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For my parents, Kathy and George, who raised me to value and pursue a rich and engaged intellectual life. And for Professor Jeremiah Murphy, who introduced me to the nuanced and captivating world of public policy.

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ABSTRACT

My dissertation considers examples of how social, economic, and political incentives associated with energy production, distribution, and consumption increase the risk of harm to society and the environment.

In the first essay, "Why America should move toward dry cask consolidated interim storage of used nuclear fuel," my co-authors and I discuss how the confluence of the U.S. Government and electricity utilities' political and economic incentives created a gridlock preventing a long-term nuclear waste disposal solution. We find that our current policies undermine the safety and security of nuclear waste and suggest a temporary, consolidated storage solution.

In the second essay, "Import-Adjusted Fatality Rates for Individual OECD Countries Caused by Accidents in the Oil Energy Chain," my co-authors and I adopt a technique from the greenhouse gas accounting literature and assign CO_2 emissions to the final consumer (rather than the producer) by allocating the risk — measured in fatalities — associated with oil production to the final consumer. The new assignments show that normal methods of tracking oil production impacts only capture part of the actual costs.

In the third essay, "Insurgent Attacks on Energy Infrastructure and Electoral Institutions in Colombia," my co-authors and I consider the economic and political incentives that energy resources create in a conflict environment. Our research shows that insurgents in Colombia, Las Fuerzas Armadas Revolucionarias de Colombia (FARC) and Ejército de Liberación Nacional (ELN), strategically time attacks on critical energy infrastructure during elections. These results are the first to quantify insurgent tactics to target critical energy infrastructure, which potentially undermine state capacity and democratic processes.

CHAPTER 1

INTRODUCTION

My dissertation considers examples of how social, economic, and political incentives associated with energy production, distribution, and consumption increase the risk of harm to society and the environment. My co-authors and I examine how risks can result from, or be exacerbated by, policy decisions influenced by perverse incentives and poor risk internalization.

The energy sector is in a policy paradox: while producing, transporting, consuming, and disposing of energy — basic energy sector operations — are principle drivers of the global economy and society, these energy operations are also associated with undesirable consequences. The undesirable consequences range from the depletion of natural resources to pollution and impacts on society such as increased risks to human health and critical infrastructure. This dissertation focuses on the increased risks associated with these necessary energy operations. The occurrence, severity, and ultimate impact of these physical risks span a wide range, governed not only by chance but also by factors such as management practices, regulation, technology, and information (see Figure 1.1). However, because these risks are evaluated within a national or global context that determines their relative importance and value, the degree to which undesirable consequences are researched, identified, quantified, and internalized varies greatly. In other words, the undesirable consequences manifesting as risks can be deemed externalities and internalized by society as costs based on external factors such as realization, quantification of consequences (potential or realized), regulation, technology, information, property rights, and political will.

Energy policy is used to manage this paradox and balance the benefits and costs of how energy is produced, distributed, consumed, and disposed of. To manage the paradox successfully over time, interested stakeholders (e.g., industry, government, public) must complete

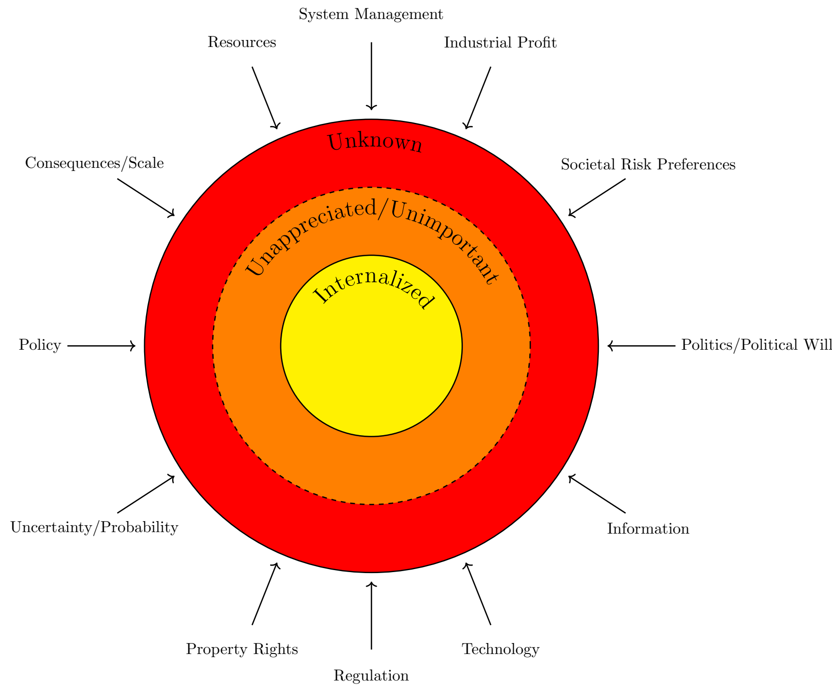

Figure 1.1: Drivers of Energy System Physical Risks Internalization

three overarching sets of steps, each of which requires strong engagement and communication among those stakeholders. The first steps toward striking a balance are identifying, understanding, and updating the risk externalities associated with each energy system. The phrase "risk externality" is used here to mean physical risks to society and the environment that are byproducts of an energy policy. We will argue that, because of the complex nature of these risks, they are underappreciated. These initial steps are a part of a continuous and iterative process that must reflect new energy-producing technologies, methods of detecting externalities (i.e. new information), and changes to regulation. The second set of steps is determining the extent of the risks and diagnosing the associated costs, whether social, political, or economic. Typically, risk assessments are used to quantify recognized risks as well as to identify new risks and to estimate probabilities and costs if those risks occur. The last, but arguably most important and difficult step, is to craft realistic solutions by incorporating the information from the first and second sets of steps into a strategy for transitioning from the status quo to a new policy regime.

Historically, risks have not been widely incorporated into energy policy decision making. There are historical reasons for this that have given rise to current incentives. First, energy sector operations have been increasing in complexity and scale over time. As the scale has increased and more stakeholders have become implicated in energy operations, new risks have arisen, and risks or accidents that might have been relatively inconsequential at a small scale have become substantial. Some stakeholders now have incentives to site historical measures and regulations of impacts that do not include new information in order to maintain the historical status quo. Second, this lack of increase in awareness about risks associated with energy systems is due in part to the nature of the risk externalities: without the realization of a risk into a consequence, the existence of a risk may remain unknown or underappreciated; energy risk externalities begin, and may remain, geographically isolated (e.g., where the plant is located); they may not be detectable by human senses/measurements until consequences are realized and acute, if ever; realized impacts are frequently cumulative; historically, the methods to adequately incorporate and understand the risks were not widely available, though the ability to detect risk externalities has been increasing over time (e.g., through assessment improvements such as Probabilistic Safety/Risk Assessment (PSA/PRA)); at a fundamental level, the label "risk" is subjective and shaped by individual preferences. These attributes of risk encourage common decision making errors, for example, high temporal discounting and the use of decision making heuristics (e.g., status quo bias). In addition to these attributes, because underappreciated risks are both normative and largely intangible, communicating risk information objectively is challenging. The difficulty in communicating risks also can encourage the misunderstanding or the disregarding of risks. Even those risks that have realized consequences often are not dealt with because there are no social and regulatory regimes to enforce accountability. In failing to incorporate new information about risks and internalize that information into updated costs and benefits, we have created systems globally to produce, sell, and distribute energy that asymmetrically favor the benefits and costs that already have established probabilities and market prices. This global system has generated complex incentives for stakeholders based on incomplete information and undermines the desire and ability to internalize more of the risk externalities caused by producing energy.

There are two additional concepts that play important roles in shaping the energy sector and require more discussion at an introductory level: risk assessment and communication subjectivity and energy policy trade-offs. In the next two subsections, I discuss some of the complications these concepts imply for the energy sector.

1.1 Risk assessment and communication subjectivity

Communicating energy policies to a range of different stakeholders creates many informational challenges. In particular, it is difficult to communicate risk to a wide audience of stakeholders over different energy systems (e.g., grossly simplified: from "experts" in the field to laypeople outside of the field or "non-experts") because risks are not typically comparable across energy systems and different stakeholders have different interpretations of the risks. Any one stakeholder may be more concerned with or be knowledgeable about a different aspect of the risks related to one energy system than another stakeholder. For example, the industry stakeholder may be concerned with the safety of employees, the safety of the public, and preventing a service interruption if an accident occurs while the public stakeholder may be most concerned with environmental damage and the safety of the local population. Greater preference for, or knowledge or fear of, particular aspects of an energy system can lead to non-linear weighing of the involved risks and other decision making distortions. Even among experts in one domain, disagreement can arise early when choosing a method to quantify or analyze the risks of a system. As a result, experts inevitably influence risk assessments with their methods, perspective, and opinions. Furthermore, in deciding what to communicate and with what metrics, experts (or others communicating risks based on risk assessments) also influence how the information is perceived and processed. Ultimately, the degree to which a risk is understood and internalized into energy policy depends on how it is communicated and therefore on the difficulties of such a communication.

1.2 Energy policy trade-offs

Energy policy operates in the grey area where technology, politics, economics, and society come together and must be weighed against each other and balanced. Frequently, juggling the priorities from each leads to incompatible policy prescriptions: fulfilling one policy objective necessarily means not fulfilling another. For example, one policy objective could be to offer customers the lowest electricity price possible while the other might be to improve air quality. The first policy objective might compel policy makers to choose coal as an energy source while the second policy objective would favor electricity from nuclear, wind, or solar. While in theory, new policies are intended only to make improvements, in practice, as the example above illustrates, many policies may improve one policy objective while worsening another temporarily or permanently. Many times, these gains and losses will affect the same people, and as a result, people will choose a policy that addresses the impact most salient to them. Incorporating externalities into policy can also give rise to situations in which the majority may be made better off, but a powerful minority, made worse off, will fight the policy. Consider as an example an electricity utility generating power from coal plants facing a carbon tax to reduce greenhouse gas emissions. Such a tax would reduce the profits of the utility, and as a result, the utility has an economic incentive to fight the carbon tax. In complex situations such as the electricity utility and carbon tax example, policy makers must often develop the "optimal and feasible" or "second best" policy regarding risks and safety instead of holding out for the "optimal" or "first best" policy. While it is not uncommon to use the second best policy in other policy sectors, the energy sector is distinctive because it has an interplay among political and social acceptability, technical appropriateness, and trade-offs among multiple energy systems. Technical expertise is crucial for creating policy and avoiding unintended risks; however, we see repeatedly that the technically correct solution may not be the economically, socially, or politically acceptable solution. In multiple examples, we also see that the failure to incorporate deep social knowledge can lead to perverse incentives that undermine policy objectives. In all cases, there are unavoidable trade-offs among policy objectives and energy systems that must be considered and communicated carefully.

The papers in this dissertation discuss three manifestations of "risk externalities" in three distinct settings: U.S. nuclear waste disposal, international oil production and trade, and critical national energy infrastructure such as pipelines and electricity transmission lines. In each case, a necessary function of the energy sector creates a risk or perverse incentive leading to additional risks. We apply the steps of the framework above — identifying new risks, quantifying the scope and costs associated with the new risks, and developing a feasible policy solution — using different risk assessment and communication methods including reframing the policy problem, non-expert risk communication leading to a policy recommendation, and econometric analysis.

In "Why America should move toward dry cask consolidated interim storage of used nuclear fuel," Professor Rosner and I discuss the U.S. Government and the electricity utilities' responsibility for used nuclear fuel storage and disposal. We focus on the political and economic incentives that have unfolded from historical policies, regulations, and politics. In agreement with others, we find that the government and utilities' incentives have delayed a long-term storage and disposal solution and helped shape the current used fuel policies that undermine the safety and security of the used fuel. We offer a policy recommendation for temporary, consolidated storage that can work despite the historical complications and existing incentive structure. Our policy recommendation takes into account the technical requirements for used fuel storage, the current inventory and location of used fuel across the country, the feasibility of storage options (status quo and new options), and the current political, social, and economic incentives and constraints.

Next, in "Import-Adjusted Fatality Rates for Individual OECD Countries Caused by Accidents in the Oil Energy Chain," my co-authors and I illustrate differential impacts on countries producing and consuming energy from oil. To do this, we adopt a technique from the greenhouse gas accounting literature of assigning CO_2 emissions to the final consumer (rather than the producer) by assigning a portion of the risk associated with oil production to the final consumer using import-export data. The motivating idea behind greenhouse gas emissions and oil production fatalities accounting is to estimate — for illustrative purposes — who bears the consequences of energy producing activities based on the current market and trading relationships. We update and use the unique dataset, the *Energy Related Severe Accident Database* (ENSAD), to quantify the consequences of energy accidents using fatalities. Our findings support the hypothesis that economic and social incentives have allowed countries who consume the benefits of energy production to avoid the environmental and social consequences of producing that energy — even if they ultimately pay for other countries to bear those consequences. For countries importing oil, the adjustment to account for the fatalities associated with consuming energy is significant. Such adjustments indicate that normal methods of tracking the impacts of producing oil capture the production cost rather than the consumption cost. As with greenhouse gas emissions, shifting the perspective of cost from production to consumption creates a greater awareness that encourages consumers to modify their behavior, even if it is just to demand cleaner, safer providers.

In the third research chapter, "Insurgent Attacks on Energy Infrastructure and Electoral Institutions in Colombia," my co-authors and I consider the economic and political incentives that an energy resource creates in a conflict environment. To do this, we look at Colombia, where energy resources are contested among three groups: the national government, the paramilitaries, and the dissident insurgent groups — FARC and ELN. We test the hypothesis that insurgent groups leverage attacks on energy resources for political gain, and not simply greed, like the widely accepted theory suggests. We know from the electoral violence literature that typically, violent attacks where voting takes place have preempted voter participation and violent threats or intimidation have manipulated votes cast. Despite these breakthroughs, we still know little about whether and how insurgents might target critical infrastructure to undermine democratic institutions. To learn more, we take advantage of an unprecedented data-set of global energy infrastructure attacks. We quantify the relationship between the timing of a fixed election schedule and attacks on critical energy infrastructure in Colombia from 1980-2011. We find that the likelihood of an attack on oil pipelines, electricity transmission lines and substations increased by 25% and that the number of attacks increased by 51% during election months, both relative to insurgent violence during non-election months. Our results are the first to examine how armed, non-state actors strategically time and deploy attacks on critical energy infrastructure to undermine state capacity and democratic institutions.

Finally, in the last chapter, we discuss the implications of the three essays, the contribution to energy policy issues, and some future research interests.

CHAPTER 2

WHY AMERICA SHOULD MOVE TOWARD DRY CASK CONSOLIDATED INTERIM STORAGE OF USED NUCLEAR FUEL

Coauthor: Robert Rosner[1]

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2.1 Abstract

Despite the recommendations of the 2012 Blue Ribbon Commission Report, the US government has made no substantial progress toward the permanent, or even temporary, consolidated storage of used[2] civilian nuclear fuel. To complicate matters, a November 2013 decision by the United States Court of Appeals (2013) in Washington, DC eliminated the very fee designed to finance used-fuel storage — which had accumulated over $30 billion so far — introducing a further obstacle (Nuclear Energy Institute, 2014b).

It was not supposed to be this way. The 1982 Nuclear Waste Policy Act bound the federal government by law to take custody of all civilian waste from power companies for final disposal, under the assumption that the waste would be permanently stored in a deep geological

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[2] While the common term for nuclear material emerging from nuclear reactors is "spent" nuclear fuel, we prefer the term "used" nuclear fuel. The reason is that from the technical point of view used fuel is really not "spent" in the dictionary sense of that word. It is technically possible to process the used fuel in a number of ways to extract yet more energy, either in the existing fleet of light water reactors or in alternate reactor designs aimed specifically at burning the fission products resulting from neutron capture, i.e., plutonium and the minor actinides. About 96 percent by weight of used nuclear fuel is uranium; the rest is composed of plutonium (approximately 1 percent), fission products, and other minor actinides. So, for all practical purposes, the amount of used fuel and the amount of uranium in that used fuel are usually treated as roughly the same.

repository at Nevada's Yucca Mountain and overseen by the Energy Department. The Act obligated the US government to begin accepting waste by 1998, but the government was unable to fulfill this promise, forcing it to remunerate the utility companies for continuing to store the waste and assume liability. This situation cannot continue.

As a solution, the commission argues that the US government should establish a widely distributed series of regional, government-run sites that would take in the used fuel from the cooling pools of several reactors, thereby consolidating the interim storage of used fuel and putting this nuclear waste into stronger, safer, more secure, more manageable — and ultimately more affordable — dry casks, as a first step toward ultimate disposal. Dry casks have withstood earthquakes and floods, and are designed to withstand the heat of fires and the impact of airplanes; the 100-ton structures are hard to steal or damage, and require no active cooling systems or power supplies. These are some of the many reasons why making the transition to dry cask-based interim storage should be made as quickly as possible, regardless of one's opinion of civilian nuclear power.

2.2 Introduction

When Congress passed the Nuclear Waste Policy Act of 1982, it earmarked Nevada's Yucca Mountain as the site of a long-term, permanent geological repository for the radioactive waste from civilian nuclear power plants. The site was theoretically able to store tens of thousands of tons of used nuclear fuel for millennia, and the act committed the US government to begin accepting the used fuel there and at a supplemental repository beginning in 1998. A system was set up to pay for it all, called the Nuclear Waste Fund; lawmakers were so confident in this arrangement that the act banned storing used fuel anywhere else — except for the temporary storage of used fuel in the immediate vicinity of the reactors, usually in the reactors' cooling ponds, for the first five years after removal from the core. (Used fuel loses the vast majority of its heat and some of its radioactivity during the period of pool storage, making it much less troublesome to transport or store.) When these cooling ponds filled up, as occurred on some sites, the excess used fuel was put into dry casks for temporary storage on-site while waiting for the permanent repository to be built. All well and good.

