Research Statement

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My research lies at the intersection of empirical industrial organization and energy and environmental economics. My work examines how energy and environmental policies can be improved by taking into account the strategic behavior of firms and consumers. A key theme of this work is how government policy can improve the efficiency of how markets provide new technologies and infrastructure, with a focus on the electric vehicle industry. I also study the valuation of non-market environmental (dis)amenities such as noise and water quality. In my work, I combine economic models of strategic interactions, market data, and econometric tools of causal inference and structural estimation. The model and its estimated parameters allow me to analyze the counterfactual impacts of potential policies on market outcomes and social welfare.

(I) Electrifying Transport

The transportation sector is one of the largest sources of climate-changing greenhouse gases and hazardous local pollutants. Transitioning the transportation system to lower-pollution options requires infrastructure investments, deployment of new technology, and changes in consumer choices. I study how policy can address market frictions in the transition to an electrified transportation system.

Incompatibility in electric vehicle charging infrastructure. In *Compatibility and Investment in the U.S. Electric Vehicle Market (revision requested by the American Economic Review)*, I study the potential impacts of mandating charging compatibility on U.S. electric vehicle (EV) sales, charging station investment, consumer surplus, and firm profits. A refueling network is crucial for market penetration by any alternative fuel vehicle, such as hydrogen, natural gas, and electric vehicles. EV manufacturers have invested heavily in building fast-charging stations throughout the U.S. However, fast-charging stations are divided across three incompatible standards. Vehicles built for one standard cannot recharge at a station of another standard, and only one adapter has been developed. Establishing a single charging standard may benefit consumers by allowing them to access all stations. However, compatibility may lower the incentives for car manufacturers to invest in charging stations. If firms' investments benefit their competitors, then they would under-invest relative to the socially efficient level.

To quantify the effect of mandating compatibility in EV charging stations, I specify and estimate a model of consumer vehicle choice using data from the U.S. from 2011 to 2015. Consumers in the discrete-choice model derive utility from purchasing a vehicle from the market, including electric as well as other fuel types. I cast the charging network of an EV as a characteristic of the vehicle. Consumers in the model consider the number of charging stations in their city as well as how many cities they can reach driving that electric vehicle. This consumer demand model is realistic and leads

to a computationally tractable supply-side model of firms' charging station investment choices. The main structural parameters of interest are EV demand elasticities with respect to prices and charging stations. I meticulously assemble a novel panel of two types of government subsidies to gain causal estimates as inputs to the counterfactual simulations. I find that compatibility in charging standards, as recently mandated by the E.U., would decrease duplicate investment in charging stations and increase the total number of EVs sold by about 20%. Given the aggressive EV adoption targets in many countries and accompanying subsidies on the order of billions of dollars annually, my findings contribute an effective, revenue-neutral option to the policy discussion. The Infrastructure Investment and Jobs Act (IIJA) of 2021, which devotes $7.5 billion toward public charging infrastructure, stipulates that stations funded by the Act must be widely accessible.

Entry and Coordination in the U.S. Electric Vehicle Charging Industry (with Katalin Springel, slides available). The 2021 IIJA directs $7.5 billion toward EV charging infrastructure and prioritizes building fast charging stations at most 50 miles apart along U.S. highways. The efficiency of this policy crucially relies on the existence of frictions in the market provision of charging stations. If the market generates "holes" in charging networks, then the every-50-mile subsidy could be efficient. Otherwise, a uniform subsidy would be sufficient to internalize any environmental advantages of electric vehicles. We assemble a novel dataset about travel patterns, vehicle registrations, charging station entry locations and dates, and station-level charging demand. We investigate whether a new charging station entrant generates positive spillovers for incumbent charging stations in different distance bands, and in a second specification, along specific routes. Preliminary findings show that charging demand for incumbents increase by .63 percentage points (or 26% of the mean utilization) when a route becomes connected with charging stations every 50 miles. In a placebo test, we find no evidence of spillovers when the entrant and incumbent are on different charging standards, thus alleviating concerns about common shocks. This is preliminary evidence of the existence of positive spillovers from entry, which is necessary but may not be sufficient for market provision of charging stations to be inefficient.

