% of peak load to ~28% of peak load.

The marginal public health benefits associated with SO<sub>2</sub>, NO<sub>x</sub>, and direct PM2.5 emissions reductions have declined over the observed time range, but are still substantial in 2017: in monetary terms, the 2017 health



The net benefits of solar photovoltaics (PV) depend on the balance of PV's upfront cost and system value, both of which have changed rapidly over the last decade. In this paper, the authors combine electricity prices, emissions rates, and weather data to map the changing value of PV at ~10,000 locations across the United States. Cost declines are found to have outrun value declines, such that the energy, capacity, health, and climate benefits of PV outweigh utility-scale PV costs at the majority of locations modeled.



benefits of PV generation are equivalent to ~70% of energy revenues in MISO and NYISO and 100% in PJM. CO<sub>2</sub> offsets have been relatively stable over this timespan, ranging from ~0.9 tons/kWac per year in NYISO and ISONE to ~1.3 tons/kWac per year in ERCOT and MISO.

Adding together the calculated energy, capacity, health, and climate benefits of PV in 2017, we calculate the upfront PV system cost that would be required for new PV generators to “break even” in terms of net present value over their lifetime. We find that at 2017 PV system costs of ~\$1.44/Wac, PV would break even at ~30% of the modeled nodes on the basis of energy, capacity, and health benefits alone, at ~75% of nodes with a

\$50/ton CO<sub>2</sub> price, and at 100% of nodes with a \$100/ton CO<sub>2</sub> price. At 2017 PV system costs, median breakeven CO<sub>2</sub> prices range from \$0/ton in PJM to \$60/ton in CAISO if public health benefits are included, and from \$45/ton in PJM to ~\$80/ton in CAISO if health benefits are excluded.

Our results suggest that PV cost decline has outpaced value decline since 2010, such that in 2017 the market, health, and climate benefits of PV outweigh the cost of PV at the majority of the locations modeled. While the balance of PV’s benefits and costs will continue to evolve as PV penetration increases, the methods presented here can be used to provide continuously up-to-date

estimates of the net benefits of PV and other distributed energy resources. ■

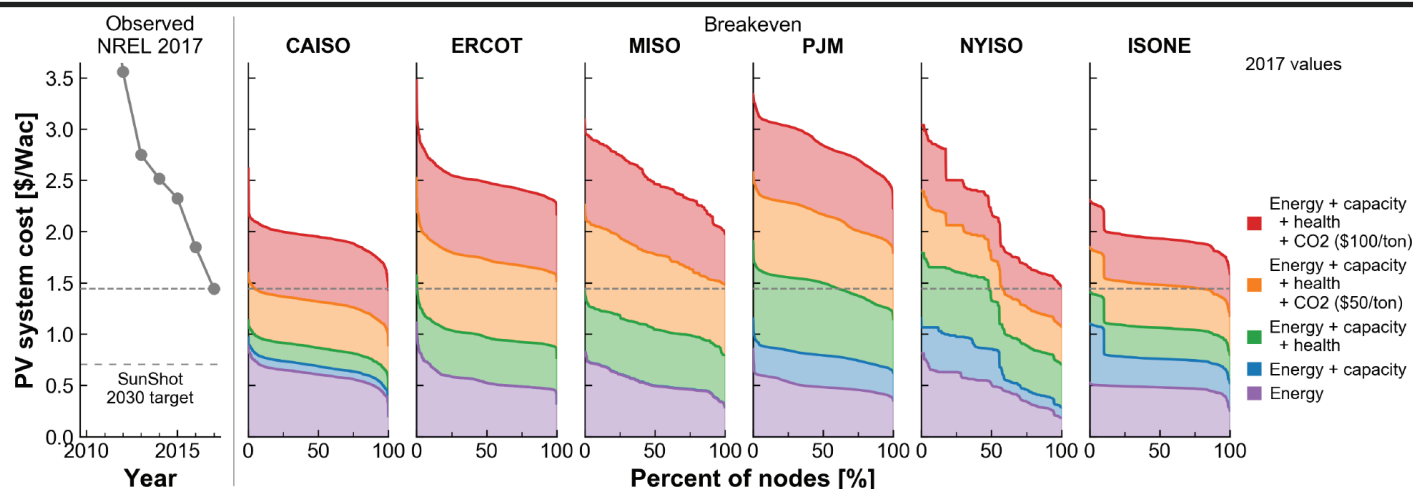
<sup>1</sup>Patrick R. Brown and Francis M. O’Sullivan (2019), “Spatial and Temporal Variation in the Value of Solar Power across United States Electricity Markets”, CEEPR WP-2019-011, MIT, July 2019.



Patrick Brown



Francis O’Sullivan



Observed PV costs are for a 100 MW 1-axis-tracking PV array. Each colored trace shows the percentage of nodes that would break even at the corresponding y-axis upfront cost, assuming that conditions in 2017 persist for the lifetime of the system.

## Estimating the Costs and Benefits of Fuel-Economy Standards

*by: Antonio Bento, Mark Jacobsen, Christopher Knittel, and Arthur van Benthem*

Many countries around the world have implementations of fuel-economy standards — a policy instrument designed to reduce the carbon footprint of the transportation sector. The U.S. has had such legislation, known as the Corporate Average Fuel Economy (CAFE) standards, ever since the mid-1970s. The standards have been updated over time,

but their mechanics are straight forward. Under CAFE, the average fuel economy of an automobile manufacturer’s fleet must be at or above a certain level. The government regulates the average emissions rate of a vehicle, but not the specific technology choice needed to reach the mandated level. Consider a firm that sells two vehicle models — one

rated 25 MPG and another at 35 MPG. If facing a hypothetical 30 MPG standard, the firm needs to shift its mix of vehicles to comply. The consequence of such regulation is that it incentivizes a firm to sell more high fuel-economy vehicles at a discount, and leading it to implicitly tax any low-fuel economy vehicles it may have, pricing them above the vehicle’s

marginal cost.

Such standards also have effects on the market. They can decrease the lifetime of high fuel-economy vehicles and increase the lifetime of low fuel-economy vehicles. Assuming gasoline prices remain relatively unchanged, the cost per mile of driving for high fuel-economy vehicles decreases, which leads to a rebound effect where consumers drive more. Finally the standards introduce a change in welfare depending on consumer behavior, which can be positive or negative depending on the consumer.