Except that Yucca Mountain was never opened, and the fee system instituted to pay for storing used fuel was struck down by the courts because the government had not met its contractual obligations. Meanwhile, there is no permanent place to put this radioactive waste, and the country's nuclear reactors are running out of space to store it all. At the same time, the United States continues to generate used nuclear fuel at a rate of approximately 2,000 metric tons of uranium (MTU) per year (Holt, 2013), where it remains at reactor sites scattered across the country in cooling ponds or temporary dry casks, transforming 35 states into the unwilling de facto hosts of civilian nuclear used fuel.[3] There are now more than 70,000 metric tons of this material in the country. (One metric ton equals 2,204 pounds.) To put this figure into perspective, that's more than 5,949,638 cubic feet, or the equivalent of filling a standard-sized NFL football field slightly more than 100 feet deep with used fuel.[4]

What to do? One good, if potentially controversial, idea is to take advantage of the dry cask technology that reactor operators know so well from handling used nuclear fuel. Let's have the Energy Department store these dry casks full of used fuel in consolidated, regional locations for interim storage, which the government would run until a permanent nuclear

[3] Though New Mexico does not have civilian radioactive waste, a military nuclear waste site is located in Carlsbad.

[4] According to the website of the Swiss National Cooperative for the Disposal of Nuclear Waste (http://www.nagra.ch/en/ volumes1.htm), a metric ton of used fuel occupies an average of approximately 2.4 cubic meters by volume when packed in a dry cask, so 70,000 metric tons of uranium would take up about 168,000 cubic meters. To convert that figure to cubic feet, we multiply by a conversion factor of 35.3 cubic feet per cubic meter, for a total of 5,930,400 cubic feet. Meanwhile, the standard football field is 160 feet wide by 360 feet long (see: http:// www.sportsknowhow.com/football/field- dimensions/nfl-football-field-dimensions. html), so it occupies 57,600 square feet. Since 5,930,400 divided by 57,500 equals 103, the football field would be filled to a depth of slightly more than 100 feet with used fuel waste.

waste storage repository is created; these interim sites could potentially be safely used for many decades or even a century if need be. Admittedly, this proposal has the drawback of potentially putting off the decision on a permanent repository for a long time, and it would create fights about where the consolidated storage sites would be located and how the dry casks would be transported there. But at least the used fuel would be located in a dozen or so centralized locations instead of in various and sundry cooling pools and temporary dry cask storage sites near every one of the 100-plus reactors in the country. And such a system would be cheaper, more secure, more easily monitored, and safer from malevolent acts of nature and of man while a long-term solution is found. But first, a brief history.

2.3 How we got here

Thirty-five states now store used commercial nuclear fuel totaling 71,775 metric tons, according to a December 31, 2013 inventory.[5] Of this used fuel in storage, 69 percent, or 49,542 metric tons, is in used fuel pools at reactor sites, while the remaining 31 percent, or 22,233 metric tons, is in 1,865 dry casks located at reactor sites or other so-called independent spent fuel storage installations.[6] This material has been accumulating since the first commercial nuclear power plants to generate electricity went online in the late 1950s (World Nuclear Association, 2014a). Since then, the United States has operated a total of 137 commercial nuclear reactors in 35 states and Puerto Rico. The vast majority of these were light water designs, 6 either pressurized water reactors or boiling water reactors.

To cover the anticipated expense of the proposed long-term storage of used fuel, utilities were required to pay a fee to the government for any used fuel already existing as of 1982. At the

[5] Used nuclear fuel in this context refers only to commercial used nuclear fuel, and does not include nuclear materials associated with military use.

[6] Data provided by Nuclear Energy Institute, 1201 F St. NW, Suite 1100, Washington, DC 20004-1218, USA.

same time, a tax of one-tenth of a penny per kilowatt-hour, or \$0.001/kWh — known as the millage (or mill) fee — was levied on all power generated after 1982 by nuclear reactors. This was all deposited into a Nuclear Waste Fund. This same act explicitly excluded the creation of interim storage facilities; any on-site used fuel pools were viewed purely as temporary fixtures, intended to be used only for that initial five-year cooling period, not decades-long storage.

For a variety of reasons, including opposition from the state of Nevada, the federal government was unable to fulfill this obligation. Consequently, the nuclear power plants' operators have been responsible for storing their nuclear waste on-site, in used fuel ponds and in temporary dry casks. To pay for it, the utilities successfully and repeatedly sued the government for ongoing partial breach of contract. The legal maneuvering proved convenient for both sides: The utility owners, though required to responsibly store the used fuel, could recover their costs by suing the government; those utilities that had not yet paid the waste fee for their pre-1982 used fuel did not have to pay for moving this historical waste to a permanent repository. Meanwhile, from the government's point of view, the legal maneuvering meant it could avoid making any commitments about a final storage solution; what's more, it can pay the legal damages through a separate judgment fund not subject to congressional appropriations (Werner, 2012).

This last part is key, because access to the existing monies in the Nuclear Waste Fund requires going through the congressional appropriations process — a process that is unlikely to achieve success, given current political polarization and tight federal budgets. And with Yucca Mountain off-limits, the government is financially unable to create a new repository. At the same time, it cannot use the millage fee to generate new funds, because a recent federal court ruling prevents the federal government from collecting it (U.S. Court of Appeals, 2013). Consequently, used fuel continues to accumulate at reactor sites, in storage facilities not hardened against potential attacks or severe accidents. Thus, the private sector assumed responsibility for long-term storage of used civilian nuclear fuel.

2.4 Nuclear waste: Pressurized water reactors vs. boiling water reactors

Currently, there are 100 civilian nuclear power plants operating in the United States — 65 pressurized water reactor (PWR) and 35 boiling water reactor (BWR) designs. Though both are light water designs, PWRs and BWRs have different fuel specifications regarding quantity, configuration, and "burn-up rate" — the percentage of fissile atoms that has experienced fission.[7]

A pressurized water reactor generates more used fuel waste by volume. However, because of the composition of the used fuel from a boiling water reactor, a BWR has a greater heat load. As a result of its smaller yet hotter volume of used fuel, the waste from a BWR requires significantly different management and storage practices — a factor to consider when assessing the vulnerability and security of used fuel. The distinction between reactor type and fuel enrichment level can mean a difference of years required for the initial cooling period. (In contrast, the long-term, permanent storage of used fuel — no matter what its source — requires millennia to reduce its radioactive toxicity.)

2.5 Wet pool storage

Whether it comes from a PWR or BWR, after used fuel is removed from a reactor core, it is moved directly into cooling ponds, where the used fuel loses a significant proportion of its heat load in that key three- to five-year cooling period. Because the cooling process

[7] Burn-up is measured by multiplying a reactor's thermal power by the amount of time the fuel has been fissioning and dividing this figure by the mass of the initial fuel inserted into the reactor.

requires somewhat cold water that is physically circulated via pumps, the rate at which used fuel cools down varies according to flow rate, volume, water temperature, circulation patterns, and other factors, making it hard to state the actual cooling rate with any more precision other than to say that the Nuclear Regulatory Commission (NRC) considers five years sufficient to cool most used fuel for transfer to dry casks.

During this time, the most unstable fission products — including isotopes of cesium, strontium, and iodine — decay. Along with plutonium and the minor actinides such as americium and curium, these products constitute approximately three to five percent of the used fuel and are responsible for most of the heat load during the first few decades of storage. Current high-density used fuel ponds can contain thousands of fuel assemblies (bundles of fuel rods); for example, the storage pools in a GE Mark I boiling water reactor span 54,600 cubic feet (Werner, 2012), or a volume equivalent to roughly two-thirds of an official Olympic swimming pool. Tens of feet of water cool the used fuel; boron-treated metal separators absorb the neutrons emitted by the decaying fuel (U.S. Nuclear Regulatory Commission, 2014a). The used fuel pond is typically located adjacent to the reactor but housed in a separate building for most PWR designs, while in some older boiling water designs the used fuel pond is located above ground, close to the reactor core.

A site will have at least one pool per reactor; however, operators may redis- tribute and rearrange the used fuel in these pools as they see fit — a pool need not be dedicated to one particular reactor's fuel. Used fuel pools located on the same site can be interconnected or separate (Pulvirenti and Hiser, 2011). Keeping the pools cool — typically, the water temperature is below 120 degrees Fahrenheit (49 degrees Celsius) — requires power to circulate the water; it is also necessary to carefully arrange the assemblies by age and fuel to control the decay process.

Once the fixed costs are paid for bringing the pool online and fitting the racks for the appropriate amount of fuel, the additional cost of each new assembly is very small, especially when compared to the other operating expenses for pool storage. The reactor's owners may pay some more to cool the fuel or to implement the high-density racks, but this cost is relatively small.

As fuel inventories have grown, utilities have re-racked their pools to accommodate more assemblies, leading to what is called "high-density" fuel storage. These require different racks to hold the assemblies, with additional neutron- absorbing materials and changed configuration requirements to ensure that the used fuel is safe (Government Accountability Office, 2012). An arrangement is considered high-density if four assemblies that have been cooling for a long length of time surround an assembly more recently discharged from a reactor core. Conversely, a low-density arrangement has a recently discharged assembly surrounded by four empty spaces (U.S. Nuclear Regulatory Commission, 2014b).

Currently, 69 percent of the used nuclear fuel in the United States is stored in one of these pools. As a result of the move to high-density storage, some pools have thousands of assemblies each; even with high-density configurations, the total storage capacities of these pools are now being reached. When the pools are full, the utilities often move the oldest (and therefore coolest) assemblies into dry cask storage; thus, dry cask storage has so far been used largely as a safety valve for dealing with excess used fuel. Consequently, dry cask storage has been viewed as merely a temporary solution — something that we propose should be changed.

There are two reasons: First, because consolidated interim storage is necessary for meeting legal obligations within the next few decades; and second, because consolidated interim storage does not compromise either safety or security — while the status quo does.

Admittedly, there are political and legal considerations. For example, what if consolidated interim dry cask storage becomes permanent storage? And there is also a problem in the wording of the 1982 Nuclear Waste Policy Act itself, which declared the on-site interim storage of used fuel from civilian nuclear reactors to be the responsibility of the reactor operators and explicitly limited the volume of *interim* storage the federal government can provide — the precise legal situation we still find ourselves in today. This situation leads to another exercise in verbal gymnastics since, by any rational definition of "interim," the current disposal of used fuel at existing reactor sites is de facto interim storage, while the utilities await a final decision about the ultimate disposal fate of their used nuclear fuel.

To explain why regional centers of dry casks constitute a better, safer, and more secure storage method than the current system of numerous, widely scattered wet pools, we offer a primer about the key technology behind consolidated interim storage: dry casks.

2.6 Dry cask storage technology

The typical dry cask is a cylinder approximately 16 feet in length and about 8 feet in diameter, with 12- to 30-inch-thick walls of metal or concrete — materials that not only protect the used fuel but also absorb the emanating radiation. Within this outer shell is a leak-proof, sealed metal cylinder that contains the used fuel. The NRC describes such casks as designed to resist "earthquakes, projectiles, tornadoes, floods, temperature extremes and other scenarios" (U.S. Nuclear Regulatory Commission, 2013).

There are 21 NRC-approved dry cask storage system designs, made by four companies. Specifications for each cask, such as fuel capacity or heat load, change according to the cask's purpose and the type of reactor from which the fuel was removed. There are casks used only for transporting fuel, casks just for immobile storage, and casks designed for both tasks (U.S. Nuclear Waste Technical Review Board, 2010). But all casks have two things in common: They encase and protect the used fuel assemblies.

To ensure the protective casing of the cask will remain intact, and to keep the used fuel from releasing radiation, the casks undergo a series of checks for safety and robustness. These tests are done under normal, abnormal, and accident conditions.

Transportation casks, for example, are dropped 30 feet onto a solid, unyielding surface; engulfed in flames above 1,470 degrees Fahrenheit (800 degrees Celsius); dropped onto a vertical bar capable of puncturing them; and submerged in water for more than eight hours. These tests are meant to simulate the extreme conditions possible during transport, and ferret out structurally weak points (U.S. Nuclear Regulatory Commission, 2014b).

Storage casks are tested similarly and must also be able to protect their contents against natural disasters, including tsunamis, earthquakes, and tornadoes. The used fuel inside must remain safely encased, cool and intact (U.S. Nuclear Regulatory Commission, 2014b).

Each cask weighs more than 100 metric tons (about 220,500 US pounds) — the amount varies depending on design — when fully loaded. Typically, 10 to 20 tons of this weight is due to the fuel assemblies, while the cask's concrete and steel account for the rest. The exact amount of used fuel that can be stored within a given cask varies by initial fuel enrichment levels, cask design,and whether the fuel came from a PWR or BWR.

Because of the extreme weight of a cask and its contents, moving one or knocking it over is very difficult, as shown when Fukushima Daiichi's dry casks withstood both an earthquake and a tsunami without damage to themselves or their contents. In fact, even after being flooded and shaken, the casks still stand upright (Tokyo Electric Power Company, 2013). By comparison, the used fuel stored in the pools at Fukushima Daiichi suffered immense damage, mostly from the pools' inability to cool the used fuel under "station blackout" conditions (i.e., loss of power) — a situation that continues to plague the Japanese government and the reactors' owners.

Dry cask storage systems are either "bare-fuel" or "canister" systems. Bare-fuel systems are casks into which the used fuel is directly placed — unlike the canister system, in which the used fuel is sealed in a stainless steel canister first and then moved between casks.

The canisters themselves are half-inch- to one-inch-thick stainless steel, leak-proof cylinders approximately 5 feet in diameter and as much as 16 feet tall (BNG Fuel Solutions Corporation, 2005).

To load used fuel, the canisters are first placed in the cooling pool. Then the used fuel is transferred into the canister, and canister and contents are removed together as a unit from the pool to be dried and sealed; before being welded shut, the containers are backfilled with an inert gas such as helium. Putting in an inert gas allows the used fuel to be cooled by convection; it also prevents deterioration or re-oxidation of the zirconium alloy metal, or "fuel cladding," that makes up the metal tubes of the fuel pins. (Also known as a "fuel rod," each pin consists of a narrow, hollow tube about 16 feet long into which fuel is inserted in the form of pellets. These pins are arranged into bundles called fuel assemblies, which are then loaded into the reactor core.) If gas were not injected into the canister, the cladding could easily deteriorate or re-oxidize, allowing the used fuel to swell and crack the pins. Because the used fuel will eventually be moved to a final repository, if these pins were ruptured that would cause real problems in the attempt to move the material from the interior of the dry cask to the final disposal container at the end repository site.

After inserting the gas and welding the canisters shut, the canisters are put inside the cask.

This whole canister system provides an additional shield against radiation, as well as a first layer of protection against used fuel degradation and corrosion (EnergySolutions Spent Fuel Division, 2012). However, canisters are only one component of a dry storage system; they are not designed to protect the used fuel from accidents, unlike the casks into which they are loaded. The use of canister systems has become the standard operating procedure for storing used fuel because this method reduces the number of steps necessary to transfer and transport used fuel.

This canister system is purely designed for the transport of *used* fuel, not *fresh* fuel. The reason is that fresh fuel is actually not very radioactive — surprising as that may seem — so the transport container for *fresh* fuel is specifically built to prevent the physical dispersal of the material in the event of an accident, not for radioactive shielding (World Nuclear Association, 2014b).

Casks specially designed for transport then move the canisters from the reactor building to the storage sites where the canisters are loaded into the immobile storage casks. The entire process of loading, drying, and sealing the canisters takes approximately a week.

Canister systems significantly simplify transport, as the hefty storage casks can remain at the storage site, so that only the canisters need to be transferred. Once on-site, the casks are placed on a secured concrete pad for surveillance and monitoring. NRC regulations (2011) say that no more than 10,000 metric tons can be stored at any one site; dry cask storage sites are licensed to hold up to approximately 625 casks.[8]

The current generation of casks is licensed for 20 years of use with a "certificate of compliance." This license can be renewed for another period of "extended operation" after a full evaluation of the cask materials, fuel, fuel assemblies, and other essential components to ensure that the fuel is secure and ultimately retrievable at the end of the cask's lifetime (U.S. Nuclear Regulatory Commission, 2011). There are annual fees associated with licensing each cask, which are billed and paid in addition to millage fees.

[8] This is calculated assuming 0.44 MTU and 0.18 MTU per PWR and BWR assembly, respectively, and also assumes 37 PWR and 87 BWR assemblies per cask from assumptions contained in James D. Werner's (2012) "U.S. Spent Nuclear Fuel Storage."

2.7 The security and safety properties of dry casks

While no solution is perfectly accident-proof, dry casks provide greater protection than storing the fuel in pools. The reasons are many.

First, dry casks have built-in "passive safety" features, in which safety measures automatically occur without the need for humans to directly intervene. For example, rather than needing a power supply or water circulation to keep the assemblies cool, casks are cooled by natural air circulation and convection (U.S. Nuclear Waste Technical Review Board, 2010; Werner, 2012). This eliminates the possibility of a loss-of-coolant accident because none of the problems related to water loss and the generation of steam — and possible hydrogen — can arise. This does not mean that dry casks are risk-free or maintenance-free, but at least they do not require the constant monitoring and electric power needed for pool storage. Consequently, blackouts do not pose a safety risk to used fuel in dry cask storage.

In addition, accidents involving any one cask do not necessarily implicate all the surrounding casks. This factor reduces both operational risks and risks from attacks. Each cask is isolated from the next, limiting the amount of used fuel exposed in any one incident. In contrast, with pool storage, one incident affecting the pool affects all the assemblies it contains. So far as malicious attacks on dry casks go, a successful attack would require a highly coordinated effort, all while presumably facing a vigorous response from law enforcement and security personnel. Because the casks are so huge, cumbersome, and heavily constructed, they are very difficult to steal or open to access the radioactive materials inside. Any attempt to penetrate dry casks would be quite time-consuming, giving security that much more time to respond. Used fuel pools offer none of these advantages.

Finally, if worse came to worst and a cask was breached, it is much easier to contain a possible leak or damage from a dry cask than to stabilize and restore an entire pool following an accident or attack (National Academy of Science, 2006).

In the case of stranded fuel, moving it to dry casks at consolidated interim storage sites from a pool would not only reduce operating costs but also ensure that the infrastructure is in place to deal with fuel degradation. Maintaining such infrastructure at decommissioned reactor sites is, in contrast, much more expensive (Government Accountability Office, 2012).

2.8 Why is interim storage a good idea?

Consolidated interim storage provides a number of benefits, even when a permanent repository has already been put in place.