The choice between the every-50-mile and uniform subsidies depends on whether charging network companies efficiently coordinate entry on their networks. We are investigating whether charging network companies help charging stations internalize their positive spillovers. For example, are entrants that fill holes more likely to share networks with incumbents on those routes? We will next build a structural model of the EV charging industry, including consumer vehicle and charging demand as well as the vertical relationship between charging networks and station site hosts. We will estimate our model and simulate the impacts of two government subsidy designs: the every-50-mile policy and a uniformly available subsidy.

(II) Regulation and Market Provision of New Technology and Infrastructure

Policies often rely on the deployment of new technology and infrastructure to solve a market failure and reach an efficient market outcome. For example, environmental regulation may try to reduce

pollution with new emission control technology or new transportation fuel. Policies may also try to provide universal access to services such as electricity or telecommunications, motivated by equity objectives and/or market inefficiencies. I study how strategic behavior, imperfect competition, and market structure affect environmental and energy policies.

Automaker collusion against environmental regulation. Violation of environmental regulation is a pervasive problem. Noncompliant agents can evade detection because the regulator has imperfect information. In *Colluding Against Environmental Regulation* (under review), joint with Jorge Ale-Chilet, Cuicui Chen, and Mathias Reynaert, we empirically investigate how firms may undermine regulatory enforcement by colluding over compliance strategies. In July 2021, three of Germany's largest automakers settled with the European Commission (EC) to pay a total of 875 million euros for restricting competition on the effectiveness of nitrogen oxide (NOx) cleaning systems in their diesel vehicles. This is the first instance of a cartel prohibition decision by the EC for cooperation in technical development as opposed to price collusion.

We begin with a simple model to illustrate how carmakers benefit from colluding over NOx cleaning technology. Firms face a pollution standard that is imperfectly enforced because of monitoring costs. Insufficient pollution abatement incurs noncompliance penalties in expectation, consisting of fines, legal costs, and reputation damages. However, abatement increases firms' marginal costs and compromises product attributes that consumers value. The resulting variable profits decrease with a firm's own abatement and increase with competitors' abatement. A firm's payoff is its variable profit minus the expected noncompliance penalty. Firms choose their pollution abatement either non-cooperatively or following a joint scheme. Our model shows that the incentives to collude are generated by the enforcement of regulation and stem from positive externalities that firms' abatement actions impose on each other's expected penalties.

We combine our model with data on vehicle sales from the European automobile industry from 2007 to 2018 to quantify the impact of collusion on automakers' profits, buyer surplus, and societal health damages. We find that the collusion lowers expected noncompliance penalties substantially and increases buyer and producer surplus. Buyers of the more polluting vehicles benefit because they have access to cheaper vehicles with larger trunks. Everyone in society is harmed by additional air pollution, and our empirical estimates show that those harms outweigh the private benefits of collusion. Antitrust complements weakly enforced environmental regulation and brings the EU regulatory environment closer to a residual-claim policy. However, the antitrust fines imposed on the working group are not sufficient. While the antitrust fines are sufficient to repair welfare damages ex-post, they fall short of deterring welfare-decreasing collusion on noncompliance ex-ante.

Cost pass-through in ethanol retail. Biofuels, made from organic matter such as corn and grass, are one potential avenue toward reducing greenhouse gas emissions from transportation. In *Cost Pass-Through to Higher Ethanol Blends at the Pump: Evidence from Minnesota Gas Station*

Data (Journal of Environmental Economics and Management, 2019), joint with James Stock, we study pass-through of compliance costs from the Renewable Fuel Standard (RFS). The RFS aims to increase the penetration of biofuels in the U.S. surface transportation system by reducing the relative price of biofuels. However, incomplete pass-through may prevent consumers from seeing the intended discount on biofuels. Using data on station-level prices and gallons sold in Minnesota from 2005 to 2015, we trace pass-through of RFS compliance costs in the supply chain. We find evidence of incomplete pass-through from the commodity level to the retail level. In particular, about 50 cents of every dollar of the RFS subsidy is captured by retailers (gas stations). In other words, for a consumer choosing fuel at the pump, biofuels do not appear as cheap as the RFS intended. Therefore, the challenge in increasing biofuel consumption first rests on ensuring that subsidies reach consumers. Our findings can explain the high compliance costs of the RFS for producers. We find that pass-through is nearly perfect in densely populated areas with more competitive fuel retail markets. The results demonstrate that supporting competition can increase the effectiveness of consumer subsidies.