These various effects are integrated in the initial simplified model, focused only on the new-car market, that is developed in this paper<sup>1</sup>. Afterwards, this model is extended to capture the multi-market interactions of the ability to buy new and old cars as well as allowing individuals to scrap their vehicle. This combined, multi-market vehicle choice model also allows the authors to bound the resulting size of the fleet of vehicles as well as the scrappage for a given fuel-economy standard. This last ability is useful since the overall affect is a consequence of these variables.

The authors use the model to present three results: (1) that the equilibrium size

of the new car fleet shrinks when new vehicles become more expensive or less attractive, (2) With a unit increase/ tightening of fuel-economy standards, new-vehicle prices (and subsequently used-vehicle prices) are pushed upwards which increases the long-term equilibrium share of used vehicles (Gruenspecht effect), and (3) that the overall equilibrium number of vehicles decline. The shrinkage of the fleet depends on the magnitude of price changes and the aggregate elasticity to the outside good.

The final analysis in this paper uses results developed by the authors' model as well as past literature concerning fuel-economy standards in the U.S. to evaluate the 2018 proposal to rollback the CAFE standards. This rollback is supported by the results of the 2018 NPRM report, which develops its own model on the cost of keeping the CAFE standards through the year 2024. The analysis conducted in the 2018 NPRM calculates the net benefit of keeping CAFE to be -\$176.3 billion USD in 2016 terms. The authors argue that the assumptions made by the 2018 NPRM are not in line with what research in the academic literature and the authors' own results support. They assert that the 2018 rollback proposal suffers from inconsistencies in the model framework and that its equilibrium analysis is done

piecemeal. Central parts of the model developed in the 2018 NPRM do not feed into others, which produces results that are not consistent with each other. If these assumptions are modified to be in line with research, the resulting net benefit calculations of keeping CAFE would be higher, which consequently means that the benefits of removing the standards would be lower than the 2018 NPRM report suggests. ■

—Summary by Bora Ozaltun

<sup>1</sup> Antonio Bento, Mark Jacobsen, Christopher R. Knittel, and Arthur van Benthem (2019), "Estimating the Costs and Benefits of Fuel-Economy Standards", CEEPR WP-2019-014, MIT, September 2019.



Antonio Bento



Mark Jacobsen



Christopher Knittel



Arthur van Benthem

## On the Efficiency of Competitive Energy Storage

by: **Richard L. Schmalensee**

Wind and solar electricity generation have become more important in recent years, reflecting both declines in their costs and growing public interest, and this trend is generally forecast to continue. These renewable technologies have near-zero marginal costs and are intermittent: their outputs vary over time and are imperfectly predictable. Energy storage can help balance supply and demand in the presence of intermittent generation and can reduce

generation cost by adding to demand when system marginal cost is low and adding to supply when it is high. As the cost of energy storage has also declined, its deployment to facilitate the integration of intermittent renewable energy has attracted considerable attention and support from policy-makers in the U.S.

Notably, the U.S. Federal Regulatory Commission recently issued Order 841,

which is intended to open wholesale energy markets to merchant storage providers. This Order rests on the presumption that existing markets will provide at least approximately optimal incentives for investment in both storage and generation: it does not contemplate the establishment of new markets or new policies. In a new MIT CEEPR Working Paper<sup>1</sup>, Richard L. Schmalensee, the Howard W. Johnson Professor of Management and Dean





When energy storage is employed to facilitate large-scale integration of intermittent renewable electricity generation, do competitive bulk power markets continue to provide incentives for efficient investment?

emeritus at the MIT Sloan School of Management, provides a formal exploration of the validity of this presumption.

Existing theoretical literature building on the work of Marcel Boiteux and Ralph Turvey suggests that, as long as scale economies and other sources of non-convexity are not too important, and prices are not capped below the value of lost load, real energy markets will provide at least approximately optimal incentives for investment in generation. A natural approach to examine the validity of the presumption that underlies FERC Order 841 is to add competitively-supplied storage and two types of periods to the classic Boiteux-Turvey model of an electric power system with multiple generation technologies and stochastic demand.

Schmalensee's analysis provides some support for the presumption that energy markets need not be supplemented with additional markets or policies to support efficient outcomes when storage is deployed. Under rational expectations, long-run competitive equilibria in which all arbitrage flows in the expected

direction satisfy the necessary conditions for minimization of expected total cost. In the most interesting, tractable cases of a Boiteux-Turvey model with storage, all efficient points are long-run competitive equilibria, and the long-run equilibrium value of storage capacity minimizes expected system cost conditional on generation capacities.

However, the second-order conditions for optimality of all stock variables at competitive equilibria cannot be shown always to be satisfied, raising the possibility that inefficient competitive equilibria exist. Given this possibility, it might be unwise for power system operators and regulators to rely exclusively on energy markets to determine generation and storage capacities. Such reliance is waning in any case in the face of problems posed by intermittent renewable generation at scale.

In particular, while FERC Order 841 envisions merchant storage suppliers participating in bulk power markets, it seems likely that at least in the near term, storage deployment in the U.S. will

be driven at least as much by state mandates and subsidies of various sorts as by incentives provided by competitive markets. But to the extent that energy markets drive investments in storage, the analysis suggests that, conditional on generation capacities, the competitive equilibrium supply of storage is likely to be efficient. ■

—Summary by Michael Mehling

<sup>1</sup> Richard L. Schmalensee (2019), "On the Efficiency of Competitive Energy Storage", CEEPR WP-2019-009, MIT, June 2019.



Richard L. Schmalensee

# Strengths and Weaknesses of Traditional Arrangements for Electricity Supply

*by: Richard L. Schmalensee*



Professor Richard Schmalensee provides a broad-brush comparison of performance under traditional arrangements for electricity supply with those that emerged after the world-wide wave of restructuring that began in the 1990s, focusing on the change in reliance on market competition and drawing on comparisons within the U.S., where traditional and restructured arrangements both exist.

In a new CEEPR Working Paper<sup>1</sup>, Richard L. Schmalensee, the Howard W. Johnson Professor of Management and Dean emeritus at the MIT Sloan School of Management, compares the performance under traditional arrangements for electricity supply with those that emerged after the global wave of restructuring beginning in the 1990s.

As Schmalensee shows in a brief historical survey, electricity supply industries (ESIs) prior to restructuring had in common a high degree of vertical integration and little to no reliance on

markets. Restructuring sought to change that through privatization, greater reliance on competition in wholesale electricity markets and, less universally, reliance on competition in electricity supply at the retail level.

On the wholesale side, all restructured ESIs have adopted a formal bulk power market, usually coupled with some sort of separation between the ownership of generation plants and the operation of transmission facilities. On the distribution side, the delivery function — the construction and operation of the physical network — is universally

performed either by a regulated investor-owned utility or a public enterprise, while the supply of electricity has been unbundled from delivery and opened to alternative vendors in some regions with competitive bulk power markets.