There are several fundamental safety and security risks with the current method of storing used nuclear fuel in cooling pools. In a loss-of-coolant accident, the assemblies in the pool can boil off the pool water; this can lead to damaged fuel rods as well as possible meltdown of the fuel assemblies. And a loss-of-coolant accident could happen in so many ways: equipment failure, electrical blackout, or terrorist attack.

Another problem when water boils off is that the resulting steam reacts with the zirconium alloy cladding to generate hydrogen gas which, when mixed with air, can ignite and cause an explosion. The Japanese were fortunate that neither an assembly meltdown nor a hydrogen explosion occurred in Fukushima Daiichi's used fuel pools, so the airborne spread of radioactive materials was much more limited than would have occurred otherwise.

By its very nature, the pool storage method is also more vulnerable to malicious attack, when compared to attacking the material located in the reactor core itself or sitting inside dry casks. Both dry casks and the containment structure surrounding the reactor pressure vessel are strong enough to withstand the impact of an airplane, for example, while the buildings that surround used fuel pools are structurally nothing more than warehouses, or "industrial grade structures" as the NRC calls them (Union of Concerned Scientists, 2011).

All these considerations have become more urgent now that the operators of the current nuclear power reactor fleet are beginning to use higher burn-up fuel.

A 2006 National Academy of Sciences (NAS) report discussed different scenarios involving aerial, ground, and combination air-ground assaults on stored used nuclear fuel. The NAS committee considered an attack on a pool of used nuclear fuel to be the most plausible situation, resulting in the worst, most widespread consequences. (This was confirmed by other research emphasizing the harm caused by the likely loss of coolant during such an attack (Alvarez et al., 2003)). Such an attack is hard to simulate exactly, because the size and scale of any consequences would depend on many factors, including the age, configuration, amount of used fuel, and the mode of attack. Nevertheless, any attack on a used fuel pool would be devastating, considering the higher concentration of radionuclides in a used fuel pool compared to the reactor core. Furthermore, as the burn-up of the used fuel increases, so does the amount of harmful fission products, such as cesium 137, which would worsen any potential consequences (Alvarez et al., 2003).

Even under normal operation, fuel can degrade and corrode while stored in pools for extended periods of time. Degradation can come from a variety of causes, including embrittlement resulting from neutron damage, and also by corrosion caused by pools containing low pH levels and strongly growing bacteria. While the severity and the pattern of corrosion vary depending on the cladding's material properties, the zirconium alloy has proven effective in resisting corrosion under normal conditions when the usual purified water with neutron-absorbing additives is used as a coolant. If impure water must be used instead — such as when seawater was introduced at Fukushima to cool down the used fuel in the storage pools and the fuel in the scrammed reactors (reactors in emergency shutdown mode) — one can expect substantial corrosion. In such an accident, even zirconium cladding is vulnerable (International Atomic Energy Agency, 1998). Such corrosion did occur at the shutdown Hanford Site in the state of Washington, motivating the construction of a new containment facility to prevent further problems and leakage from the pool (GlobalSecurity.org, 2014).

Thus, there are a number of reasons that used nuclear fuel should be moved from pools as quickly as realistically possible to more secure and safer storage, keeping the amount of used fuel in cooling pools to the minimum.

2.9 Demonstrating performance

One of the key problems bedeviling civilian nuclear power is the federal government's inability to carry out its legal obligations and take ownership of civilian used nuclear fuel, as mandated in the 1982 Act. Because a functioning permanent repository is most likely to be decades away, the only way the federal government can move ahead is by pursuing interim storage. Any permanent repository alternative to Yucca Mountain will require enormous new financial resources, not likely to be available soon.

Past experience shows that it will likely take decades to site, build, and license a permanent repository, even under the best circumstances. This leaves the government with two options: remain with the status quo of leaving used fuel to be overseen by the utilities; or begin receiving fuel in consolidated interim dry storage under federal supervision.

The advantages to the status quo are that the federal government does not need to take any of the political risks entailed in building interim storage facilities, immediately move any waste, or deal with the fiscal challenges involved. It is always easier to "kick the can down the road" and delay the inevitable until it is some future administration's problem. Indeed, one argument against consolidated interim dry cask storage is that it will become the "next can," and consolidated interim dry cask storage could become another storage arrangement by default, one that reduces the incentives to construct a final repository. Though this is a very real possibility — reinforced by the August 26, 2014 NRC decision to allow indefinite above- ground storage of used nuclear fuel (Vietti-Cook, 2014) — consolidated interim dry cask storage is nevertheless the best way to proceed. Using consolidated interim storage allows the government to fulfill its current legal obligation, or "demonstrating performance." And the dry cask system is a safer method for storing used nuclear fuel on the timescale likely to be needed to establish a final permanent repository for used fuel.

There are many advantages to the federal government fulfilling its legal commitment to accept used fuel. For one thing, it would halt the ongoing lawsuits by utilities. So far, the 71 breached contracts have caused the US Judgment Fund to award approximately $1.2 billion to utilities (Garvey, 2009), $565 million of which has already been paid out (U.S. House Committee on the Budget, 2009). For another, there are costs to delay, including the expenses involved in exposing the nuclear fuel cycle to unnecessary risks and the costs to the federal government's reputation. Once used fuel is accepted by the federal government, it could reinstate the millage fee from the utilities — $750 million annually (Blue Ribbon Commission on America's Nuclear Future, 2012) — restoring the flow of funds needed for long-run, permanent storage. What's more, the government could start to reduce the cost of storing waste, especially at sites where reactors are no longer online, by minimizing the amount of used fuel located in storage pools. According to Nuclear Energy Institute estimates, it costs from $10 million to $20 million to build a consolidated regional dry storage site, with annual maintenance and operations fees ranging between $5 million and $7 million (Nuclear Energy Institute, 2014a). In contrast, maintaining fuel in on-site pool storage costs between $8 million and $13 million annually at a reactor that is shut down (Government Accountability Office, 2009).

Another benefit to starting now: reducing litigation costs. Federal liabilities grow every year that the government fails to accept used nuclear fuel. Currently, the Energy Department is arguing multiple cases in federal court, costing millions of dollars in legal costs and settlements with utilities — as of 2009, the Energy Department had paid upward of $154 million in litigation-related costs alone (Coyle, 2009). At this point, the US government, even if it began accepting used fuel in 2020, would still be required to make damage payments to utilities of $12 billion (U.S. House Committee on the Budget, 2009).[9] A consolidated interim storage facility system could begin compliance in that time frame and help reduce the ever-increasing liabilities and litigation costs.

By potentially restoring the ability to collect the mill fee, the funding source for a permanent repository would be restored, rather than allowing damage payments to mount.

2.10 Addressing arguments against dry cask storage

While the advantages of interim consolidated regional dry cask storage in the United States are well recognized (Werner, 2012), there are challenges to making the transition. Moving to dry cask storage would require significant financial investments in building the supply chain that produces the casks, constructing the storage sites, transferring fuel into the casks, and positioning the casks on pads — and how all this would be paid for remains unclear. Second, there are risks involved with moving used fuel into casks and transporting it on roads and rails. Finally, dry cask storage is not a "build and forget" solution. There is still the risk of material degradation in the casks, and ongoing inspection and maintenance would be needed if used nuclear fuel is indeed allowed to remain in such above-ground storage indefinitely.

The supply chain presents a particularly significant hurdle. Currently, dry cask manufacturers cannot produce enough casks to keep up with the large-scale transfer of used fuel from reactor sites. It would take years to be able to meet the additional demand (Electric Power Research Institute, 2012). Furthermore, the capacity to transfer fuel from pools at each site

[9] To complicate matters, utilities disagree about the amount of the damages, with some utilities estimating $50 billion in damages, based on the 2020 compliance date (Coyle, 2009).

is limited by the availability of site personnel and infrastructure — the equipment necessary to move these casks is expensive and often unavailable due to the need to conduct other necessary operations. Given these limitations, and considering that moving fuel can take up to a week per cask, some researchers estimate that moving all of the used fuel to casks would require more than a decade and cost between $3.5 billion and $3.9 billion in labor and new infrastructure (Electric Power Research Institute, 2012).

In addition, moving used fuel into dry storage would increase the radioactive exposure of any personnel making the transfers. Because the nuclear industry has moved to higher burn-up fuel, which has increased concentrations of highly radioactive materials (Electric Power Research Institute, 2012), this concern has increased. Nevertheless, no incident has occurred in the many years of transporting fuel — and an incident with one cask is dwarfed by an incident with one pool. Extensive studies, principally by Sandia National Laboratories, have validated the safety performance of dry casks and transportation casks. In addition, it is probable that, should the move to a system of consolidated dry cask interim storage gain momentum, new methods and materials will be developed that should improve safety.

Finally, although the risk of cladding and canister degradation in dry casks is small in the short term, it is not zero over the long run. Dry cask performance is not well understood on decades-long time-scales. (The Energy Department is currently conducting a High Burnup Dry Storage Cask Research and Development Project to better understand the behavior of dry cask storage over longer time periods (Electric Power Research Institute, 2014)). It is possible that the casks may need to be replaced at some time in the future (Government Accountability Office, 2009). But the nature of the casks means that they can be replaced and their contents transferred, making the occasional, isolated need for canister replacement manageable and consistent with the NRC's view that aboveground storage for very long periods is technically feasible and safe.

While the various concerns cannot be ignored, the risks associated with consolidated dry cask interim storage are relatively small when compared with the risks of leaving used fuel on-site — especially when used fuel remains in storage pools and at decommissioned reactor sites. This is true even if one adopts the position of the NRC and the Energy Department that the probability of an attack on a wet pool is low: The ability for an incident to occur — whether by accident or design — and escalate rapidly is dramatically reduced if used fuel is dispersed among large numbers of robust dry casks, as opposed to being located in a common storage pool. Furthermore, moving used fuel to a consolidated interim dry cask storage regional facility will ease the eventual transition to a permanent repository. And the used fuel will be stored more safely until a permanent solution is found. While such interim storage might well further delay that process, it is nevertheless the responsible, safe, and secure way to proceed.

One final obstacle to any type of interim storage is the 1982 Nuclear Waste Policy Act itself: It legislated interim storage facilities of the kind discussed out of existence. To move to consolidated interim storage of used nuclear fuel, the Act would need to be amended or superseded by a new one. This legal obstacle to interim storage, combined with the series of political, organizational, and financial debacles besetting Yucca Mountain, has had the ironic effect of making the status quo comfortable and financially convenient for all concerned: The federal government can deal with the financial penalties without needing to resort to the cumbersome and politically fraught congressional appropriation process, while nuclear power providers are fully compensated for the costs of dealing with their used nuclear fuel.

The loser, however, is the public — that is, all of us.

Dealing with used nuclear fuel is a problem that will not go away on its own. Delay simply increases the eventual costs required to finally dispose of this radioactive material. Unfortunately, the public is the party most affected but least able to resolve the problem, while those in a position to resolve it are the least motivated to fix things.

Nevertheless, the US government should move forward. Consolidated dry cask-based interim storage is more politically feasible and financially affordable than a final permanent repository; is capable of being implemented far more quickly than a permanent repository; helps resolve the liability issues faced by the federal government; builds the storage and transportation infrastructure that will eventually be needed once a permanent repository scheme is developed and implemented; and is safer and more secure than the current storage method. Moving toward consolidated regional interim storage for used nuclear fuel does not commit the US to a particular energy future, but it does make the federal government take possession of existing used fuel and responsibly store it, thus honoring its commitments and responsibilities while a permanent solution is developed. After all, the United States should choose its future energy-supply profile unconstrained by historically unmet legal obligations and the effects of ongoing political stalemates.

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CHAPTER 3

IMPORT-ADJUSTED FATALITY RATES FOR INDIVIDUAL ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD) CAUSED BY ACCIDENTS IN THE OIL ENERGY CHAIN

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3.1 Abstract

Oil and its derivatives are crucial components of economic growth and prosperity globally. The economic and social gains from producing, trading, and consuming oil are readily estimated and observed. However, during each of the phases of oil production and trade, beginning with exploration and extraction, physical damages, injuries and fatalities, and economic losses are frequently incurred from accidents such as pipeline explosions. Specifically, Organization for Economic Cooperation and Development (OECD) countries consume the majority of the oil produced annually yet most accidents occur in non- OECD countries. Drawing from the input-output analysis literature, this paper uses a one-dimensional accounting method based on trade data to determine the crude oil consumption fatality rates of the OECD countries annually between 1978 and 2008. This analysis results in meaningful changes to production based fatality calculations. In particular, OECD countries import the majority of their annual fatality rates from non-OECD countries. Based on 5 patterns that emerge, the authors postulate that historical trade relationships, differential policies and

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regulations, as well as levels of technology adoption, may influence these outcomes. This fundamental analysis applies the now-popular consumption-based accounting method taken from multi-regional input-output and life-cycle assessment to a risk assessment setting. The authors introduce the method in this setting such that, as in the case of embodied emissions, it can act as a basis for further econometric analyses, develop more awareness and a greater sense of shared, international responsibility, as well as instruct policy changes for best practices in the field of energy.

3.2 Introduction

Accidents occur during all stages of energy production and distribution. In the case of oil, accidents can occur in processes ranging from exploration and extraction, transportation, and refining to end-use. These accidents can be due to human error, natural disasters, technical failure (Hirschberg et al., 1998) or in some cases, intentional attacks (Giroux et al., 2013). Depending on the location and severity of the accident, the consequences may be measured and internalized in various ways. How physical damages or economic losses caused by an accident such as a refinery fire or oil spill are remediated depends on the affected parties, the scope of the damage, and the legal and regulatory requirements of the location where the accident occurs. Some countries impose strict regulations to ensure greater internalization of accidents; for example, the United States Oil Pollution Act of 1990 requires that operators must prepare disaster contingency plans and, in the case of an accident, owners of an offending vessel or facility are held partially liable for damages (U.S. Environmental Protection Agency, 2014). However, many other e less developed e countries, such as Nigeria (Alba, 2010) or former Soviet Union countries (Brizga et al., 2014), either lack the regulations or the capacity to enforce regulations which would appropriately incentivize firms and other actors to take further precautions against accidents or to fund recovery following an accident (Frynas, 2012).

Countries with low regulation and enforcement capacities typically have other domestic challenges or limitations that may take priority or hinder progress. One sobering perspective on potential trends suggests developing countries use an immediacy-prioritizing policy: treat the first order problem — poverty, for example — followed by the less urgent problem, perhaps environmental degradation or safety (Alba, 2010; Johnson et al., 2007). The differences in relative priorities from country to country opens the opportunity for potential gains from trade (Johnson et al., 2007). Examples of this dichotomy are differences in labor costs or regulatory restrictions that industries and firms might exploit (Frynas, 2012; O'Rourke and Connolly, 2003). Furthermore, countries lacking access to more sophisticated technology may not be capable of meaningful operating improvements (Brizga et al., 2014).

These trends are paralleled by another international trend characterizing producing and consuming countries: developing countries produce and developed countries consume (Caldeira and Davis, 2011; Peters et al., 2011). Often, countries belonging to the Organization for Economic Cooperation and Development (OECD) and those not belonging (non-OECD) epitomize these differences between developed and developing countries in terms of national technical and regulatory capacities. While it may be argued that the firms operating in these developing countries and responsible for accidents may be multinational, national governance (Alba, 2010; Frynas, 2012) and access to technology can play a large role in reducing impacts by introducing and/or enforcing regulations and improving safety standards.

As international trade has continued to liberalize, these disparities and the differential impact of trade on countries at various levels of development has been investigated extensively from a greenhouse gas emissions and environmental impact perspective (Davis et al., 2011; Hertwich and Peters, 2009; Mozner, 2013; Peters et al., 2011; Wiedmann, 2009). Within this literature, multiple approaches to reallocation of responsibility for greenhouse gas emissions and pollution are debated: production- based, control-based, and consumption-based approaches (Guan et al., 2014; Lopez et al., 2014). Production-based accounting, exclusively considers emissions generated within the boarders of a country. Control-based methods assign responsibility to the multinational companies producing emissions; and, finally, consumption-based methods assign responsibility to the final beneficiary, including emissions that accumulate due to trade. This paper situates the responsibility of accidents in the oil chain within the framework of this debate.

Opponents of production-based emissions accounting suggest that it does not capture the emissions associated with trade. For example, Peters et al. (2011) show that developed countries have increased emissions associated with consumption while reducing territorial emissions e effectively outsourcing their carbon footprint. Proponents of control-based accounting suggest that pollution should be assigned at the firm level such that multinational organizations operating in other countries improve operating standards and help in technology transfer to less developed countries (Lopez et al., 2014).

This analysis uses the consumption-based perspective to consider reallocation of fatalities due to accidents involving the trade of crude oil. This perspective is supported by evidence that unsafe practices in developing countries are driven by the demand for inexpensive products in developed countries. Additionally, the consumption-based approach is favored over the other approaches because of the structure of the international oil industry. First, the production-based fatality rates do not attribute the impacts to trade, and because the majority of accidents occurring in the industry occur during transportation (Burgherr et al., 2012; Eckle and Burgherr, 2013), this omission is meaningful. Second, there are numerous multinational companies involved in oil trading between extraction and transportation, and therefore, assigning responsibility to multinational companies would be difficult and ad hoc. In addition, the concerns of "carbon leakage" that motivate a control-based approach for greenhouse gas emissions does not have the same meaning in the context of accidents in crude oil production, since the locations of natural resources are fixed.

Concerning oil production, the differences between developed and developing countries have been attributed to differences in environmental regulation, low institutional capacity (Frynas, 2012; Razavi, 1996), and a lower level of technology (Frynas, 2012). Institutional corruption or relative weakness of a state has also been found to play a significant role in how well or poorly resources are used in developing countries (Fearon, 2005; Robinson et al., 2006). Determining which of these drivers might cause the difference in fatality rates related to oil production or conducting an econometric analysis of these data are both outside of the scope of the analysis presented here. Instead, this paper is motivated by a sustainability perspective to draw attention to these disparities; that is, by looking at accidents from a consumption-based perspective rather than a production- or control-based perspective in order to capture a more inclusive view of impacts of oil trade (Yang et al., 2014).