Cooperative governance and infrastructure in rural areas. Nearly a century ago, the U.S. successfully electrified its rural areas through the Rural Electrification Administration (REA). With Joe Shapiro, we study the impacts of rural electrification in the U.S. and examine the factors that contribute to the success of U.S. rural electrification efforts. Specifically, we ask whether one or both of the following factors were pivotal in the success of the U.S. REA: (i) working with grassroots, non-profit cooperatives and (ii) subsidized loans (electricity cooperatives could borrow at the 10-year bond rate, and later, at 2%). We ask why cooperatives are successful in providing infrastructure in sparsely populated areas. We hope to contribute to an understanding of how to electrify rural areas in the present day as well as how to implement universal service programs for broadband internet. This project uses archival data. We have collected and digitized annual statistics from 1935 to 1950 on the miles of power lines electrified, the number of households connected, and aggregate energy consumed. Our strategy for causal identification of the impact of electrification relies on the travel itinerary of the REA's electric appliance demonstration group, which aimed to increase demand for electricity connections. We will specify and estimate a structural model of household demand for electricity and cooperative governance and decision-making. Using our model, we will simulate electricity coverage areas with different cooperative voting rules and loan subsidies.

(III) Non-Market Valuation of Environmental (Dis)Amenities

Benefit-cost analysis is at the heart of regulatory and policy decisions. Some policies may indirectly worsen an environmental disamenity, such as the Federal Aviation Administration's decision about whether to concentrate flight paths over narrow corridors, while others such as water quality regulations have clear costs yet diffuse benefits. I hope to contribute novel data and empirical strategies while providing empirical estimates that support policy decisions.

Housing value impact of flight noise (draft will be available soon). With Christopher Knittel, Xibo Wan (MIT post-doc), and scientists from the MIT Aero-Astro department, we are investigating the housing-value impacts of the Next-Generation Air Transportation System (NextGen). NextGen uses advanced aircraft positioning systems to route flights more precisely. This improves safety and reduces fuel consumption. However, NextGen concentrates flights and thus flight noise into narrow corridors, which may negatively impact the health, productivity, and well-being of residents below them. The negative impacts of the policy may not be entirely offset by noise reduction outside these corridors, as the effects of noise may be nonlinear in duration or frequency of events. The rollout of NextGen across U.S. airports over time and the concentration of flights into narrower corridors allows us to use a geographic differences-in-difference approach to recover the causal impact of flight noise on housing values. We evaluate the costs to residential housing value from NextGen and compare these costs to the environmental benefits. We find that the introduction of high-precision RNAV and/or PBN procedures has led to an average 1.5% decrease in the prices of houses surrounding the airport.

Recreation value of clean water (draft will be available soon). The U.S. has spent nearly 5 trillion dollars to improve water quality since the founding of the Environmental Protection Agency. However, the benefits are diffuse and difficult to measure due to data constraints, often leading to failed benefit-cost analyses for specific investments and grant programs. With Christopher Knittel and Xibo Wan, we study the value of water quality at recreation sites using data from mobile devices. These mobile data provide a large and representative sample of the U.S. population for whom we observe the home location linked to all recreational visits. We combine the mobile movement data with data on water quality to construct a comprehensive, novel, and detailed dataset of over 6,000 water recreation sites and link them to water quality measures and the visits made by 43 million households. We estimate a discrete choice model of recreation demand for lakes and rivers using the mobile movement and water quality data. We find that closing the most popular sites would lead to a loss in surplus of $11 per capita, on average. These estimates highlight significant benefits of clean water regulation that have previously been difficult to capture.