Schmalensee goes on to consider evidence on how restructured and traditional ESIs have performed in three areas: (1) the cost and price of supply from existing generating facilities, (2) the level of generation capacity, and (3) the efficiency of prices charged to ultimate customers.



Although wholesale power market design has proven more difficult than originally envisioned, once that process has been worked through competitive markets have succeeded, by and large, in providing greater incentives for efficiency than either regulation or government ownership. Data on changes in power quality, reliability, and innovation caused by restructuring are sparse, but there is strong evidence suggesting that restructuring and the introduction of formal bulk power markets reduced the cost of generating electricity from existing facilities through improved incentives and reduced transactions costs.

Given the economies of scale in generation and highly inelastic demand, unregulated or lightly regulated bulk power suppliers have, at times, been able to exercise market power — for instance contributing to the California electricity crisis in the early 2000s — yet overall it seems unlikely that greater exercise of market power has erased the efficiency gains from lowered generating costs.

Likewise, on the level of generation capacity, restructuring shifted the capacity risk from over-investment driving up rates to under-investment driving down reliability. As a consequence, supplements to energy markets have been introduced in several regions, including capacity markets and out-of-merit-order dispatch, becoming a very important source of revenue for generators.

While these supplements seem to have generally ensured procurement of adequate capacity, and encouraged the development of demand response aggregators offering demand reduction services to the wholesale market, the heavy role of administrative decision making in the design of such market supplements makes it hard to argue that restructuring has improved the efficiency of investment in generation capacity.

At the retail level, finally, only a subset of regions have adopted competition

through retail choice. Commercial and industrial customers, in particular, have strongly advocated for retail choice, and also obtained increased access to real-time and time-of-use pricing that better reflects system conditions. They are also more likely to possess the technical and operational means to benefit from these. Residential customers, by contrast, have shown considerable inertia when it comes to retail choice. Hence the efficiency gains from restructuring are less obvious in the household sector than with commercial and industrial customers.

Both traditional, vertically integrated utilities and restructured ESIs with strong reliance on markets face new challenges due to rapidly evolving generation technologies. Historically, ESIs have typically relied on dispatchable resources, and their regulatory frameworks have advocated technology neutrality. Emerging regimes, by contrast, have seen government policies favor variable energy resources (VERs) such as wind and solar, whose maximum output is intermittent and only imperfectly predictable in advance. That property, coupled with the zero short-run marginal costs of VERs, are significantly impacting traditional and restructured ESIs.

Anecdotal evidence from the restructured Californian and traditional Hawaiian ESIs suggests that these impacts again extend to generation operations, generation capacity, and pricing at the retail level. In ESIs with bulk power markets, VER penetration driven by government support policies has resulted in the occasional appearance of zero and negative prices, and both traditional and emerging systems see VERs exerting economic pressure on inflexible baseload generators. Storage capacity is expanding in both regimes to help manage VER-induced volatility, again driven in part by government mandates.

As for generation capacity, increased VER generation in bulk power markets will lower spot market energy prices, which — together with capped wholesale

prices — will prompt continued reliance on capacity markets. As currently designed, however, these may not be well-suited to meet the challenges of high, subsidized VER penetration. How exactly they might be adjusted is not entirely clear, although a more suitable design will have to account for subsidies and accord greater value to flexible, dispatchable capacity while simultaneously considering decarbonization mandates.

Finally, as regards retail pricing, Schmalensee offers examples of how real-time or time-of-day pricing can reduce the cost of transitioning to 100% renewables by inducing load-shifting, yet neither Hawaii nor California have moved aggressively so far to impose change on consumers.

Overall, the comparison of both ESIs suggests that traditional systems — where utilities and their regulators can engage in classic integrated resource planning and project-by-project decision-making — may prove more agile in dealing with emerging challenges such as widespread VER penetration. At the same time, the information advantage of utilities over regulators is likely to be substantial, and the flip side of greater agility may be higher costs and rates than could be attained under competition in restructured markets. ■

—Summary by Michael Mehling

<sup>1</sup> Richard L. Schmalensee (2019), "Strengths and Weaknesses of Traditional Arrangements for Electricity Supply", CEEPR WP-2019-016, MIT, October 2019.



Richard L. Schmalensee

# The Roosevelt Project: A New Deal for Employment, Energy and Environment

*by: Ernest Moniz and Michael Kearney*



The issues of employment, energy and environment are playing out against a complicated set of changes affecting workers.

Advocates for addressing climate change aggressively point to the urgency of accelerating a low-carbon energy transition and the benefits that can accrue to the national economy and global environment. However, just as in the case of international trade, the attendant dislocations for workers and communities and regional economic disruptions are also real and have been addressed inadequately.

This reality provides a significant headwind for addressing climate change in a timely way and could lead to delay rather than acceleration of essential decarbonization. Supported by the Emerson Collective, the Roosevelt Project aims to enable tailwinds by developing innovative regional solutions to the problems that rapid change to the

energy landscape will bring to workers and communities across the country.

The issues of employment, energy and environment are playing out against a complicated set of changes affecting workers. Income inequality has grown significantly over the last three decades, with median U.S. incomes stagnant despite substantial productivity gains (Levy and Temin). Though recent years have seen modest increases in wage growth (2.6% in 2017 and 2.8% in 2018), inflation adjusted wage growth remains sluggish (1%). Globalization and technology advances are widely accepted as important drivers of this development. Moreover, increasing levels of automation through robotics and artificial intelligence promise to exacerbate these factors.

Public policy factors also play a role in the economic dislocation that has occurred over this period. Challenges to the traditional social compact are coupled with growing concerns for worker job security, and are reinforced by policy, regulatory and technological change. Future policy initiatives could also have similar distributional impacts that policy makers must consider.

Most importantly, these challenges are not attenuating; they are projected to become more acute. The speed of technological advances in autonomous vehicles challenges workers (drivers) even as it offers near-term efficiencies, safety and new services in the economy as a whole. Information and communications technology advances have led to enormous value creation in



multiple domains via automation and flexible supply chains, but these technologies have also enabled a fragmentation and self-selection of information sources about national and global events, with varying levels of fidelity to fact. The impacts of change are also unevenly distributed geographically, negatively affecting some regions of the country while positively affecting others.