The method used in this paper is a simplified, one-dimensional multi-regional input-output analysis (MRIO) intended as a first step to shed light on the difference in accident rates and the magnitude of those differences over a 30-year time period. Using this approach, the paper takes stock of the accidents that happen both in the public-private, national domain and also those accidents that occur in the public-private, international domain. This diverges from the motivating literature in three main ways: First, this quantifies the impact of accidents rather than normal operating conditions e risk assessment rather than life-cycle analysis. Second, the authors do not consider intermediate or derivative products in the present analysis. Third, the approach presupposes technology and capacity differences that cannot immediately be quantified. For example, in MRIO different technological abilities are incorporated into calculations of emissions and impacts (Mozner, 2013; Wiedmann, 2009) whereas these differences cannot necessarily be directly input in the current application. Subsequent studies might wish to comment on potential causal relationships or apply econometric models to these findings.

This sustainability perspective of international risk assessment highlights the ways in which trade distributes risks internationally in patterned ways. This approach is chosen to determine the geographical distribution of risks and how the consequences of those risks may be concealed through trade, and to reallocate the consequences based on consumption. It is a part of a larger effort undertaken to understand and quantify risks of energy systems using the Energy Related Severe Accident Database (ENSAD). In order to make decisions about future energy systems, trade agreements and how to allocate resources, it is necessary to translate and make an accounting of the consequences accidents have on human health. This approach is based on a large literature on the environmental effects of international trade, beginning with Leontief's discussion of input-output analysis and tracing pollution externalities (Leontief, 1970). Other, more recent work, creates a similar accounting system that explicitly attributes carbon dioxide using time series analyses of trade data (Peters et al., 2011) and multi-regional input-output analyses (Davis and Caldeira, 2010). In the same way as these works, this paper reframes the costs of consumption. This paper, motivated by the same desire to trace unwanted byproducts of economic activity, also builds directly on the prior work of Hirschberg et al. (1998) and Burgherr et al. (2012) that introduce and refine The Energy Related Severe Accident Database (ENSAD) and complete analyses on global energy related accidents. Burgherr et al. (2012) make a comparative assessment of the coal, oil, and natural gas energy chains. In this paper, Burgherr et al. (2012) extend the allocation of fatalities to more country groupings, narrowing from the European Union, OECD, Non-OECD subdivisions regionally and economically. Building from these previous works, this paper extends the analysis temporally and spatially to include annual OECD and non-OECD group fatality rates applied to imports at the OECD country level. This detailed account of fatalities assigned by consumption reveals 5 common patterns across the import-adjusted fatality rates for OECD countries that highlight some potential relationships and trends to be investigated with more robust methods in subsequent work.

The paper proceeds in Section 2 where the authors discuss the data sources and describe the raw trends in the data. In Section 3, an overview of how the data were cleaned and compiled is provided followed by the methods for calculation. Finally, in Section 4 the results are discussed. The paper concludes with a discussion of the implications of this analysis in Section 5.

3.3 Methods

In order to calculate country-level fatality rates adjusted for international imports, the authors utilized two sources of data. First, a dataset developed by the Paul Scherrer Institute (PSI) in Villigen, Switzerland was used: The Energy Related Severe Accident Database (ENSAD) (Burgherr and Hirschberg, 2014; Hirschberg et al., 1998). Second, for the crude oil production and trade data-sets the authors used the International Energy Agency (IEA) database (International Energy Agency, 2014). The authors chose to use an accounting method at the country level to refine previous work that adjusted imports at a country-group level rather than by country. The method is a variation on MRIO in that it is applied to accident conditions; and it does not incorporate derivative products, nor input differences in technologies directly. However, this accounting method was chosen in order to make more comprehensive observations about trade and its often unobserved impacts, as were the motivating environmental models. Future work should be directed at establishing more causal claims, informed by the results shown.

3.3.1 Accident data

ENSAD is a comprehensive database of the severe accidents having occurred from 1970 to 2010. To standardize the term "severe," PSI created its own definition based on the best practices and existing agreement in the field (Burgherr and Hirschberg, 2008, 2014; Hirschberg et al., 1998): To be considered a severe accident in the ENSAD database, the incident must meet at least 1 of the following 7 criteria (Burgherr et al., 2004):

- At least 5 fatalities, or
- At least 10 injuries, or
- At least 200 evacuees, or
- Extensive ban on consumption of food, or
- Releases of hydrocarbons exceeding 10,000 metric tons, or
- Enforced clean-up of land and water over an area of at least 25 km^2, or
- Economic loss of at least 5 million USD (2000).

The ENSAD database also includes other accidents not meeting these requirements; however, because many smaller accidents go unreported, this analysis is limited to the "severe" standard as one can be more confident in the completeness of the entries on the worldwide level.

3.3.2 International oil trade data

In order to calculate import and export trade flows for crude oil, the authors employed the IEA Oil Information Statistics database, which is composed of multiple datasets, such as OECD Imports, OECD Exports, and World Oil Statistics. These data are available with a subscription (International Energy Agency, 2014). The differences between OECD and non-OECD were focused on because of international trade agreements and technology sharing agreements. Other country group divisions are possible, though not considered in this analysis.

3.3.3 Data description

The authors adopted the ENSAD definition of "severe" and used the fatalities criteria in this paper; therefore, only those accidents with 5 fatalities or more were included in the calculations. In addition, based on data considerations described subsequently, this paper focuses on a 30-year time period from 1978 to 2008. Since 1978, there have been 460 severe accidents associated with the oil energy chain worldwide, resulting in over 21,570 fatalities. Of the total number of accidents, 133 occurred in OECD countries, while 327 occurred in non-OECD countries. The number of fatalities was also greater in non-OECD countries where 19,017 of the fatalities occurred while 2553 fatalities were attributable to OECD accidents.

Figures 3.1 and 3.2 show annual numbers of severe accidents (1) and associated fatalities (2) for the period 1978-2008. A Mann-Kendall test is used to analyze these historical trends. This non-parametric test, verifies whether a monotonic trend in the data exists (Kendall and Gibbons, 1990; Mann, 1945). The null hypothesis is an absence of trend, and the confidence level used is 5%.

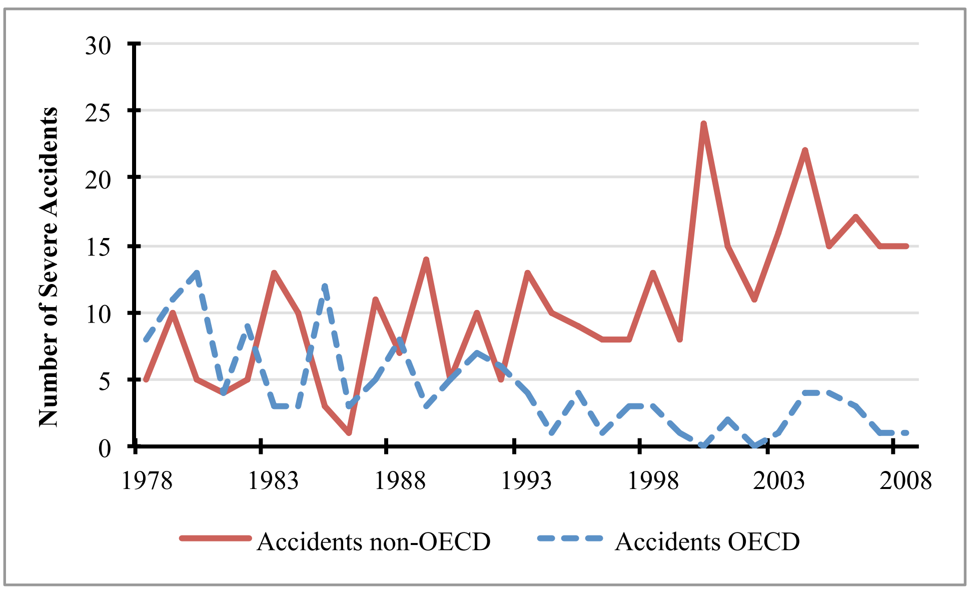

Figure 3.1: Graph of the historical trends in the number of severe accidents between 1978-2008 in OECD and Non-OECD countries. The solid red line is used to represent the non-OECD while the dashed blue line represents OECD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The results of the Mann-Kendall two-sided test indicate that the number of severe accidents in OECD countries has declined monotonically ($\tau = -0.514$, p= 0.0001) while the number of

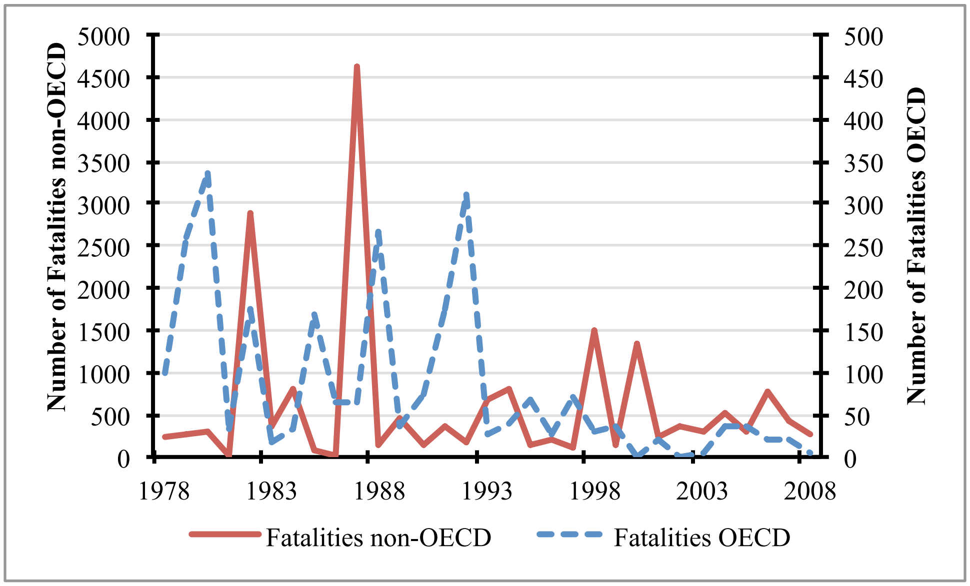

Figure 3.2: Graph of the historical trends in the number of severe accidents and the number of fatalities between 1978-2008 in OECD and Non-OECD countries. The solid red line is used to represent the non-OECD while the dashed blue line represents OECD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

severe accidents in non-OECD countries has increased monotonically ($\tau = 0.497$, p= 0.0001) (Figure 3.1). These trends do not take production into account as is done later in the analysis; however, it is of note that whatever the cause of OECD accident rate decline — perhaps technology innovations or changes to regulation — it is not having the same effect on non-OECD countries. In Figure 3.2, one can observe that the number of fatalities per accident is declining monotonically in OECD ($\tau = -0.446$, p = 0.0005) but not in non-OECD countries ($\tau = 0.127$, p = 0.3). The results are not significant due to multiple extreme accidents that strongly influence the results. If the two largest spikes are excluded from the non-OECD (solid line), the tau statistic for the non-OECD countries is positive ($\tau = 0.181$, p = 0.15), though again, not statistically significant. Therefore, no conclusions can be made about a trend in these data. These spikes describe particularly bad years or singularly extreme events; in 1982, a road tanker exploded in a tunnel in Afghanistan killing 2700 people; in 1987, a passenger ferry collided with an oil tanker killing 4386 people in the Philippines; in 1997, 900 people were killed when a pipeline exploded in Nigeria. These victims were attempting to take fuel from the pipeline; and in 2000, there were multiple accidents of theft from pipelines in Nigeria in which hundreds of fatalities resulted. These large consequence events are also visible in the country import-adjusted fatality rates in the result section (Figure 3.8-Figure 3.12). It also follows in Figure 3.2 that the number of fatalities occurring as a result of severe accidents is driven by fatalities in the non-OECD countries.

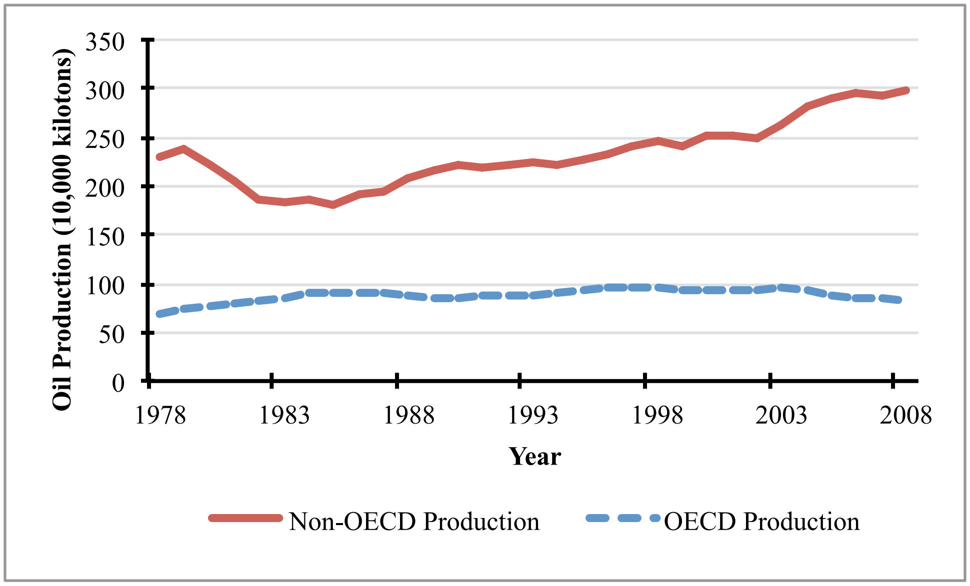

Figure 3.3: This is a graph of the historical trend of oil production in the OECD (dashed blue line) and Non-OECD countries (solid red line) between the years 1978-2008. These data are from the International Energy Agency (2014). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The oil trade data was aggregated by combining information from OECD Imports, OECD Exports, and World Oil Statistics (International Energy Agency, 2014). From these data, one can see production in OECD countries has remained fairly consistent, while there has been a large increase in the production of oil occurring in non-OECD countries (Figure 3.3). Saudi Arabia, the Russian Federation, Iran, China, and Venezuela are the greatest contributors to this increase in production where Saudi Arabia and the Russian Federation lead with 17.0% and 16.3% of the total, respectively.

3.3.4 Calculations

An in-depth update and verification of the accident data was first conducted by the authors to include additional observations and to update older entries for which new information was available.

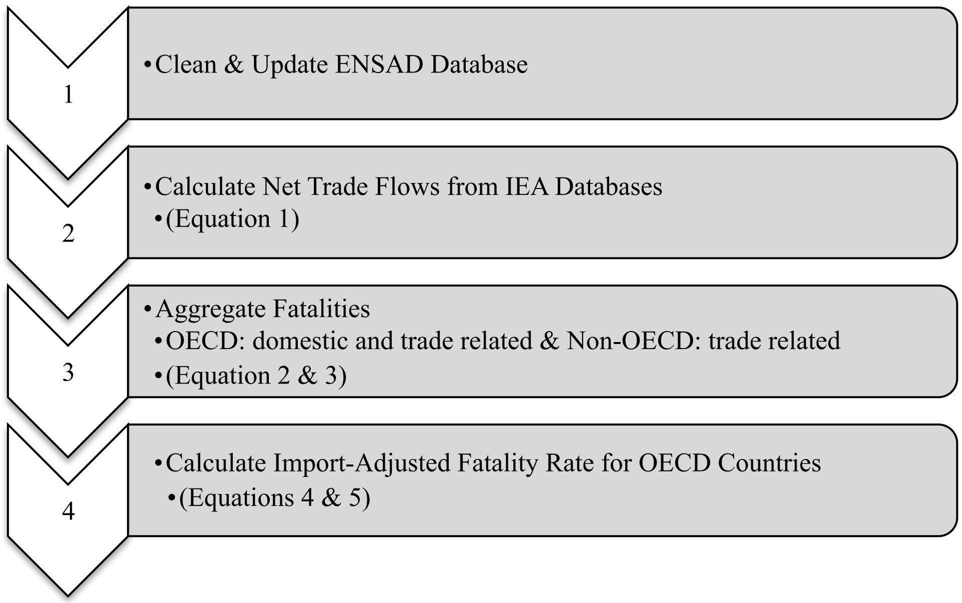

Figure 3.4: The method for calculating the import-adjusted fatality rate displayed below in flow chart form.

Afterwards, using the datasets described above, an import-adjusted fatality rate for each of the 34 OECD countries was calculated (Figure 3.4). Next, the amounts of crude oil that each OECD country produced domestically, imports from other OECD countries, and imports from non-OECD countries were calculated using the IEA data. The datasets used from the *Oil Information Statistics* reported trade data for slightly different lists of countries and products. The authors harmonized these lists by placing unmatched countries in their most closely fitting group that had been created by the IEA (e.g., "Other Africa"). One discrepancy the authors note between the *World Oil Statistics and the OECD Imports and Exports* is that *OECD Imports and Exports* have *Crude Oil Imports and Exports* whereas the *World Oil Statistics* tracks Crude Oil and NGL exports. Therefore, one should expect a downward bias in the data — that is, the share of oil exports would in fact be larger than the one calculated. As a result, the fatality rates that are calculated here should be thought of as upper bound estimates. While the authors realize the results are conservative due to this, they are conservative consistently across countries. Third, the dataset *World Oil Statistics* contains data only as far back as 1971, which con- strained the number of years for which the analysis could be done. Ultimately, a 30-year trade and accident window was chosen based on these data constraints.

For every OECD country, an import adjustment or the net amount of crude oil imported from each individual country was calculated as a percentage of the exporting country's total exports. These calculations were motivated by those in Hirschberg et al. (1998). The calculation is shown in Equation 3.1 where $\%\ exportsXY$ is the percentage of exports from country X to country Y and $netimportsYX$ is the net import of country Y from country X of kilotons of crude oil.

$$\%exports_{XY} = \frac{netimports_{YX}}{\sum_{Y}\ exports_{XY}} * 100\% \tag{3.1}$$

The share of each country's exports, consumed in each of the 34 OECD countries, was calculated. The decision was made to use net imports rather than gross imports in order to avoid the issue of "double counting." In this context, double counting would mean that a kiloton of oil imported by country X from country Y that produced it, would contribute to both the domestic production fatality rate of country Y and the import adjusted fatality rate of country X. Effectively, this would result in an upward bias on the fatality rates. Using net imports is also the convention followed in Peters et al. (2011) and Davis and Caldeira (2010); however, in the latter paper, countries with negative values are seen as net exporters and positive values are net importers. There are two possible approaches to consider in light of the net or gross distinction. The first suggests the importing country should only be responsible for the accidents associated with the imports they receive and consume, captured by a net import calculation. An alternative perspective suggests that a gross import should be used to capture the full costs of moving oil and oil derivatives around the world. The distinction between gross and net is not a critical one for many of the OECD countries, such as the United States where the products that are imported are also consumed domestically; however, as noted above, this distinction will result in a negative fatality rate for some countries, an issue which is discussed in more detail in the results section.