Many of the threads to be woven together in the Project have decadal time scales and longer: climate change impacts, mitigation and adaptation; major business and capital commitments required for a low-carbon economy; education and training opportunities; policies and institutions

for addressing decreasing social mobility and rising inequality. Yet, disruptions to workers and communities can be quite sudden when economic conditions change – even when aggregate changes are in slow motion – and they often occur with little warning. Clearly, an integrated policy approach to reducing the costs of rapid change needs to show some near term progress while setting the vectors for long-term success.

The Roosevelt Project derives its name from three prominent figures in American history: Theodore Roosevelt for his stewardship of the environment during his presidency, protecting over 230 million acres of public land; Franklin Roosevelt for embodying a commitment to expanding the middle class in

response to the Great Depression and developing America's infrastructure in the New Deal through a variety of programs including the Tennessee Valley Authority, Works Progress Administration, and the Bonneville Power Administration, among others; and Eleanor Roosevelt for her staunch support of social justice issues, through, among other activities, chairing the UN Commission on Human Rights and overseeing the development of the Universal Declaration of Human Rights. This project looks to combine the legacies of these three titans of American history to develop policy priorities and an action plan that will enable us to move beyond the false choice of economic growth or environmental security. ■■■

*“... We’re going to have to straddle between the world as it is and the world as we want it to be, and build that bridge... that’s when we can start creating political coalitions that will listen to us, because we’re actually recognizing that some people have some real concerns about what this transition is going to do to them, to their pocketbook, and we’ve got to make sure that they feel like they’re being heard in this whole process.”*

— President Barack Obama  
South Lawn Panel Discussion on Climate Change  
October 3, 2016



Steve Ansolabehere



Jason Beckfield



John Deutch



David Foster



Daniel Gallagher



Amy Glasmeier



David Hsu



Valerie Karplus



Michael Kearney



Christopher Knittel



Richard Lester



Ernest Moniz



Fiona Murray



Robert Sampson



Richard Schmalensee



Dustin Tingley

Led by former U.S. Secretary of Energy and Cecil and Ida Green Professor of Physics and Engineering Systems emeritus Ernest J. Moniz, the faculty and senior research group at the Roosevelt Project aims to produce a series of policy white papers on energy and climate policy in the United States.

# Investigating the Necessity of Demand Characterization and Stimulation for Geospatial Electrification Planning in Developing Countries

*by: Stephen J. Lee, Eduardo Sánchez, Andrés González-García, Pedro Ciller, Pablo Duenas, Jay Taneja, Fernando de Cuadra García, Julio Lumbreras, Hannah Daly, Robert Stoner, and Ignacio J. Pérez-Arriaga*



Despite substantial progress in recent years, the global community is projected to fall short in its goal to achieve universal electricity access by 2030. State-of-the-art electrification planning models enable planners to outline pathways towards improving the economic feasibility of extending access. The studies presented in this paper employ the Reference Electrification Model (REM) to investigate the value of accurately modeling detailed demand characteristics for electrification planning endeavors. REM prescribes cost-optimal supply technology designs for large areas of interest at building-level granularities given information about existing infrastructure, supply technologies, and demand characteristics.

The International Energy Agency (IEA) recently estimated that roughly 860 million people live without electricity today. While this figure represents noteworthy progress from the 2016 figure of roughly 1 billion without access, there is still significant room for improvement. The IEA projects that, unless progress is accelerated, 650 million will still be left without access to electricity in 2030. While complex sociotechnical factors can hinder progress towards universal electricity access, economic constraints predominate for the majority of cases. In 2018, the IEA estimated that achieving universal energy access by 2030 would

require roughly \$55 billion of investment per year, with the majority being apportioned for electricity access. These expenditures are almost double the amount of investment expected.

State-of-the-art electrification planning models enable planners to outline pathways towards improving the economic feasibility of extending access. The studies presented in this CEEPR Working Paper<sup>1</sup> employ the Reference Electrification Model (REM) to analyze sensitivities for a 10,914 km<sup>2</sup> area of Uganda with 366,946 individual consumers, representing 20 consumer types. REM uses information about areas

with poor electricity access to determine cost-optimal electrification modes (e.g., grid-connected, mini-grid, or stand-alone system) for each consumer, estimate costs of electrification, and produce detailed engineering designs of recommended systems. The model takes account of highly granular economic and technical detail: it considers multiple customer types with different demand profiles, individual lines, transformers, and generation assets, medium and low voltage network codes, voltage drops, solar resource availability, and even topographical and streetmap-level information if desirable. The studies presented are unique from those

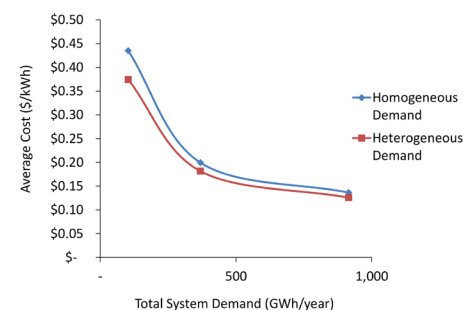
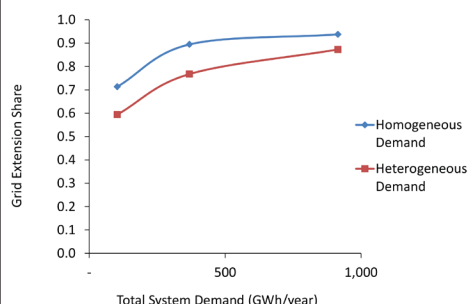
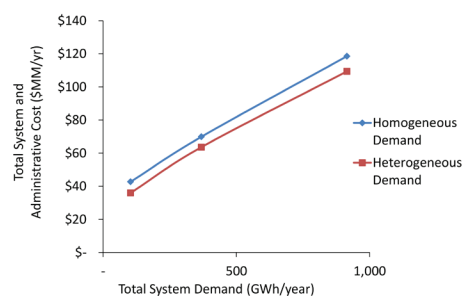


previously reported due to the high (individual consumer-level) spatial granularity, engineering design detail, and large areal extent of analysis.

A number of contributions are made. First, the criticality of adequately estimating demand and its evolution is demonstrated for large-scale planning; notable cost and supply technology sensitivities are observed as a function of anticipated demand levels. Over the domain of aggregate demand values modeled, the average cost of service provision range from \$0.13/kWh to \$0.37/kWh: a nearly three-fold difference. Second, the importance of representing demand heterogeneity is elucidated via modeling a diversity of consumer types. In the "central demand case" presented, modeling demand heterogeneity results in least-cost plans that are 9% less costly than modeling assuming one single customer type. Modeling heterogeneity also decreases prescribed grid extension shares from 89% to 77%, increasing the prevalence of mini-grid and stand-alone systems. Lastly, the potential economic benefits of demand stimulation are characterized.

We show how stimulating demand can lead to positive feedback loops: increasing electricity demand can lower electricity unit-costs through the realization of economies of scale and improved network utilization, which can improve the viability of additional electric loads, continuing the cycle. Specific studies comparing the economics of clean cooking via electric and liquefied petroleum gas (LPG) cookstoves show how these feedback loops can jointly benefit progress towards universal access to clean cooking and electricity. The demand assumptions modeled show that coordinated planning can reduce electricity costs by 34% and increase electric cookstove viabilities from 42% to 82%. ■ ■ ■

<sup>1</sup> Stephen J. Lee, Eduardo Sánchez, Andrés González-García, Pedro Ciller, Pablo Duenas, Jay Taneja, Fernando de Cuadra García, Julio Lumberras, Hannah Daly, Robert Stoner, and Ignacio J. Pérez-Arriaga, (2019), "Investigating the Necessity of Demand Characterization and Stimulation for Geospatial Electrification Planning in Developing Countries." *CEEPR WP-2019-018*, October 2019.



(Top left) As demand increases, total system and administrative costs increase nearly linearly.

(Top right) As demand increases, the share of consumers prescribed grid extension-based supply increases as well. Homogeneous demand assumptions bias plans towards higher costs and high grid extension shares.

(Bottom left) Finally, average costs per kWh of electricity served show significant economies of scale.



Stephen J. Lee



Eduardo Sánchez



A. González-García



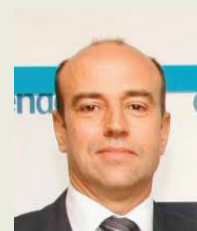
Pedro Ciller



Pablo Duenas



Jay Taneja



F. de Cuadra García



Julio Lumberras



Hannah Daly



Robert Stoner



Ignacio J. Pérez-Arriaga

# Implementing Negative Emissions Technologies (NETs): An Innovation Note

by: *John M. Deutch*

As prospects for emission reductions consistent with the temperature goals of the Paris Agreement look increasingly doubtful, attention is shifting from emissions reduction technologies to emission removal technologies. Such negative emissions technologies (NETs) include storage of carbon in coastal ecosystems, terrestrial carbon removal and sequestration, bioenergy with carbon capture and sequestration (BECCS), direct air capture, carbon mineralization of CO<sub>2</sub>, and sequestration of CO<sub>2</sub> in sedimentary geological formations.

If successfully deployed at scale, these NETs could fundamentally improve the likelihood of reducing global warming. So far, however, policymakers have been unable to agree on and adopt a practical suite of programs that would enable NETs to cross the “innovation bridge” from concept to deployment. What is needed, therefore, is a design for a NET innovation program that enables implementation of these technologies on a timescale aligned with the 2015 Paris Agreement objectives.

Implementation of such a program requires addressing multiple interconnected factors relevant to climate policy, including technical considerations as well as matters of economics, regulation, and market design. Importantly, for a new solution such as NET to gain policymaker approval and access to the necessary resources, advocates must come forward with a design for a concrete innovation program. A new MIT CEEPR Working Paper<sup>1</sup> outlines a management structure that will allow NET innovation to successfully cross the bridge from development to deployment.

Drawing on a 2018 National Academy of Sciences (NAS) study on NETs, the Working Paper describes four promising technologies in terms of technology readiness, scale up, extraction costs, carbon removal potential, and environmental impact: afforestation and reforestation, changes in forest management, uptake and storage by agricultural soils, and BECCS. While the NAS study contributes to the understanding of these technologies

and the types of research projects that can promote relevant innovation, it falls short of defining a structure to guide the creation and management of a practical NET innovation program.

As the Working Paper proceeds to outline the elements of such a NET innovation program, it first discusses the role of the Federal Government. Acknowledging the strengths and limitations of federal agencies in administering innovation programs, it outlines several potential roles and institutional options for the Executive Branch, especially in promoting early-stage fundamental research. Once innovation advances downstream to demonstration and early commercial deployment activities, market-based policy incentives and collaboration with private sector actors gain in importance. Quasi-public corporation projects offer a particularly promising structure to manage large-scale innovation projects at scale, from early stage technology R&D to deployment.

Stable funding is of particular



Attention is increasingly shifting to negative emissions technologies (NETs) as a lever to complement or substitute decarbonization efforts. Such technologies raise urgent technical questions around their risks, costs, and benefits, however, calling for a substantial research initiative to advance innovation on NETs and promote their demonstration and deployment.



importance for large, long term technology programs, suggesting a need to avoid the annual Congressional appropriations cycle and opt for federal multi-year funding arrangements instead. Congressional approval of such an arrangement will be highly dependent on whether the NET innovation program possesses a well-defined and credible management structure that includes a mechanism for periodic Congressional review to assess performance milestones and approve project continuation.

A large, interdisciplinary organization is therefore recommended to achieve NETs deployment at the necessary scale, with staff that is capable of addressing and integrating the technical, economic, regulatory, environmental, financial and political aspects required to realize a fielded practical system. The Working Paper describes organizational elements of such an organization, including executive and technical functions, the capability to perform robust policy analysis, and strong international cooperation and public outreach components.

Recalling the divisions about financial burden sharing for mitigation efforts in the international community, the Working Paper discusses some of the

implications of a U.S.-led investment in a NET innovation program, including questions of how to finance the corresponding public expenditures, how to deal with asymmetrical efforts by other countries, and how to manage rights to intellectual property (IP) in the context of federally supported NET innovation. Despite climate change and its solution being inherently global challenges, the analysis also tempers expectations of fruitful international collaboration beyond periodic transparency of efforts given the likelihood of politicization.

If the most urgent scientific and technical questions around the benefits, risks, and sustainable scale potential of NETs are to be successfully answered, a substantial research initiative to advance such NETs has to be launched as soon as practicable. To be successful, however, such an initiative needs an organization, supported by adequate resources, to formulate and execute a comprehensive multi-year plan based, to the extent possible, on quantitative analysis of the costs and benefits of emissions removal technologies relative to other carbon reduction measures.

Ambitious decarbonization goals, coupled with unreflected technology optimism among political leaders, risk

undermining the credibility of public authority and providing imperfect information to businesses, private investors and the public. If a NET initiative is to receive the significant resources required to develop and demonstrate the technology, it must be based on an explicit implementation structure. It is time for the climate community to go beyond calling for action and propose concrete practical innovation initiatives for scrutiny and possible adoption. Serious action will require serious work. ■

—Summary by Michael Mehling

<sup>1</sup> John M. Deutch (2019), "Implementing Negative Emissions Technologies (NETs): An Innovation Note", CEEPR WP-2019-012, MIT, August 2019.