Afterwards, using the severe accident data collected from the ENSAD database between the years of 1978 and 2008, the authors calculated the fatalities for every country trade group, J, (determined in IEA database) engaged in trade relationships with the OECD countries during each year, i (Equation 3.2).

$$fatalities_{Ji} = \frac{\sum_{k=\ \forall\ countries \in J}\ fatalities_{ki}}{\sum_{k=\ \forall\ countries \in J}\ k} \tag{3.2}$$

In order to capture the trade-related accidents for the import adjustment — to avoid double counting — the data from ENSAD for the exporting portion was limited to accidents only occurring in export-related functions (e.g. extraction and transportation) and not occurring in end-use functions (e.g. power plants). This calculation is shown in Equation 3.3 where $importfatalityrate_{YJi}$ signifies the fatality rate (fatalities per KT crude oil) imported by an OECD country Y from a country group J in the year i.

$$importfatalityrate_{YJi} \ = \sum_{k=\ \forall\ countries \in\ J} \left(\frac{fatalities_{ki}}{total\ exports_{Yki}} * \frac{net\ exports_{Yki}}{total\ exports_{ki}} \right) \tag{3.3}$$

It was not possible to accurately establish annual fatality rates by exporting country, as severe accidents are not commonplace. Were one to use the fatalities from each country by year, countries in which a catastrophic accident had occurred during a particular year would have a high fatality rate not necessarily representing the industry nor its practices accurately. Therefore, a representative fatality rate was calculated at the OECD/non-OECD membership level; the number of fatalities was aggregated for each OECD and non-OECD and used in a calculation of the fatality rate for the countries belonging and not belonging to the trade group according to aggregate consumption (Equation 3.4). Equation 3.4 calculates the fatality rates where $fatalities_{Mi}$ is the sum of all the fatalities in year i from all countries in either OECD or non-OECD (M) and $consumption_{Mi}$ represents the total consumption of the country group, M.

$$
\begin{aligned}
&fatalityrate_{Mi} = \frac{fatalities_{Mi}}{total\ consumption_{Mi}} = \\
&\frac{\sum k{=}\forall\ countries{\in}M\ fatalities_{ki}}{\sum k{=}\forall\ countries{\in}M\ k} * \frac{\sum k{=}\forall\ countries{\in}M\ k}{\sum k{=}\forall\ countries{\in}M\ consumption_{ki}}
\end{aligned} \tag{3.4}
$$

Using a country-group level fatality rate provides a good approximation of the state of safety regulation and technology for countries with similar trade policies. However, there were some exceptional countries, which would potentially disproportionately influence these group-level fatality rates: in the non-OECD, China, India and Nigeria had much higher fatality rates than other countries in the group for most of the years under consideration. Furthermore, in the OECD, the United States, Italy and Japan had higher fatality rates than other OECD countries for most of the years under consideration. However, the effect of any potential outlier country varies substantially from year to year, evidenced by single catastrophic events causing large spikes (Figure 3.5). Ultimately, the annual country group fatality rates are used rather than calculating particular countries separately in this paper. To represent accurately each of the countries' individual fatality rates will require advanced statistical methods.

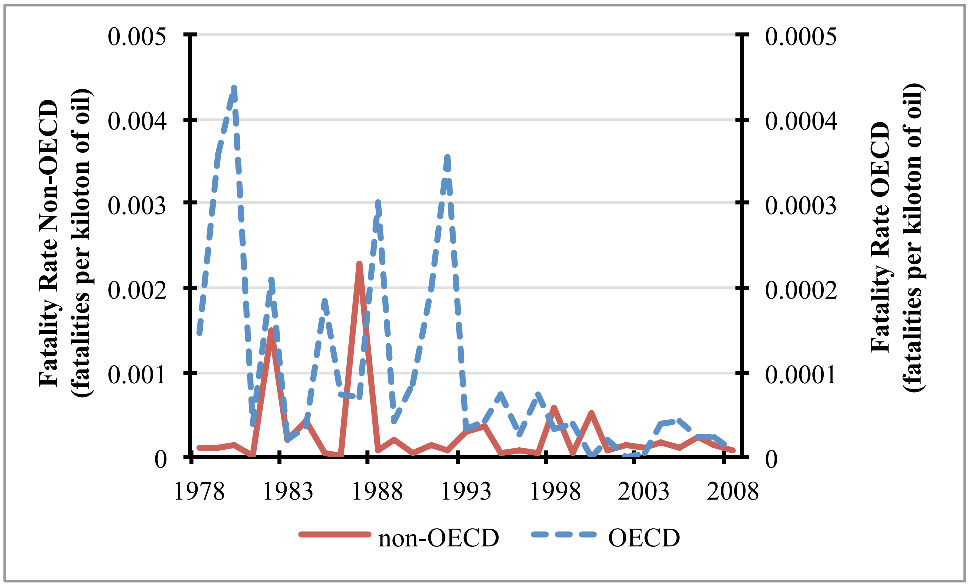

Figure 3.5: Group level fatality rates for OECD (dashed blue line) and Non-OECD countries (solid red line) between 1978 and 2008. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Finally, to calculate the domestic fatality rates, accidents along the entire oil chain were included in domestic production for oil consumed domestically and summed with the imported fatality rates (Equation 3.5).

$$totalfatalityrate_{Yi} = \frac{fatalities_{Yi}}{total\ production_{Yi}} + \sum J \sum k{=}\forall\ countries{\in}J\ \frac{fatalities_{ki}}{total\ exports_{Yki}} * \frac{net\ exports_{Yki}}{total\ exports_{ki}} \tag{3.5}$$

3.4 Results

As shown in Figure 3.1, the historical raw data indicate an increasing trend in the number of severe accidents occurring in non-OECD and a decreasing trend in the number of severe accidents in OECD countries, both of which are statistically significant. Figure 3.2 shows the number of fatalities annually in OECD countries remains lower than in non-OECD and the decreasing trend is statistically significant. By contrast, the annual number of fatalities in the non-OECD countries fluctuates with a potentially suggestive positive, but not significant, tau. Averaging the sources of the OECD country fatalities rates, one can see the average imported fatality rate from non-OECD countries exceeded that of the average imported fatality rate from OECD countries; that is, on average across the 30-year time period, OECD countries are importing more fatalities from non-OECD countries than from OECD countries. This result supports the finding that the import adjusted OECD fatality rates were consistently generated by non-OECD sources (Figure 3.6).

3.4.1 Country-level results

At the country-level, one can see that the import-adjusted fatality rate, defined in Equation 3.5, significantly differs from the domestic fatality rate for each OECD country, evidenced by the individual OECD country graphs (Figure 3.8-Figure 3.12). However, adjusting for imports does not uniformly affect all of the OECD countries; in fact, patterns emerge. The authors attribute these patterns to differing domestic capacities and trading relationships though do not specifically investigate the causes of these differences. To capture similarities between OECD countries, the authors identify 5 overarching patterns and assign the OECD countries to those 5 pattern-groups (Table 3.1):

Table 3.1: OECD country groupings shown by fatality rate pattern (asterisk indicates country chosen to represent category).

Net Exporting Influence	Non-OECD Dominated Influence	Domestic Influence	OECD Influence	Multiple Influences
Australia	Austria	Greece	Finland	Belgium
Canada	Chile	Italy	Ireland	France
Denmark	Czech Republic	Japan	Sweden*	Germany
Mexico*	Hungary	Turkey*	Switzerland	Netherlands
Norway	Korea			Portugal
United Kingdom	New Zealand			Spain
	Poland*			United States*
	Slovak Republic			

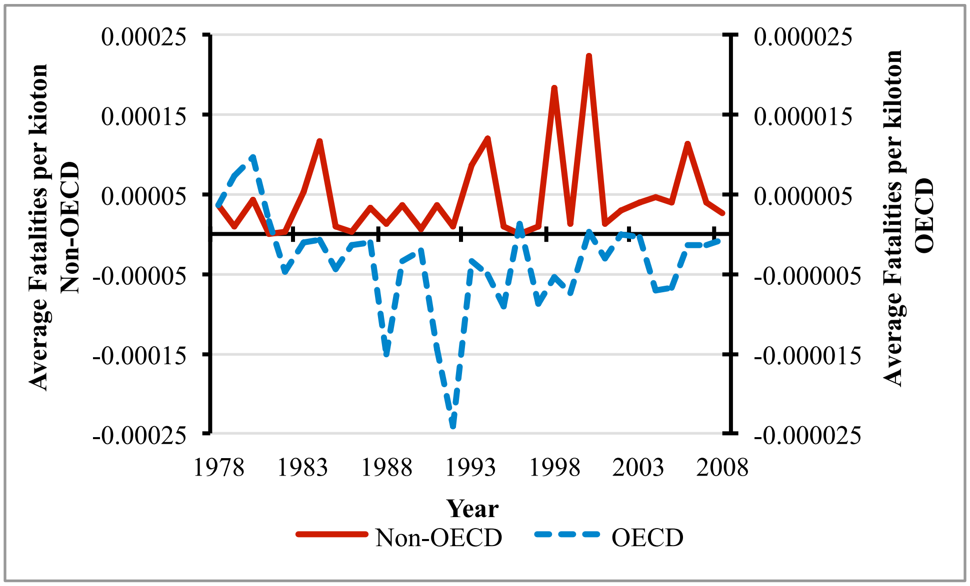

Figure 3.6: OECD average imported fatality rates are displayed by source for the years 1978-2008. The non-OECD average fatality rate is represented by the solid red line and measured on the left-hand axis; OECD average fatality rate is represented by the dashed red line and measured using the right-hand axis. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

- Net Exporting Influence
- Non-OECD Dominated Influence
- Domestic Influence
- OECD Influence
- Multiple Influences

Estonia, Iceland, Israel, Luxembourg, and Slovenia do not import substantial enough amounts of crude oil — if any at all — to influence oil related domestic fatality rates, which were all zero. As expected, these countries with energy supplied by other sources (e.g., Iceland's electricity is generated by hydroelectric and geothermal sources (Ioftsdottir et al., 2013)) do not have increased import-adjusted fatality rates. Thus, the results for these countries are omitted. For each identified pattern, a representative country was chosen to discuss and illustrate the results. The remaining countries can be found in the electronic supplement arranged by pattern-group. All of the OECD countries are assigned to a pattern-group, except those without significant imports listed above. These patterns, though suggesting a quantifiable economic relationship, are not based on quantified differences. Subsequent work may wish to make more precise groupings.

3.4.2 Net Exporting Influenced countries

The Net Exporting Influence pattern is characterized by multiple years of negative fatality rates. In large part, these negative fatality rates are from the OECD; however, there are also negative non-OECD peaks in some countries' profiles. The negative fatality rate indicates that the country is importing and re-exporting oil with the same country, but re-exporting more than it imports, or that it is only exporting to that country. Countries in this category may also have domestic accidents and positive fatality rates as well, depending on the source of the oil.

3.4.3 Non-OECD Dominated Influence countries

The Non-OECD Dominated pattern has countries in which the vast majority — if not the entirety — of their fatality rates are imported from the non-OECD. These values enter positively in the graphs in black. The reported data indicates that many of the countries in this group did not begin importing from the non-OECD until the late 1990s — all of the countries in this group have a similar patterning of accidents over the timeframe, varying in proportion with import volumes, as expected.

3.4.4 Domestic Influence countries

Countries categorized as Domestic Influence have significant contributions to the annual fatality rate coming from domestic production over the 30-year period. These countries also tend to import a significant amount from non-OECD countries rather than the OECD. Some countries appear to improve in safety standards, domestically; however, other countries in the group appear to continue to have very severe accidents into the 1990s and 2000s. Commonly, one might think OECD countries would have a better accident record than the countries in this group demonstrate.

3.4.5 OECD Influenced countries

Countries with OECD Influenced fatality rates import a significant amount of the annual fatality rate from the OECD, indicated by the red bars entering positively in the graph. There are still large contributions from the non-OECD, and often a larger contribution than that from the OECD; nevertheless, the focus remains on the OECD contribution as it is largely absent from annual fatality rates for other OECD countries unless also coupled with domestic incidents or a country that is a net-exporter.

3.4.6 Multiple Influences countries

Countries in the Multiple Influences category have annual fatality rates contributed to by each source over time. These countries have a strong background influence from the non-OECD countries and OECD countries with various domestic accidents. During the first half of the 30-year timeframe, the OECD contributes significantly to each of these countries, peaking in the late 80s before becoming very low in the late 90s. The influence from the non-OECD remains steady over time, and the domestic production incidents range from random to patterned.

These patterns also have spatial relationships, though there are some outlying countries. This geographical clustering is strongest in the European region. The countries with a large number of domestic accidents cluster on the Mediterranean Sea, while OECD Influenced tend to be in northern Europe. Non-OECD Dominated countries are clustered in central-eastern Europe, and the Multiple Influenced countries are clustered in Western Europe. The Net- Exporting Countries do not have a geographical clustering pattern (Figure 3.7). These clusters may be associated with the spread of technology as well as historical trading relationships and the structure of the various economies and market regulations.

In addition, there is a relationship between the year of ascension into the OECD and the group to which the country belongs: countries belonging to the Non-OECD Dominated Influence tend to be countries that joined the OECD later (Table A.30). This may be explained by historical oil trading partnerships with non-OECD countries that have not changed, even after gaining access to new possible trade arrangements.

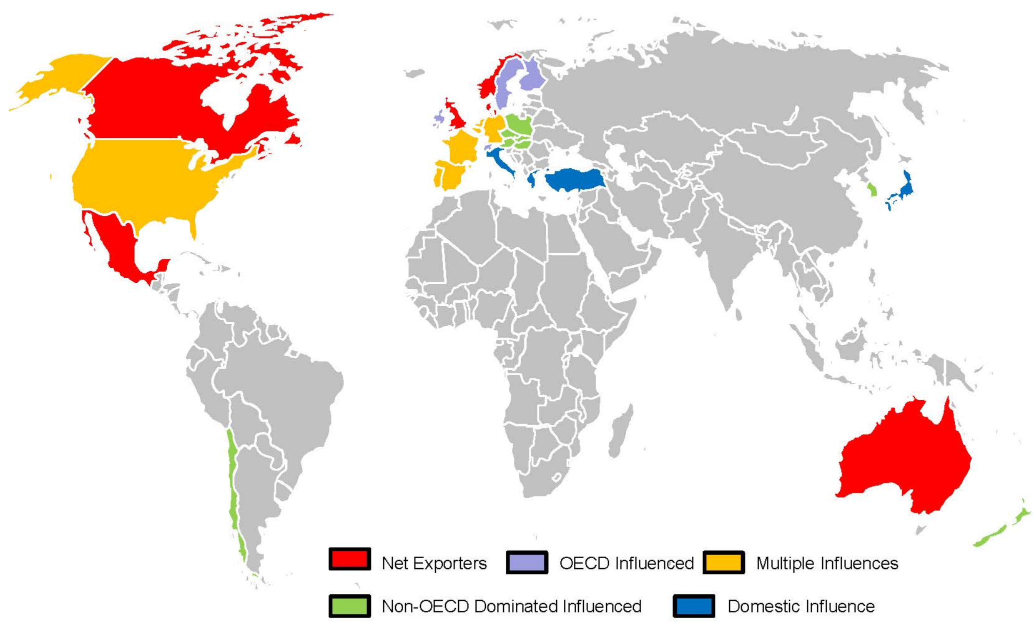

Figure 3.7: A map of fatality rate groups shows geographical clustering.

3.5 Net Exporting Influence countries

As a representative example, Mexico is chosen (Figure 3.8). It is the 10th largest oil producer in the world, and a net-exporter of crude oil and therefore, plays an important role in sustainable and safe oil production (Energy Information Agency, 2013a). Despite extensive experience, Mexico has an annual fatality rate heavily influenced by domestic fatalities. Furthermore, Mexico is a net-exporter to OECD countries. For example, 71% of production is exported to the United States alone (Energy Information Agency, 2013a). This is seen by the red bars entering negatively in Figure 3.8.

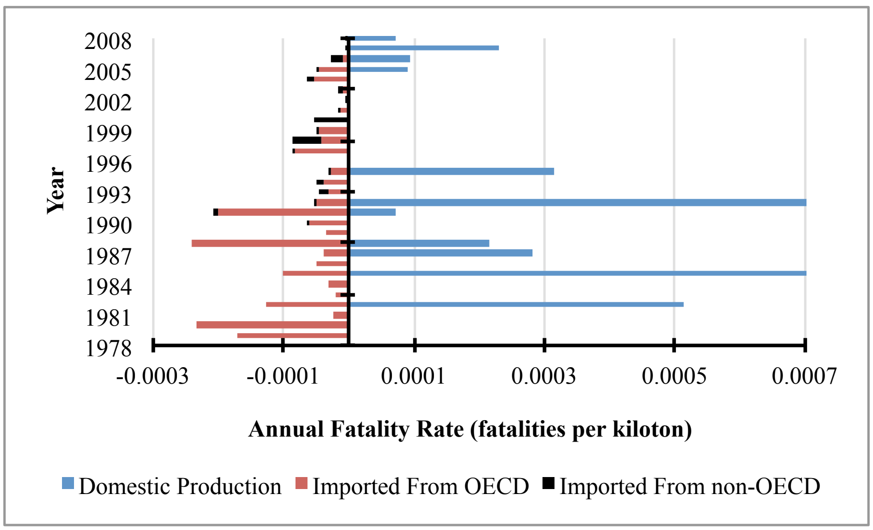

Figure 3.8: The annual fatality rate of Mexico is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Since 1978, there has been a decrease in the domestic fatality rates in Mexico. This may be due in part to the consumption of oil products remaining fairly constant in recent years, while production has been declining. The apparently lack in fatalities during the mid-90s, appears to be largely attributable to good domestic accident rates, as oil exports were steadily increasing during that time. This time period also follows Mexico's ascension into the OECD group in 1994. The cluster of domestic accidents during the 2000s coincides both with decreasing exports, and a few severe accidents. Specifically, in 2005, a warehouse illegally storing and selling gasoline exploded; in 2006 The Quetzalcóatl, a gasoline tanker, exploded killing 8 people and evacuating over 400 from the City of Coatzacoalcos, a gulf state of Veracruz; in 2007 a drilling platform and production platform collided off the coast of Dos Bocas, killing 19 workers; and in 2008, 6 people were killed when a road tanker crashed into a taxi in Vixidú, Oaxaca. The negative trend in fatality rates from OECD exports also declined over the observed time period, which is due to the OECD fatality rate decreasing during the same period. Exports to their largest importer, the US, increased continuously during this time period implying that the decline is not due to a smaller volume of trade.