John M. Deutch

## Providing the Spark: Impact of Financial Incentives on Battery Electric Vehicle Adoption

by: **Bentley C. Clinton and Daniel C. Steinberg**

Battery electric vehicles (BEVs) offer one pathway to reducing emissions from light duty vehicles; however, BEVs are generally more expensive than their internal combustion engine vehicle (ICEV) counterparts, due in large part to the current cost of batteries. National and subnational entities around the world offer incentives to BEV adopters in an effort to narrow this price gap

between BEVs and ICEVs. Are these policies effective in driving BEV purchases? Does the format of the incentive matter to prospective buyers?

In this study<sup>1</sup>, we examine the use of vehicle rebates and consumer tax credits for BEVs. We analyze a data set of vehicle registrations and incentive offerings to quantify the role that these incentives

have on vehicle purchases in the United States.

Controlling for the availability of vehicle charging infrastructure, fuel price levels, and local demographics, our analysis demonstrates a measurable increase in BEV adoptions in the presence of state-level purchase incentives. Specifically, we estimate that from 2011



This analysis estimates that state-level subsidies in the form of vehicle purchase rebates were responsible for an 11% increase in overall BEV registrations in the United States from 2011 to 2015 — an 8% increase per \$1,000 of incentive.

to 2015 state-level incentives increased adoption 11%, or 7% per \$1,000 of incentive value offered. Examining these trends by incentive type, our results indicate that vehicle rebates have significant effects on BEV adoption levels (8% per \$1,000 of incentive). Our estimates did not identify a positive effect for incentives offered as tax credits, though we caution that the lack of significant findings may be a result of limited policy variation in our data. Additionally, we allowed effects to differ across vehicle type, focusing on differences between purchases of Tesla models and non-Tesla models. We found no evidence that response levels differed based on the vehicle make that consumers ultimately purchased.

As decarbonization benefits are a commonly-cited rationale for transportation sector electrification, we use our results to derive preliminary estimates of welfare effects of these policies. We employ existing measures of regional emissions damages in the US to compare total program costs to estimated environmental benefits. As one would expect, aggregate environmental benefits are highest in regions with cleaner (i.e., lower-emitting)

electricity generation, however program costs—in particular, the level of free-ridership—outweigh these estimated benefits in all states that offer rebates. The decreasing emissions intensity of electricity generation in the US as well as additional benefits associated with increased adoption, such as long-term market growth, economies of scale advantages, network externalities, and accelerated innovation, could substantially affect net welfare outcomes.

Results of this analysis highlight three important observations about the future of transportation sector electrification: (i) incentives that mitigate the price disparity between BEVs and ICEVs are effective means to promote BEV adoption; (ii) within our sample, direct vehicle rebates appear most effective in driving new BEV registrations; and (iii) BEV adoption incentives as an instrument to solely achieve near-term carbon emission reductions should be carefully considered in the context of the emissions intensity of generation and against other instruments. This last point illustrates the importance of undertaking further work to quantify non-emissions consequences of BEVs

and hence providing a more complete picture of their benefits and costs. ■ ■ ■

<sup>1</sup> Bentley C. Clinton and Daniel C. Steinberg (2019), "Providing the Spark: Impact of Financial Incentives on Battery Electric Vehicle Adoption", *CEEPR WP-2019-015*, MIT, September 2019.



Bentley Clinton



Daniel Steinberg



# Crackdowns in Hierarchies: Evidence from China's Environmental Inspections

by: *Valerie J. Karplus and Mengying Wu*

A common byproduct of rapid industrial growth, severely polluted air damages human health and causes premature death. Researchers often attribute hazardous air quality to inadequate enforcement of environmental regulations, but the causes and extent of implementation failures are poorly understood. We study enforcement in China, an industrializing country that has experienced repeated episodes of severely degraded air. In late 2015 the central government announced rotating environmental inspections (*huanbao ducha* in Chinese) to strengthen enforcement by city-level environmental protection bureaus against polluting firms. Inspection teams from the Ministry of Environmental Protection are deployed to cities, where they conduct month-long reviews of local governments' environmental protection efforts. The goal of the inspections is to ensure all provincial-level regions follow the central government's instruction when implementing pollution control measures. These inspections constitute an example of an informal institution that temporarily raises central scrutiny

and regulatory enforcement at the periphery. We define such pre-announced increases in the stringency of regulatory scrutiny or enforcement as a "crackdown".

In this Working Paper<sup>1</sup>, first, we study how a centrally-led crackdown, in the form of rotating environmental inspections, affected pollution over time at coal power plants. We use high-frequency, plant-level data to quantify effects on the concentrations of a major short-lived industrial air pollutant, sulfur dioxide ( $\text{SO}_2$ ). We find that while crackdowns are in progress, pollution falls by 25-27%, a substantial decline. After inspectors leave, pollution reverts to prior levels within approximate two months. These findings suggest that crackdowns had no long-term effect on environmental performance as local agencies have weak incentives in environmental cleanup. By observing how power plants respond during crackdowns, we further investigate the origins of China's regulatory enforcement gap. During inspections, firms employ short-term measures that

reduce both  $\text{SO}_2$  emissions and electricity production. This finding confirms cost of reversal as a mediating factor in determining effects of crackdown. After inspections end, plant activity rises above baseline, while  $\text{SO}_2$  emissions gradually increase to prior levels. How the cost and reversibility of firm responses interact with a crackdowns' time horizon appear to be important determinants of whether the targeted behavior is deterred or simply displaced in time or space. Duration and expectations about the frequency of a crackdown's recurrence may interact with decisions about whether to implement a (less costly) short-term or (potentially more costly) long-term solution. In the case of China's environmental inspections, we find that firms employed short-term measures—turning scrubbers on, or temporarily restricting electricity output—that were relatively easy and rewarding to reverse. This corresponds to an expectation that crackdowns impose short-term pressure. Our findings suggest that an ongoing threat of scrutiny outside of inspection periods is needed to strengthen firms'



The researchers investigate how firms respond to crackdowns on public policy enforcement. During environmental inspections in China, concentrations of sulfur dioxide ( $\text{SO}_2$ ) at coal plants fall on average by 25-27%, but return to prior levels thereafter. A plant's accountability to central versus local regulators affects how long post-inspection reductions last.

incentives to fully comply with regulatory requirements such as installing scrubbers and operating them continuously.

Second, our findings shed light on the effect of agents' heterogeneous accountability structure on enforcing the principal's goal. Reversion occurs most rapidly among firms accountable to the central government, which originated the crackdowns, while cleanup persists longer among firms accountable to the local government. The differential rates of reversion may reflect an updating of expectations about the likelihood of punishment by the remaining (local) authority once the center has left. Managers of state-owned enterprises (SOEs) that outrank the city government ("upper SOEs") may have been more confident that they could escape detection or punishment, and returned to polluting sooner, while those subordinate to the city government ("lower SOEs") may have had residual uncertainty about the extent of any increased stringency in local government oversight. Our results are consistent with this uncertainty resolving several months after inspections end, when all plants had returned to prior polluting levels. The

short-lived nature of crackdowns and the more rapid reversion of centrally-connected state-owned enterprises suggests that the central authorities may be unable or unwilling to sustain cleanup pressure. To resolve such misalignment, the central government could continuously scrutinize the environmental performance of upper SOEs directly on an ongoing basis, rather than via regional campaigns.

We then consider the effectiveness of involving citizens in environmental oversight in the crackdown context. We study one component of the crackdowns: allowing citizens to complain about pollution via hotlines, mailboxes, and social media while an inspection is in progress. The local environmental protection bureau was required to investigate and formally respond to all complaints against plants located in a city. We find that citizens do not tend to complain about dirtier plants on average, and although plants receiving complaints reduce pollution more during crackdowns, they also return more rapidly to baseline levels of pollution after crackdowns end. However, inspections may also improve perceptions of state effectiveness among the broader populace. The

media's likening of inspections to organizational approaches used in imperial China (Imperial Commissioner, *qinchai dachen* in Chinese) may only strengthen this perception. The inspections could thus shore up legitimacy in a time of (environmental) crisis — an important benefit for leaders in an authoritarian regime. These benefits could accrue to the crackdown's originators, even if there is no lasting effect on pollution. However, the durability of the inspection approach not yet known. Legitimacy benefits to the central leadership may erode if citizens discover that pollution reductions do not last. ■

<sup>1</sup>Valerie Karplus and Mengying Wu (2019), "Crackdowns in Hierarchies: Evidence from China's Environmental Inspections", CEEPR WP-2019-017, MIT, October 2019.



Valerie Karplus



Mengying Wu

## Diary of a Wimpy Carbon Tax: Carbon Taxes as Federal Climate Policy

by: **Christopher R. Knittel**

A federal carbon price of \$7 in 2020 could reduce emissions by the same amount as all flagship climate policies adopted by the Obama administration. That is the headline result of a new research paper released by the MIT Center for Energy and Environmental Policy Research (CEEPR)<sup>1</sup>, which models the carbon price needed to achieve projected emission reductions under Obama-era vehicle mileage standards, the Clean Power Plan, and a biofuel mandate.

"What this shows is the power of a price on carbon", says Christopher R. Knittel, the George P. Shultz Professor at the MIT Sloan School of Management and CEEPR Director. "As little as a 7¢ price increase per gallon of gasoline and less than half a penny per kWh of electricity could get us the same climate benefits as the fragile, costly and litigious regulations that represent President Obama's climate legacy. And let's not forget that all these regulations are under attack by the current administration."

Over time, the carbon tax would rise to match the growing stringency of those regulations. "But we're still only looking at \$22 per tonne in 2025 and \$36 per tonne in 2030 if we include all major greenhouse gases", notes Knittel. Matching the emissions reductions forecast under each regulation would not be enough to get the U.S. on a long-term path to decarbonization, however. "The previous administration's rules would have only taken us part of the way," Knittel adds. Still, if we get





# CARBON TAX

Christopher Knittel uses MIT's Emissions Prediction and Policy Analysis (EPPA) Model to calculate the carbon tax required to replace the major federal climate change policies that existed as of 2016: Corporate Average Fuel Economy (CAFE) Standards on light-, medium-, and heavy-duty vehicles; the Clean Power Plan (CPP); and the Renewable Fuel Standard (RFS).

# \$7

*The level of a carbon tax in 2020 that could reduce emissions by the same amount as the flagship climate policies of the Obama administration.*

really serious about climate policy, the costs will only rise – and the cost-saving potential of carbon pricing will become even more important.”

Nevertheless, despite near-unanimity among economists that putting a price on greenhouse gas emissions is required to efficiently address anthropogenic climate change, carbon pricing has been vilified from both the left and the right. From the left, pricing carbon has been perceived as a “wimpy” tool, coupled with concerns that such a tax would be regressive and disproportionately impact low-income and minority households. From the right, carbon pricing is lumped in with other taxes that are, from an economics standpoint, a drain on the economy even though carbon pricing improves the efficiency

of economies.

As decision makers in the nation’s capital consider policy options to revitalize U.S. climate policy for 2020 and beyond, these results could be a political game changer. Knittel hopes that this first effort to model the carbon tax equivalent of alternative climate regulations could help build a consensus around more cost-effective policies. “Instead of trying to bring back earlier rules such as the Clean Power Plan, a new administration would do well to focus on one of the many carbon tax proposals introduced on Capitol Hill by both sides of the political aisle,” he suggests. “If we can make a given climate outcome more affordable, then we can also aim higher sooner. And we know that, under all scenarios, we have to

drastically increase our efforts to meet the climate challenge.” ■

—Summary by Michael Mehling

<sup>1</sup> Christopher R. Knittel (2019), “Diary of a Wimpy Carbon Tax: Carbon Taxes as Federal Climate Policy”, CEEPR WP-2019-013, MIT, August 2019.



Christopher Knittel

## Notable Changes

With the start of a new academic year, CEEPR has continued to grow, and we are pleased to have the following faculty, students, and visitors join our group this autumn.

**Clare Balboni** joins the MIT CEEPR faculty as the 3M Career Development Assistant Professor of Environmental Economics at the Department of Economics. Her research focuses on topics in environmental economics, trade and development economics. Recent research includes an in-depth study of adaptation of road networks in the face of climate change and an analysis on whether large infrastructure investments should continue to favor coastal areas in the coming decades as natural disasters intensify and sea levels rise.

CEEPR also welcomes **Jacquelyn Pless** to the faculty as an Assistant Professor in the Technological Innovation, Entrepreneurship, & Strategic Management group at the Sloan School of Management. Jacquelyn's research primarily focuses on trying to develop a better understanding of how to drive and accelerate innovation that protects environmental systems, especially clean energy innovation. Current work examines how the interaction of tax credits and grants for research and development impact firm behavior and innovation investments, how environmental regulation impacts firm performance, and the role of start-ups in the energy sector.