3.6 Non-OECD Dominated Influence

Poland represents the members of the non-OECD Dominated Influence group (Figure 3.9). This decision was made first because there are import data for the entire span of the 30 years, unlike some other countries in the group; second, Poland is a net importer of oil (Energy Information Agency, 2013b) and while producing more oil every year, produces less than 1600 KT/year and has a negligible domestic fatality rate. Over the 30-year time period, Poland imported almost all of its fatality rate from Russia; beginning in 1996, Poland started importing oil from the United Kingdom, Norway and Kazakhstan, among a few other insignificant trades with, for example, Ukraine and the Czech Republic. Nevertheless, Poland continues to import more from its primary historical source of oil, Russia, even after gaining access to OECD trading relationships in 1996. These are fatalities that would not be recognized with typical accounting systems. Conversely, using a consumption based accounting system one can see these fatalities. Thus, it appears Poland is either unaware of the poor accident record in Russia or has other priorities that it perceives as more vital to its national interest, such as access to oil for economic growth.

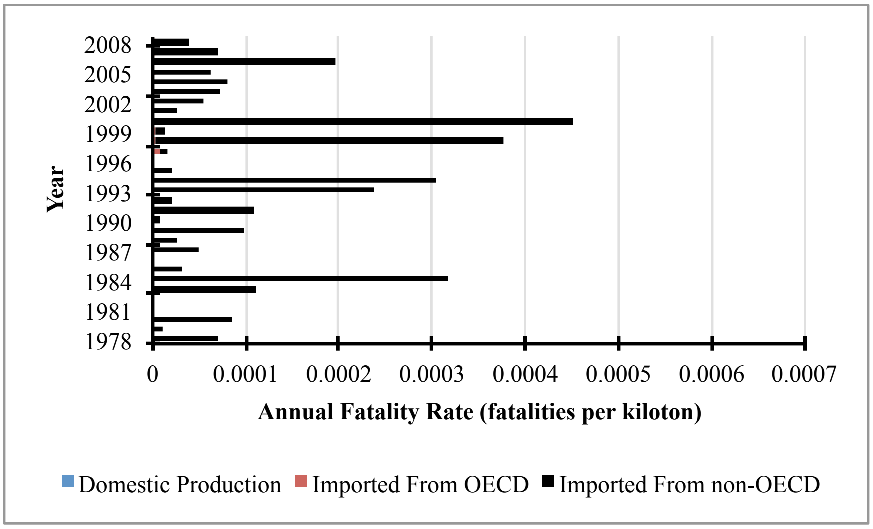

Figure 3.9: The annual fatality rate of Poland is graphed for the years between 1978 and 2008. The black bars indicate a source from the non-OECD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.7 Domestic Influence countries

To discuss the attributes of the Domestic Influence countries, Turkey is chosen. Turkey has been an OECD member since 1961 (Figure 3.10). Though one of the more extreme cases in this group, it highlights a few important issues. First, like other countries in this group, Turkey has a series of high fatality rate years solely attributable to domestic production. In a few cases, these accidents extend beyond the scale that was chosen for the exposition across countries. The spikes in the years 1979, 1994, 1997, 1998 and 1999 are due to individual accidents in each year rather than multiple accidents.

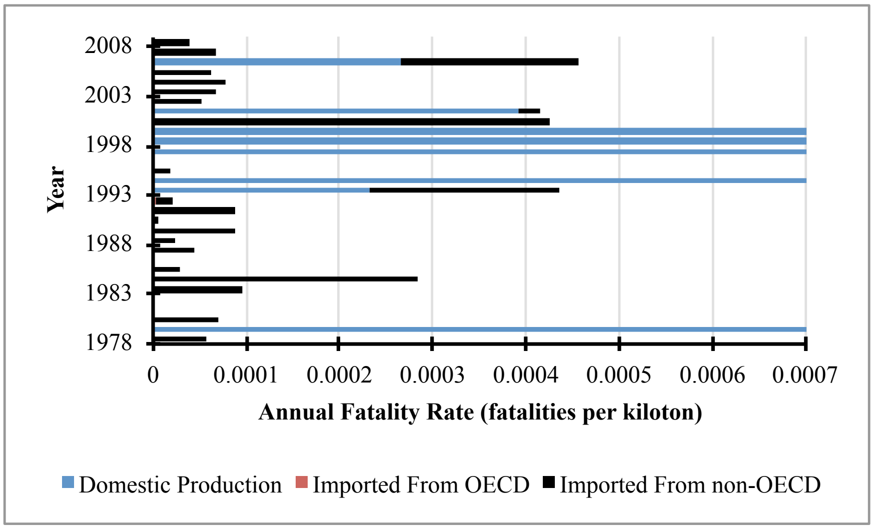

Figure 3.10: The annual fatality rate of Turkey is graphed for the years between 1978 and 2008. The black bars indicate a source from the non-OECD and the blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In 1979, 75 people were killed when a tanker exploded after a collision with another vessel. Given production for that year, the fatality rate would be 6.8 103 fatalities/KT. In 1994, an oil tanker collision resulted in 38 deaths — for this year; the domestic fatality rate is actually $1.5e^{-3}$ fatalities/KT (the uniform scale adopted for all the countries to make better comparisons does not extend far enough to capture this). In 1997, 1998, accidents involving road tankers killed 48 and 20 people, respectively, resulting in accident rates of $1.8e^{-3}$ fatalities/KT in 1997 and $7e^{-4}$ fatalities/KT in 1998. Lastly, in 1999, 37 people were killed in a refinery fire caused by an earthquake, making that year a domestic fatality rate of $1.7e^{-3}$ fatalities/KT. Furthermore, the fatality rates do not abate over the time period even as domestic production in Turkey declines after 1992. This decline in production is apparently replaced by non-OECD imports, mainly from Russia and Iran. Turkey also imports a significant amount from other non-OECD countries, which is characteristic of countries in this group.

3.8 OECD Influenced countries

Over the 30-year observed period, Sweden imported a significant amount of its annual fatality rates from the OECD, indicated by the positive red bars (Figure 3.11). Sweden is the example country because it has data for the entire span of time, and like other countries in this category, it does not begin to produce oil significantly until after 2000.

One can see that the fatality rate due to the OECD declines during the 30-year period — imports from Norway also peak in 1999 before beginning a steady decline. Some of this is replaced by imports from Russia and domestic production. The contribution of non-OECD fatalities remains fairly consistent during this time period — overall imports from non-OECD also, though fluctuating in source, remain fairly steady on aggregate. During 1987-2001, Sweden changes from reliance on mainly the UK and Saudi Arabia to being more diversified, which seems to coincide with an overall reduction in the annual fatality rate arising from OECD which is presumably "replaced" by an increased contribution from non-OECD sources.

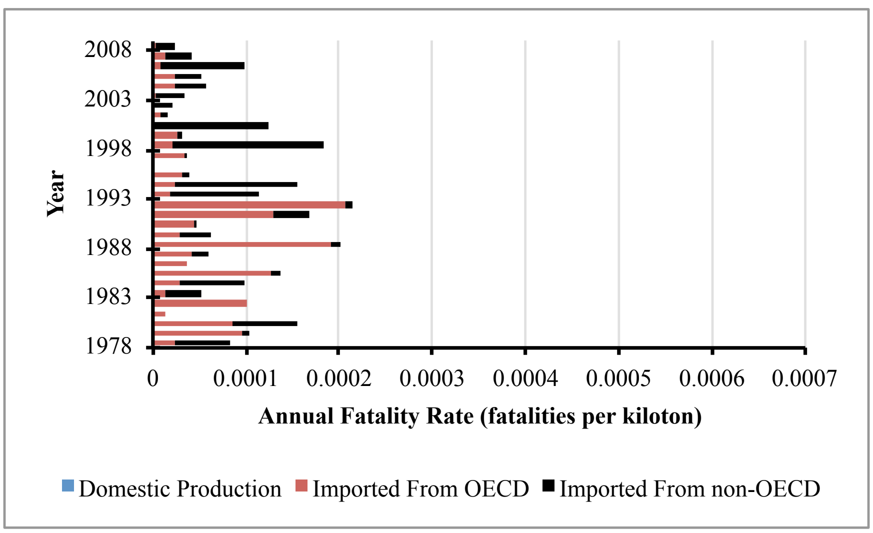

Figure 3.11: The annual fatality rate of Sweden is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD and the black bars indicate a source from the non-OECD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.9 Multiple Influences countries

Finally, the U.S. represents the Multiple Influence group as it has significant contributions from all three sources (Figure 3.12). Like other countries in this group, the U.S. does not export oil in appreciable amounts; typically, the oil imported by the U.S. is also consumed in the U.S. As in some other countries already discussed, imports from the non-OECD countries make up the majority of the adjusted fatality rate in most years for countries in this group.

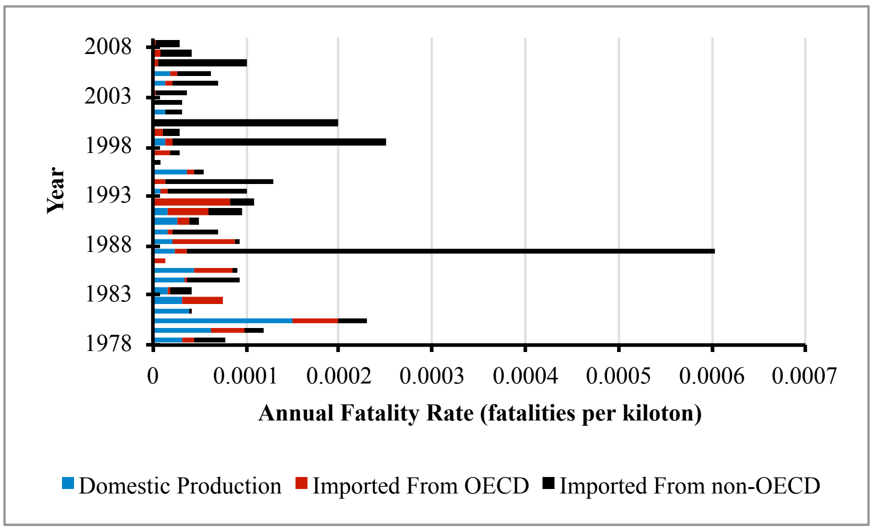

Figure 3.12: The annual fatality rate of the U.S. is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Interestingly, the U.S. has a historically significant fatality rate associated with domestic production, which has been declining with respect to domestic production over the 30-year period. However, these domestic accidents appear to be replaced by incidents from non-OECD countries. There is a decline in US oil production over this period, complemented by an increase in imports from many other countries, non-OECD and OECD alike. The largest increases in imports come from Canada, Venezuela, Nigeria and Saudi-Arabia. One might expect the fatality rates of the United States to be higher relative to other countries due to the sheer amount of oil imports; however, when normalized by consumption, the values scale downward.

3.10 Discussion

These results demonstrate that the majority of severe accidents and the associated impacts arise in non-OECD countries that may not have the best available infrastructure, technology, regulation, or practices for oil production and distribution. Results are presented for the 29 OECD countries with fatality rates associated with oil production. Over time, one can see that the number of accidents and the share imported by OECD countries is not declining, indicating a lack of "market discipline;" that is, trade flows do not substitute away from countries with poor safety performance. Peters et al. (2011) find a similar trend in carbon dioxide emissions and international trade: the increase in emissions in developing countries are not offset by any reported reductions in developed countries. If this corollary of increased pollution due to a lack of market discipline also holds for oil, with increasing production in the non-OECD, it may also be the case that the worst practices are located where the resources exist, where the regulations are relaxed, and occur during transportation where blame cannot easily be assigned.

The 5 patterns that emerge illustrate that adjusting for imports does not affect countries uniformly, and that particular trading strategies and relationships result in fatality rate patterns as well — in some cases making a fatality rate "negative." Through this analysis, one can visualize substitutions between domestic, OECD and non-OECD sources of oil and how this affects fatality rates. Across all patterns, the largest contribution to the aggregate fatality rate comes from non-OECD countries imports that more frequently have severe accidents, and this is persistent in each of the five groups. That is, non-OECD countries incur more accidents e and more severe ones e when producing and exporting oil. Furthermore, the number of severe accidents in the non-OECD countries increases over the 30-year period. Though likely due in part to increased production and not necessarily due to declining standards, the nominal increase still results in more fatalities and other economic losses. After normalizing for production, the non-OECD fatality rate fluctuates and does not decline as the rate in the OECD does. Still, it is encouraging that the fatality rate has not increased in lock-step with increased production; rather, it has been muted by increasing production. Despite severe accidents occurring, OECD countries continue to import, in ever-greater proportions, crude oil from countries that have not apparently improved production standards significantly, evidenced by the persistently higher average fatality rate.

A consumption-based method to reallocate the consequences of accidents in the oil chain suggests a different level of policy recommendations, focused on international trade agreements, than a production-based or control-based approach would suggest (Guan et al., 2014). The authors believe interventions at the trade level, though not without challenges (e.g., free trade negotiations), would be more effective than production- or control-based interventions. First, a policy based on a consumption fatality rate would target the consequences of international trade due directly to transportation and other export activities in ways that accounting for production alone would not. In addition, this accounting perspective can highlight those consequences as countries engage in new trade arrangements or chose sources of energy (Mozner, 2013).

Second, using control-based accounting, if it were even possible to conduct in a justifiable and consistent way, may encourage companies to avoid regulation, and perhaps more importantly, the burden of regulation and enforcement would continue to fall solely on the countries with low capacity. Because of the dynamic nature of trading, any policy should be coordinated among countries such that counterproductive substitutions are not made. For example, the OECD countries might partner with non-OECD countries to improve operating performance rather than substituting away from these countries, which may have other negative implications for safety (i.e. the oil is sold to a third party and then resold to the OECD country increasing the length of risk exposure). In addition, no derivative products were considered in this analysis. These additional dimensions should be investigated in future work.

From a sustainability perspective, OECD countries consuming imported oil should be aware of the costs associated with particular trading agreements despite not being acutely impacted by these accidents. This perspective shares the responsibility, ethically and consequentially, with countries that directly benefit and also may motivate these countries to support and engage in more sustainable practices (Davis and Caldeira, 2010). Furthermore, according to Princen (1999), a consumption-based perspective appropriately characterizes the problem at its source, consumption. Ultimately, there are three main levers to reduce the impacts of accidents related to oil trade and production: increase safety standards and regulations; reduce the distance of oil trade to reduce risk exposure; or to reduce the amount of oil trade. A consumption-based approach can support each of these three levers.

3.11 Conclusion

Using the trade flows and historical accident data from the oil chain, annual fatality rates for each OECD country by the source of the oil (domestic, OECD imported, or non-OECD imported) have been determined. This was done using an accounting method drawn from multi-regional input-output methods to calculate the annual fatality rates for the OECD and non-OECD groups and using trade data to adjust domestic fatality rates for imports. From these results, 5 distinct patterns emerged among particular OECD countries: Net Exporting, Non-OECD Dominated Influence, Domestic Influence, OECD Influenced and Multiple Influences countries. These groups also suggest both a spatial and temporal pattern. The geographical clusters may be associated with the spreading of technology or historical trading patterns, whereas the cluster membership appears to be related to the year of ascension into the OECD. The annual fatality rates and the groups illustrate fatality rates and trends in fatality rates vis-à-vis domestic consumption e in this way, the authors show the distribution of risk caused by oil production versus consumption, measured in human lives, that typically might go unnoticed. These results add to a growing literature on sustainability and the initiative to make decisions about oil sources taking the distribution of consequences into account. This analysis confirms there is a larger impact of a country's oil consumption and differential burdens of risk among producing, exporting and importing countries. These results are consistent with the narrative of developing countries bearing more of the impact of the goods developed countries consume, but this paper increases the imperative to reassess how and where to measure consequences of energy consumption. These preliminary findings will help direct future research toward the quantifying disparities associated with energy resource trading, including, for example, the Value of a Statistical Life (VSL), as well as research on instruments to cope with these disparities and the sources of such disparities, such as interventions through trade agreements.

3.12 Acknowledgments

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CHAPTER 4

INSURGENT ATTACKS ON ENERGY INFRASTRUCTURE AND ELECTORAL INSTITUTIONS IN COLOMBIA

Coauthors: Austin L. Wright,[1] Peter Burgherr,[2] Matteo Spada,[2] Robert Rosner[1]

4.1 Abstract

Over the past decade, social scientists have made a number of breakthroughs in studying the impact of violence on electoral participation, electoral outcomes, and institutional development (Höglund, 2009). These studies have shown that insurgents can effectively directly target, intimidate, and pressure the voting population to achieve political objectives (Acemoglu et al., 2013; Dunning, 2011; Bratton, 2008). Violent attacks where voting takes place have preempted voter participation and violent threats or intimidation have manipulated votes cast. Overall, studies have shown that physically violent electoral environments undermine the democratic process. Despite these breakthroughs, we still know little about whether and how insurgents might target critical infrastructure to undermine democratic institutions. We take advantage of an unprecedented dataset of global energy infrastructure attacks. We quantify the relationship between the timing of a fixed election schedule and attacks on critical energy infrastructure in Colombia from 1980-2011. We find that the combined likelihood of an attack on oil pipelines and electricity transmission lines and substations increased by 25% and that the combined number of attacks increased by 51% during election months, both relative to insurgent violence during control months. Our results are the first to examine how armed, non-state actors strategically time and deploy attacks on critical energy infrastructure undermining state capacity and democratic institutions. We anticipate these results will have not only important implications for state building efforts

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and critical infrastructure protection in resource-rich, institutions-poor countries, but also in more developed countries where critical energy infrastructure has increasingly become strategic assets and targets.

4.2 Introduction

To what extent can critical infrastructure become a tool for insurgents? Non-state insurgent actors have increased attacks on critical energy infrastructure over time (Giroux et al., 2013). As critical energy infrastructure becomes more complex and interconnected, attacks on this infrastructure can have far reaching consequences not only for the economy but also for democratic institutions. Leveraging exogenously scheduled elections in Colombia and microlevel energy infrastructure attack data, we use multivariate linear regression to show that insurgent groups, *Las Fuerzas Armadas Revolucionarias de Colombia (FARC)* and *Ejército de Liberación* (ELN), time attacks on critical energy infrastructure in the months before an election. We probe this result further considering whether these attacks are intended to disrupt, influence, and delegitimize democratic elections and institutions as with direct electoral violence. These findings are particularly interesting as democratic societies — burgeoning and established — try to identify indirect threats to the electoral process from advancing technologies.

The international community promotes democratic ideals in order to legitimize institutions and the government as well as to promote social and political development (Höglund, 2009). Many suggest that the social and political stability that theoretically results from democratic regimes is also linked to economic development, though the precise relationship has not been determined (Robinson, 2006). In a democratic society, the government wins legitimacy by public mandate, and retains that legitimacy by carrying out its mandate: providing services central to the functioning of the society such as public safety or electricity. Consequently, the international community focuses development projects on building out public service infrastructure, such as transmission lines, roads, and water pipes. Thus infrastructure is crucial to society, the economy (World Bank, 1994), and to a functioning state, supplying services to firms as well as individuals (Prud'homme, 2005). Yet, in the case of some developing and conflict-ridden countries, democratic processes and infrastructure expansion can be controversial and contested. This is particularly the case in resource-rich countries where property rights may be disputed and elections are seen as a way to control resources (Bratton, 2008; Acemoglu et al., 2013) and in places where foreign firms are extracting resources and generating hostility and feelings of exploitation in the local, often impoverished, community (Appel, 2012). In these contexts, elections can become insurgent targets for violence, manipulation, and fraud, while energy infrastructure can become insurgent targets for rapacity (Anifowose et al., 2012) or attack. Energy infrastructure has become a target to achieve an objective (e.g., "economic warfare") based on idiosyncratic symbolism (e.g., anti-capitalist) (Toft et al., 2010).

In recent years, electoral violence in developing and conflict-ridden countries has attracted more attention, trying to determine the conditions for, causes of, and impacts of such violence. Researchers find insurgents strategically time violent attacks close to elections to influence electoral participation and outcomes (Höglund, 2009; Newman, 2013), especially in locations where governments do not have an inclusive electoral process (e.g., violence as participation and protest) (Aksoy, 2014). Electoral violence also has a significant impact on voter registration, voter turnout, the election schedule (Höglund, 2009; Dunning, 2011), and voter preferences (Gould and Klor, 2010), and which candidate is elected to office (Acemoglu et al., 2013). Elections held in violent or threatening environments, as opposed to directly targeted elections, also experience distortions in outcomes and participation (Berrebi and Klor, 2008; Weintraub et al., 2015; Bratton, 2008). Whether in an environment of violence or targeted directly with a violent attack, elections affected by violence lose perceived legitimacy (Höglund, 2009). Though it is often assumed that insurgents use violent tactics to benefit one candidate or party, in Afghanistan, Weidmann and Callen (2012) find that violence can also be used to generate nonpartisan distortions in the democratic process (e.g., fraud). Aksoy and Carter (2014) develop the important, related distinction between how insurgent groups emerge to challenge democratic institutions based on specific ideologies. According to Aksoy and Carter's two main group designations, *within-system* groups wish to influence and participate in democratic institutions while *anti-system groups* wish to overthrow the existing regime (Aksoy and Carter, 2014). This literature indicates that both the environmental conditions and the insurgents' intentions can distort election outcomes or undermine the electoral process.

While this research confirms insurgents use electoral violence to undermine the democratic process, these studies are focused on undermining democracy using direct, interpersonal violence. This literature does not address indirect attacks as a tactic. Indirect attacks may include attacks on critical infrastructure (e.g., electricity transmission lines or the cyber network) that prevents voting or intimidates the voting population without necessarily causing immediate, physical harm. Failing to address indirect attacks, the literature leaves an important gap to be filled. Directed, violent attacks may be an effective way for insurgents to achieve short-term objectives. However, insurgents are faced with a trade-off between influence and alienation. Insurgents risk alienating the population from whom they ultimately seek endorsement with direct, interpersonal violence and attacks. Consequently, insurgents may vary their tactics to maintain influence and support (Criado, 2011). Responding to this gap in the current political science and economics literature, our research investigates indirect, physical attacks, rather than cyber attacks, as an insurgent tactic.

Over the past three decades, there has been an increase in the number of non-state actor attacks on critical energy infrastructure globally (Giroux et al., 2013). There are many plausible reasons for this increase considering the insurgents' objectives and the strategic options available to insurgent groups. First, energy resources are growing in importance and value to society and the economy. Thus, attacks halting operation or diverting energy resources can have significant and long-lasting economic impacts (Meriage, 2000; Homer-Dixon, 2002) without causing direct physical harm to the population. The interconnectedness of energy infrastructure with other critical infrastructure (Kröger, 2008) further makes energy infrastructure more appealing to would-be attackers. Energy infrastructure also spans long distances making it hard to secure. Consider as an example electricity transmission lines or pipelines. These linear structures extend hundreds of miles reducing the likelihood that an attack would be thwarted or that the perpetrator would be caught (Giroux et al., 2013). Furthermore, launching an attack on infrastructure is relatively “low-tech” and inexpensive (Homer-Dixon, 2002). Finally, in countries where resources are contested, especially between local groups and large multinational companies, infrastructure targets are symbolic (Toft et al., 2010).

Given the characteristics of energy infrastructure and the social conditions where insurgents are actively fighting democratic regimes, it is of great interest whether insurgents can and do use critical energy infrastructure to undermine the democratic processes and institutions commonly pursued for development and relied on for the regular functioning of a developed country.

Empirical strategies to answer this question are bedeviled by multiple challenges, first and foremost, data availability and endogeneity. Until now, energy infrastructure attack data have not been widely available. Initially, this lack of data led some to conclude insurgents were not motivated to target energy infrastructure except in particular cases (Toft et al., 2010). However, access to additional data challenges that conclusion. From an estimation perspective, the difficulty is to overcome endogeneity — in particular, simultaneity bias — to quantify the causal relationship between violence and the timing of elections. In the case where elections are not on a set schedule, simultaneity bias means that one cannot determine whether the election motivates attacks (e.g., attempts to sabotage) or whether the attacks cause the timing of the election (e.g., attacks force an election to be rescheduled). Simultaneity bias is also problematic in assessing the effects of attacks on the outcomes of an election.

Colombia presents an ideal setting to overcome both data and endogeneity issues. First, we have a new, rich database of energy infrastructure attacks carried out by FARC and ELN, two groups whose history, capabilities, and structure are well-studied. Second, we are able to exploit an exogenously determined election schedule, eliminating the simultaneity bias issues. Finally, Colombia is particularly interesting because it is a stable democracy despite years of civil conflict. The longevity of both the democracy and civil conflict make our results germane for countries with similar "conflict-democracies," including the Philippines, Indonesia, and Thailand. Furthermore, our results can offer individual insights for developing countries experiencing civil conflict and countries with established democracies.

We have structured the paper as follows: In Section 4.3, we discuss the literature motivating and relating to our work. We describe the civil conflict in Colombia as well as relevant background on the oil and electricity sectors and electoral system in Colombia in Section 4.4. In Section 4.5, we introduce and detail our sources of data. In Section 4.6, we present the estimation strategy. Following, in Section 4.7, we explain the results and implications of these results. We test the sensitivity and robustness of our results in Section 4.8. Finally, in Section 4.9, we make our conclusions and recommendations for future work.

4.3 Review of Literature

Our research draws from and contributes to four distinct branches of literature: electoral violence, the Colombian civil conflict, critical energy infrastructure vulnerability, and the resource curse. First, we consider electoral violence research generally and also Colombian-specific research on violence and elections. Next, we delve into the large literature on the Colombian civil conflict, ranging from qualitative and sociological to empirical studies. The literature on critical energy infrastructure protection is centered on underdeveloped, resource-rich but conflict-ridden countries as these countries have experienced comparatively more attacks related to resource extraction. Finally, the resource curse literature is centered on international commodities from which we mainly consider work concentrated on oil in alignment with our focus on energy and Colombian resources.

Research on electoral violence has focused mainly on direct attacks on voters, voter manipulation by threat (e.g., Bratton, 2008), and violent conditions under which elections take place (e.g., Berrebi and Klor, 2008; Gallego, 2011). Scholars have endeavored to quantify causal relationships between the timing of and effect of such violence on elections despite endogeneity concerns between violence and election schedules and outcomes. Indeed, these research findings suggest that insurgents time violent attacks strategically (Condra et al., 2016; Berrebi and Klor, 2008; Bratton, 2008; Newman, 2013). Scholars also have shown that violence has an effect on voter preferences (Berrebi and Klor, 2008; Gould and Klor, 2010) and both a persistent temporal effect (Weintraub et al., 2015) and non-linear spatial effect (Berrebi and Klor, 2008; Weintraub et al., 2015) on election results. The motivation and effect of these attacks also have been shown to depend on the maturity (Condra et al., 2016; Höglund, 2009) and representativeness of the democracy (Aksoy, 2014; Höglund, 2009).

In the context of Colombia, there are mixed findings about the use of and effect of insurgent violence on elections. Gallego (2011) suggests, using an instrumental variable research design, that FARC successfully launches interpersonal attacks (e.g., bombings, kidnappings) to reduce voter turnout. Rather than an instrumental design, to overcome endogeneity challenges, Weintraub (2015) considers the one-year lag-effect of FARC's attacks on elections. He finds a non-linear relationship between the violence and support for candidates in the 2014 presidential election: municipalities with either many attacks or very few attacks showed greater support for the anti-insurgent candidate. In contrast, Acemoglu et al. (2013) do not find any relationship between insurgent attacks and congressional elections. Rather, Acemoglu et al. find paramilitary attacks have a significant effect on elections. Dube and Naidu (2010) also suggest that paramilitaries exert force rather than the insurgents during Colombia's elections.[3] Acemoglu et al. (2013) assert that insurgents do not use strategic attacks during elections because it is against their ideological core. They argue that FARC and ELN are leftist — *anti-system* — insurgents committed to overthrowing the government with a revolution rather than participating in the electoral system. Yet, research on the larger insurgent narrative as well as historical and current insurgent behavior suggest elections are an opportunity for insurgents to disseminate their ideological message to a wider audience (Leech, 2011) either through attacks or by ensuring the election of a sympathetic politician. Elections are also found in other country contexts to be a key institution to target in order to further an insurgent agenda (Condra et al., 2016).

The broader literature on the Colombian civil conflict and the growing literature on the "resource curse" emphasize the role of violence vis-à-vis energy resources in ongoing civil conflicts. Based on extensive qualitative research, Richani (2005) maps out the "War System" in Colombia — an economy within Colombia in which the majority of beneficiaries are outside of Colombia — that arises from the extractive industries such as oil. In this War System, multinational oil companies reinforce and exacerbate the conflicts among the insurgents, the government, and the paramilitaries, all of whom have a financial and social interest in the natural resources (Richani, 2005). Similarly, Dunning and Wirpsa (2004) assert that the exploitation of oil in Colombia, and the role of multinational companies in that exploitation, generates conflict over oil resources that has larger geopolitical implications. Using an econometric approach, Dube and Vargas (2013) show that the price of oil directly influences the level of insurgent activities and conflict in Colombia, as predation becomes

[3] Note: The papers from Gallego (2011), Acemoglu et al. (2013), and Dube and Naidu (2010) all use the Conflict Analysis Resource Center (CERAC) database, while Weintraub et al. (2015) use Human Rights Watch Data.

more valuable when oil prices are high. Carreri and Dube (2016) also use an econometric approach to show that the value of oil influences Colombian democratic institutions and is a good predictor of who will be elected to office. In other country settings, literature on the resource curse and internal conflict try to disentangle the financial (e.g., Collier and Hoeffler, 2004; Anifowose et al., 2012), political (e.g., Robinson et al., 2006), institutional (e.g., Fearon, 2005), and social causes (e.g., Appel, 2012) of violence associated with commodities — in particular, fossil fuels. Though the literature overall agrees there is an influence of commodities on violence and conflict, the causal mechanism continues to be a subject of research and controversy.

How violent actors choose tactics and targets to optimize their objectives and communicate their grievances is often discussed in the terrorism literature. Given their situational, resource, and capability constraints, insurgents and terrorists are characterized as rational actors solving an optimization problem (Powell, 2007; Wright, 2015). Within that optimization problem, some researchers suggest, is the need to be responsive to a public audience and avoid alienating possible supporters through an over-use or misuse of violence (Pape, 2003; Criado, 2011; Condra et al., 2016). This appeal to the local populace can make alternative targets (Condra et al., 2016), such as energy infrastructure, appealing.

The literature discussing indirect attacks against energy infrastructure is not well-explored. Toft et al. (2010) consider energy infrastructure in isolation. They suggest, with some exceptions, that energy targets are not appealing for would-be-attackers. These exceptions include places where energy targets have idiosyncratic symbolism (e.g., anti-capitalist) or particular economic or social leverage (e.g., "economic warfare") (Toft et al., 2010).[4] In another resource rich location, Nigeria, Anifowose et al. (2012) compare attacks on oil pipelines over ten years in the five different regions of the country using GIS mapping. Along with

[4] Colombia is included in the list of countries from Toft et al. (2010) with the special setting primed for energy infrastructure attacks.

identifying specific patterns of attack within Nigeria, they find that poverty and attacks on pipelines are negatively correlated, indicating an economic motivation for the attacks. Appel (2012) investigates the social, political, and economic effects of multinational oil and gas companies operating in Equatorial Guinea. He concludes that these industries separate from and alienate the local communities and generate bad-will within the country. This narrative suggests that energy infrastructure could be a symbol of a larger social struggle, as Toft et al. (2010) suggest. Notably, none of these papers use an econometric approach. Rather, these studies rely on statistical and contextual analyses using limited data sources.

From this literature, our research stands out for four main reasons. First, we have access to a novel dataset on energy infrastructure attacks. Second, these data allow us to quantify a causal relationship using econometric methods that can be more insightful than descriptive statistical and contextual research alone. Third, we contribute to the Colombia literature by revealing a richer understanding of the insurgent narrative and its translation into tactical choice. Finally, and most importantly, we consider the largely neglected topic of indirect attacks to influence democratic institutions. This tactic is manifesting not only in developing countries like Colombia but also in developed countries that are increasingly vulnerable to attacks on critical infrastructure, for example, the alleged cyber interference during the recent U.S. presidential election (Lynch, 2017).

4.4 Background on Colombia

Colombia offers an interesting setting in which to investigate whether and how insurgents leverage attacks on energy infrastructure to meet their objectives for at least three main reasons. First, FARC and ELN, have been active in Colombia for decades. This both provides years of attack data from the same two active insurgent groups, but also over the past seven decades, FARC and ELN's grievances, tactics, motives, and capabilities have been extensively studied, helping us to construct a cohesive narrative. Second, Colombia is rich in natural resources and relies on those resources to fuel the economy. Therefore, those in control of the natural resources also control the largest part of the Colombian economy. As a result, we see the major actors in the conflict — the government, the paramilitary, and the insurgents — with a stake in the resources and in the infrastructure. Third, from an institutional perspective, Colombia is one of the oldest, most-stable democracies in South America. The regular schedule of democratic elections, despite the ongoing civil conflict, provide an exogenous source of variation to test our research questions empirically. In addition, we can estimate the impact of the attacks on democratic elections without disentangling the effect of democratic nascency on the elections, though stylized procedures of the elections still must be carefully considered. The following three sections discuss these aspects in depth to provide the context for our research.

4.4.1 Geography & Resources

Colombia is composed of 32 departments and the capital city, Bogotá. It is further divided into 1122 municipalities. The country is neither densely populated nor evenly developed by department. The geography and diverse terrain of Colombia have complicated development and governance (Dobovsek and Odar, 2010). From one department to the next, a full range of development may be seen; the wealth and development disparity among Colombians has earned them one of the highest Gini Index Coefficients (53.5) (World Bank, 2016).[5] This inequality in Colombia — rooted in ownership of land, distribution of land, and land-use — has a played a central role in the ongoing civil conflict as various groups have tried to assert their economic rights (Flores, 2014; Leech, 2011).

The Colombian economy relies heavily on exports of the country's abundant natural resources

[5] A widely used index to measure inequality: http://data.worldbank.org/indicator/SI.POV.GINI.

as well as the foreign investment made for the exploitation of those resources: principally crude oil, coal, coffee, and gold. Since the 1990s, foreign direct investment in these sectors has been increasing to all-time highs (Maher, 2015; U.S. Central Intelligence Agency, 2013). This "Apertura Económica" (economic opening) has led to increased privatization in Colombia and increased foreign investment (Maher, 2015). Some suggest social and economic issues, including the inequality, substandard infrastructures, the drug trade, and the insurgencies, have threatened foreign investment income for the government (U.S. Central Intelligence Agency, 2013). However, others suggest a nuanced positive complementarity between violence and foreign investments. According to this narrative, violence has been used as a tool by the Colombian government to displace its citizens, especially in places rich in oil resources (Maher, 2015). On the one hand, the economic opening suggests that capturing natural resources and deterring foreign investment are ways the insurgent groups gain power over the economy, and by extension, the government. On the other hand, the economic opening suggests that infrastructure built by foreign direct investment, such as energy infrastructure, symbolize the exploitation and inequality FARC and ELN ostensibly fight.