Professor **Kostas Metaxoglou** is an Associate Professor in the Economics Department at Carleton University and is spending his academic sabbatical at the MIT Sloan School of Management and CEEPR as a Visiting Professor. He joined the faculty at Carleton as an Assistant Professor in 2013 having previously worked as a senior consultant and manager with the Antitrust practice of Bates White LLC. His research focuses on Energy Economics, Industrial Organization, and Applied Econometrics

and has appeared in outlets such as the *Review of Economics and Statistics*, the *Journal of Applied Econometrics*, and the *American Journal of Agricultural Economics*. His most recent projects are related to the U.S. electric power sector and include topics on estimating the effects of power plant emissions on agricultural productivity, assessing the environmental implications of market structure, and studying the role of investment in coordinating environmental regulations across different jurisdictions. He will be collaborating with CEEPR faculty on topics related to the effects of power plant emissions on health, the implications of the U.S. shale gas boom on the global trade and consumption of coal and emissions, and how the use of intermittent renewable sources in electricity generation affects the scheduling of ancillary services provided by fossil-fueled sources.

This semester, CEEPR supports several new students from MIT's Technology and Policy Program as Graduate Research Assistants.

**Michael Cheng** will be working directly with CEEPR Director Christopher Knittel on various projects pertaining to climate change and education, including the development of an MIT high school curriculum on climate change and the analysis of the effects of climate change education on household electricity usage.

With the launch of the Roosevelt Project, several students have joined CEEPR's cohort this year, and Senior CEEPR RAs **Tomas Wesley Green** and **Benny Ng** have shifted over to the project with new research foci.

Tomas will continue to be supervised by Professor Christopher Knittel as he studies the effects of climate policy on U.S. households and how effects vary by geography, socioeconomic status, urbanity, and policy design. They are hoping to understand the trade-offs

between equity and efficiency, and the distribution of incidence of carbon taxes.

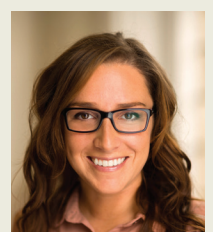
Benny and **Sade Nabahe** will be working with David Foster, a former senior advisor to Secretary of Energy Ernie Moniz during the Obama administration. Together, the team will explore the future of the energy and energy efficiency work force—its current challenges and anticipated changes. Among the topics their white paper will discuss are work force training challenges being created by new technologies, the role of big data management, smart cities, IoT, artificial intelligence, the utilization of robotics, the adequacy of existing federal and state job training programs, the role of apprenticeship programs, and how evolving business models might change workforce demands.

**Nina Peluso**, a first-year TPP student, joined the Roosevelt Project to study historical industrial transitions and the relationship between industrial success, local economic development, and corresponding public policy. Her research will inform best practices for policymaking in the context of a deeply decarbonized U.S. economy.

In addition, CEEPR welcomes **Sohum Pawar**, a second-year TPP student. As a Research Assistant for the Roosevelt Project, Sohumi is studying how U.S. regions that rely on carbon-driven industries can use the development of entrepreneurial capacity to harness the benefits of the transition to a low-carbon economy, in an equitable and resilient manner.



Clare Balboni



Jacquelyn Pless

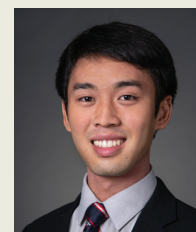


Finally, CEEPR continues to maintain our Visiting Student program, and this semester we are hosting **David Matthäus**, a Ph.D. candidate under the supervision of Professor Gunther Freidl from the Technical University at Munich in Germany. During his time at CEEPR, David will assess empirically what an effective design for auctions of

renewable energy support looks like. He will also be working closely with CEEPR Deputy Director Michael Mehling on designing a mechanism to reduce the risk, and thereby the financing cost, of renewable energy investments worldwide and will assess the impact with a simulation model.



Kostas Metaxoglou



Michael Cheng



Tomas Wesley Green



Benny Ng



Sade Nabahe



Nina Peluso



Sohumi Pawar



David Matthäus

# PUBLICATIONS

## Recent Working Papers

### WP-2019-018

**Investigating the Necessity of Demand Characterization and Stimulation for Geospatial Electrification Planning in Developing Countries**

Stephen J. Lee, Eduardo Sánchez, Andrés González-García, Pedro Ciller, Pablo Duenas, Jay Taneja, Fernando de Cuadra García, Julio Lumbreras, Hannah Daly, Robert Stoner, Ignacio J. Pérez-Arriaga, October 2019

### WP-2019-017

**Crackdowns in Hierarchies: Evidence from China's Environmental Inspections**  
Valerie J. Karplus and Mengying Wu, October 2019

### WP-2019-016

**Strengths and Weaknesses of Traditional Arrangements for Electricity Supply**  
Richard L. Schmalensee, October 2019

### WP-2019-015

**Providing the Spark: Impact of Financial Incentives on Battery Electric Vehicle Adoption**  
Bentley C. Clinton and Daniel C. Steinberg, September 2019

### WP-2019-014

**Estimating the Costs and Benefits of Fuel-Economy Standards**  
Antonio M. Bento, Mark R. Jacobsen, Christopher R. Knittel, and Arthur A. van Benthem, September 2019

### WP-2019-013

**Diary of a Wimpy Carbon Tax: Carbon Taxes as Federal Climate Policy**  
Christopher R. Knittel, August 2019

### WP-2019-012

**Implementing Negative Emissions Technologies (NETs): An Innovation Note**  
John M. Deutch, August 2019

### WP-2019-011

**Spatial and Temporal Variation in the Value of Solar Power across United States Electricity Markets**  
Patrick R. Brown and Francis M. O'Sullivan, July 2019

### WP-2019-010

**Decentralized Economic Dispatch for Radial Electric Distribution Systems**  
Sruthi Davuluri, July 2019

### WP-2019-009

**On the Efficiency of Competitive Energy Storage**  
Richard L. Schmalensee, June 2019

### WP-2019-008

**Optimal Commodity Taxation with a Non-Renewable Resource**  
Julien Daubanes and Pierre Lasserre, May 2019

All listed and referenced working papers in this newsletter are available on our website at [ceep.mit.edu/publications/working-papers](http://ceep.mit.edu/publications/working-papers)



Professor David Newbery of EPRG (left) and Professor Christopher Knittel of MIT CEEPR (right) with UK Minister of State at the Department of Business, Energy and Industrial Strategy Kwasi Kwarteng MP (center) at the 2019 EPRG-CEEPR International Energy Policy Conference in London on September 2-3, 2019.