4.4.2 The Revolutionary Armed Forces of Colombia & The National Liberation Army

The civil conflict in Colombia is commonly traced back to La Violencia (1948-1958), beginning in 1948 when the widely acclaimed social activist and liberal reformer Jorge Eliecer Gaitán was assassinated. A symbol of growing social struggles, Gaitán's death provides an explicit date to punctuate the outbreak of violence over land reforms, political inclusion and participation, and inequality (Taylor, 2009). From this turmoil, and from seeds of discontent planted in the decades preceding, three main non-government groups emerged:

two main insurgent groups,[6] Las Fuerzas Armadas Revolucionarias de Colombia (The Revolutionary Armed Forces of Colombia, FARC) and Ejército de Liberación (The National Liberation Army, ELN), and the paramilitary — an unofficial, local militia for the government. Though apparently having a similar objective, the two distinct insurgent groups had different origins: FARC was largely peasant grown, while ELN emerged from the efforts of an urban dissident, intellectual group. Nevertheless, each insurgent group sought 'regime change' toward a Marxist model (Leech, 2011; Kydd and Walter, 2006). The paramilitary developed to protect wealthy landowners from FARC and ELN. In the decades following La Violencia, unfulfilled promises of reforms ultimately reinforced the support for insurgent opposition, and a large spreading of FARC and ELN was seen between the 1970s and the 1990s into rural, peasant communities as well as resource-rich locations (Sanchez and del mar Palau, 2006; Richani, 2005). Since then, the struggle has been exacerbated by drug trafficking and weak central governance (Dobovsek and Odar, 2010). Some estimates suggest, hundreds of thousands of people have died and millions of people have been displaced from their homes as a direct result of the civil conflict (Renwick, 2016). Nevertheless, the conflict has been and, until the recent peace agreement, remained largely between the government, paramilitary, and insurgent groups (U.S. Central Intelligence Agency, 2013), each purportedly representing the Colombian interest.

Energy infrastructure are vital and disputed assets for the paramilitary and the insurgents operating in Colombia. For the last few decades, FARC, ELN, and the paramilitary have been heavily involved with energy production and distribution, in particular as the monetary and societal value of energy resources has risen. FARC, ELN, and the paramilitary as well as multinational companies have tried to exert control over resource rich locations (Sanchez and del mar Palau, 2006; Leech, 2011; Richani, 2005; Maher, 2015). To reduce threats from conflict over resources, multinational companies have typically hired paramilitary, private, or

[6] There were also other smaller insurgent groups such as M19. However, we do not include them in our analysis.

insurgent security for their operations. Which group is hired depends on the local adversary (Dunning and Wirpsa, 2004; Sanchez and del mar Palau, 2006). Interestingly, insurgents and paramilitaries alike are known to levy “taxes” on production in regions they control in return for unmolested operations (Meriage, 2000). FARC and ELN also have imposed “community taxes” and extracted additional funds from multinational energy companies through subcontracts guaranteed to insurgent owned companies (Richani, 2005). For each group, control over energy producing areas and distribution routes offers a steady source of income and financing for other activities. When control of a territory is particularly important or contested, these groups may attack energy infrastructure to steal or reroute resources such as oil, to punish and extort those in control, or to seize the territory and its resources. Occidental Oil and Gas Corporation cites “measurable” interruptions in oil production, including shutting down oil fields due to these attacks (Meriage, 2000). Mainly FARC and ELN, rather than the paramilitary, attack energy infrastructure to interrupt extraction or diverted resources away from normal distribution (Dunning and Wirpsa, 2004; Giroux et al., 2013).

FARC and ELN have been attacking energy infrastructure in Colombia for many years, specifically targeting oil and electricity infrastructure (Meriage, 2000; U.S. Energy Information Administration, 2016; OpenOil, 2015; Maher, 2015). Attacks on linear energy infrastructure, for example, oil pipelines and electricity transmission lines, are relatively simple to carry out. First, these linear infrastructure stretch hundreds of miles along which many sections are left unprotected. This reduces the likelihood that an attack will be thwarted and that the perpetrator will be caught. Second, this infrastructure is valuable. Therefore, when attacks halt operation, cause blackouts, or divert energy resources, the economic impact can be significant and long-lasting (U.S. Energy Information Administration, 2016). Furthermore, as the resources are contested, especially between local groups and large multinational companies, these targets are symbolic of capitalism and exploitation (Toft et al., 2010; Richani, 2005). In the case of electricity lines, attacks can interfere with the functioning of society and the economy as well as hinder the extractive industry (Maher, 2015). Furthermore, attacks on electricity infrastructure can intimidate and frighten the population, without the use of direct harm. In Colombia, the electricity sector also allows foreign investment, potentially making transmission lines and substations a symbol of foreign interference. Taken together, these attributes make energy infrastructure monetarily, socially, and politically valuable targets in Colombia.

4.4.3 Petroleum Industry & Infrastructure

Since the Colombian oil industry began at the turn of the 20th century, foreign multinational companies have invested heavily in discovery and exploitation of oil reserves. In fact, the Colombian government has relied almost entirely on these multinationals for resource development though, until recently, always requiring the companies to have a partnership with Ecopetrol, the state-run oil company (OpenOil, 2015). Multinational companies are required to pay "regalias" or royalties, historically as much as 20% of their production profits (Echeverry et al., 2008). These royalties are distributed to the local municipalities, and intended to bring wealth back to the communities from which the natural resources were extracted. These monies are controlled by the local government, mayors, and municipal councils. As a result, insurgents, the paramilitary, and corrupt politicians hoping to enrich themselves, strive to control these resources (Dunning and Wirpsa, 2004).

Colombia has five refineries owned by the state-owned oil company, Ecopetrol. With such a small refining capacity, Colombia refines less than half of its annual oil production. However, the oil transportation system in Colombia is extensive. There are seven main pipelines that transport crude oil and petroleum products in Colombia. Of those seven pipelines, three connect the production fields and refineries to the export terminal at Coveñas, on the northwest coast of the country. Pipelines in Colombia can be built in one of three ways:

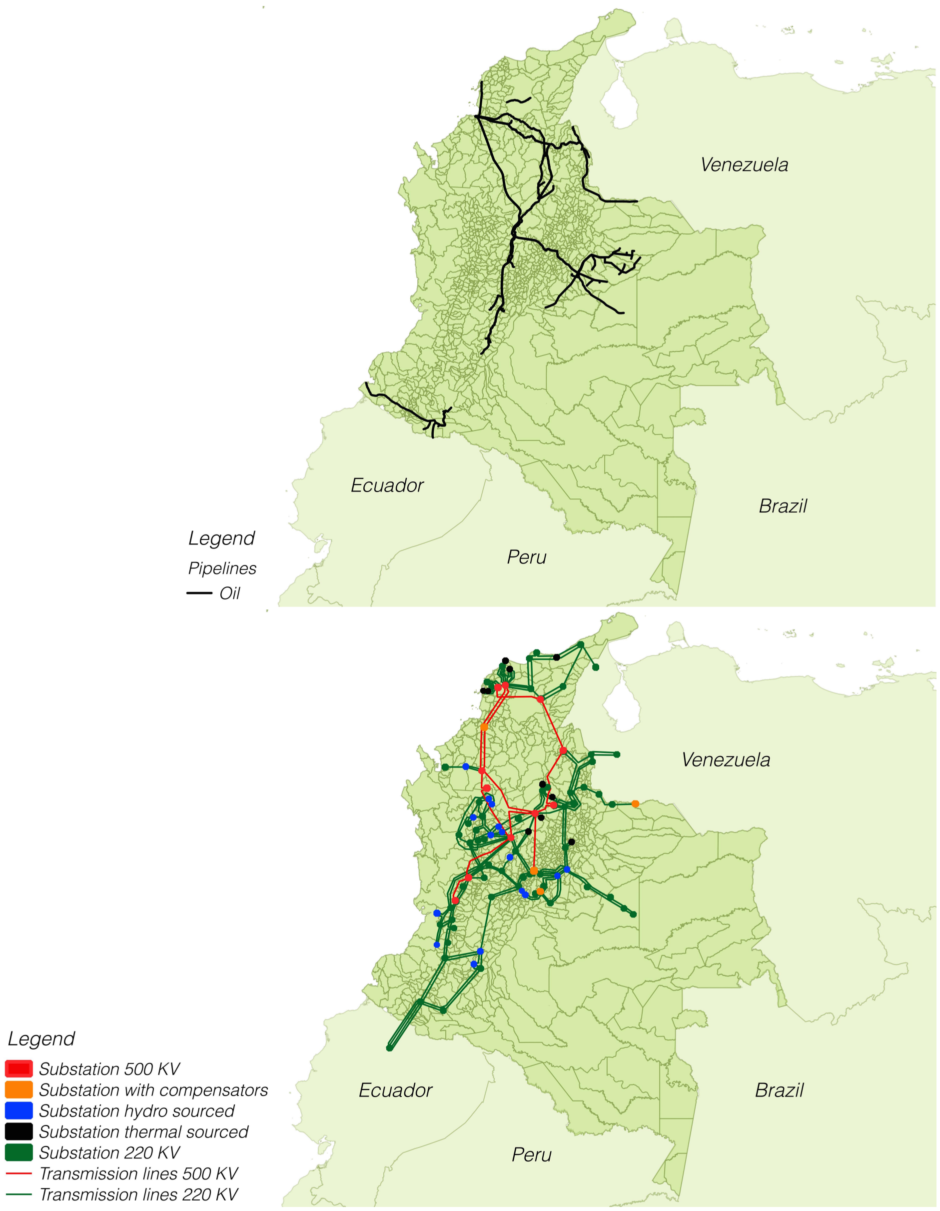


Figure 4.1: Maps of energy infrastructures in Colombia.

underground (usually 1-2m) in trenches, above ground, or suspended to traverse the varied geography (Ecopetrol, 2017). These pipelines are typically joint ventures between Ecopetrol and multinational oil companies, such as British Petroleum or Occidental (OpenOil, 2015) (Figure 4.1). Beginning in the early 2000s, multinational companies invested in oil production and transport. In particular, American companies made large investments in the Colombian oil market and in protecting the required pipeline infrastructure. This vested interest in security has reduced the number of successful attacks on the Colombian pipeline network (Maher, 2015).

4.4.4 Electricity Industry & Infrastructure

The electricity sector was privatized during the 1990s. Prior to the 1990s, one state-owned entity was controlling the generation, transmission, and distribution of electricity. This state entity was dismantled and replaced by the Regulatory Commission for Energy and Gas (Comisión de Regulación de Energía y Gas) to coordinate private and public firms under one regulatory and financial framework (Viscidi, 2010). This privatization effectively increased foreign investments into the country and improved the quality and reliability of electricity distribution (Zarate and Vidal, 2016). The main transmission line operator — Interconexion Electrica S.A. E.S.P. — owns and operates approximately 71% of the transmission lines in Colombia with its two partner companies INTERCOLOMBIA and TRANSELCA (ISA, 2016). ISA is a publicly traded company with investors ranging from the United Arab Emirates to Norway (Wall Street Journal, 2017). There are also nine other smaller companies providing similar transmission services in Colombia, typically in less developed areas. In total, ISA maintains over 12,000 km of electricity transmission lines that run nationwide (ISA, 2016) (Figure 4.1). The majority of the electricity is produced from hydropower sources (Zarate and Vidal, 2016) and demanded by the manufacturing (43.6%) and mining sectors (22.6%) (Compañía de Expertos en Mercados S.A. E.S.P., 2016). In recent years, surplus electricity has been sold and exported to Ecuador and Venezuela (Zarate and Vidal, 2016), providing an additional source of income for the government.

4.4.5 Electoral System

Despite its long-lived civil conflict, Colombia is one of the oldest democracies in Latin America (Pachon and Sanchez, 2014) with two main political parties, the Liberals and the Conservatives. Most elections in Colombia are on a regular schedule: Presidential elections occur every four years in May; the Upper House of the National Legislature or "Senado" and the Lower House of the National Legislature or "Cámara de Representates" elections occur every four years in March. Local elections such as Municipal Council elections and Departmental Assembly elections also occur on a predetermined schedule, though the schedule has been adjusted over time: typically every four years in October. The schedule of these elections is determined well in advance and the dates of the elections are fixed, regardless of violence. Other local elections such as Mayoral and Gubernatorial elections began in the late 1980s and early 1990s. These elections have irregularities associated with violence. Mayoral elections, for example, which began in 1988, are regularly scheduled but often there are additional off-cycle elections or "atypical elections" in some municipalities. Though the reason for atypical elections is not always clear, it appears that these election dates are endogenous to violence, as mayors are routinely assassinated by insurgents and paramilitary actors (Human Rights Watch, 1998). While the elections at the national level — occurring across the country on the same day — appear to be more regular, the voter turnout rate is low, averaging 40.76% between 1940s-1990s. This low turnout is attributed, at least in part, to violence and the atmosphere of violence (Taylor, 2009).

Over the last few decades, the Colombian electoral system has under gone some procedural changes. In 1991, a new constitution was written in Colombia. Among many other changes made to the law, the new constitution required presidents to be elected for terms of four years by absolute majority. Prior to the Constitution of 1991, presidents were elected by a plurality vote (Roland and Zapata, 2005). Now, in situations where candidates do not capture 50% of the popular vote, a second round of voting — a runoff election — takes place between the top two candidates from the first round. In the senate, one hundred senators are elected from lists nationally for a term of four years, though there are no term limits. Two additional senators are elected by the indigenous communities, making the full Upper House one hundred and two members. The one hundred and sixty-two members of the Lower National Legislature are elected from a closed-list from each department. Legislature seats are assigned to achieve proportional representation according to the department population. At the local level, governors and mayors are elected for a three-year, non-renewable term by a plurality vote (Acemoglu et al., 2013; Georgetown University School of Foreign Service, 2016; Roland and Zapata, 2005). The departmental assembly and the municipal councils are elected for four year terms by popular vote (Secretaría General del Senado, 1991), as with the congressional elections.

The procedure for voting has also changed since 1991. Prior to 1991, ballots were printed and distributed privately by the parties and the popular press such as newspapers. To cast the ballot, the voter placed the ballot in an envelope, went to a polling station, and put the ballot into a ballot box. Multiple races for office (e.g., departmental assembly and municipal council) appeared on the same ballot. Following the 1991 constitutional change, ballots were printed and distributed by the state at polling stations. Rather than one ballot for all the open offices, there were multiple ballots printed, one for each open office. In the switch from private- to state-printed ballots, the design of the ballots also became more complex, leading to more invalidated votes (Taylor, 2011).

4.5 Data Description

The attack data come from a new database, the Energy Infrastructure Attack Database (EIAD), that was created by the Paul Scherrer Institute (PSI) and the Center for Security Studies at the Eidgenössische Technische Hochschule Zürich (ETHZ) (Giroux et al., 2013), and has subsequently been maintained and updated through a collaboration with PSI and the University of Chicago Harris School of Public Policy Studies. The EIAD captures all reported energy infrastructure attacks and incidents perpetrated globally by non-state actors dating back to 1980. The recorded attacks are sourced from other databases, private firm data, government reports, and open-source media outlets. While all efforts have been made to create a complete data-set, we acknowledge that attacks may go unreported and will not appear in our database.[7] For the years 1980-2011, the complete Colombia database contains 2,381 observations of attacks against energy infrastructure and associated personnel: electricity, petroleum, natural gas, coal, and hydropower. For the majority of these observations, we have information about the location (in many cases we have geo-coded observations), date, perpetrator, whether the attack was successful, and the infrastructure involved in the attack. Of the total number of attacks, we use the 2,005 observations that could be uniquely attributed to FARC or ELN.

To construct our longitudinal panel for analysis, we aggregate the attacks in each municipality over the 31 years of data, resulting in 384 month-year observations of every one of the 1122 distinct municipalities in Colombia. However, during the 31-year observation period, the municipality boundaries in Colombia shifted, giving rise to new municipalities and chang-

[7] For example, in his testimony before the U.S. House of Representatives Subcommittee for Government Reform on Criminal Justice, Drug Policy and Human Resources, Mr. Meriage, the Vice President of Executive Services and Public Affairs for Occidental Oil and Gas Corporation, stated their pipelines had been attacked over 779 times between 1985-1999, causing $100 million dollars in damages (2000). This is one piece of anecdotal evidence confirming our database lacks observations, since from 1980-2011, our database includes 2,381 (2,005 attributed to FARC and ELN) event-based observations of energy infrastructure attacks in Colombia (Figure 4.2), and though approximately 40% are targeting the oil sector, the observations are not all from Occidental.

ing the boundaries of existing municipalities. Using a consistent approximation method, we account for these changes by reverting the boundaries from 2015 boundaries with 1122 municipalities to 1980 municipality boundaries, totaling 956 municipalities. In the majority of historical cases, new municipalities have split from older municipalities based on official administrative criteria, and in those cases, we were able to simply merge the two municipalities directly. However, in 35 cases, or 18% of the 192 boundary changes, a new municipality was created drawing land from multiple existing municipalities. In those cases, we merged all of the contributing municipalities into one, resulting in 25 municipalities with the merged boundaries assumption.[8] To verify that this approximation does not drive our results, we rerun our models excluding the merged 1980 municipalities. These results can be found in the Appendix in Table B.3.

Table 4.1: Count of month-year number of observed attacks.

	1 Attack	2 Attacks	3 Attacks	4 Or More Attacks
Oil Sector	321	66	4	1
Electricity Sector	738	138	34	8
Other Sectors	33	4	0	0
Total	1092	208	38	9

With this approximation, we have a total of 367,488 municipality-month-year observations, some month-years of which experienced multiple attacks (Table 4.1). However, as can be seen in Table 4.1 recording the number of attacks in the entire panel, the majority of observations did not experience any attacks — the panel is largely composed of zeros. Since reliable identification and estimation relies on the variation in the outcome variables and covariates, and our outcome variable does not have a lot of variation, we also run non-linear specifications

[8] To understand the approximation, suppose municipality A gave land to form both municipalities B and C. Then, according to our approximation, A, B & C will appear as one municipality in 1980. In another scenario, suppose municipality A was formed using land from both B and C. Since we are not able to track down the exact contributions from each B and C with the data we have, A, B & C again will appear as one municipality.

to try to account for these "excess" zeros as robustness checks (Section B.1).

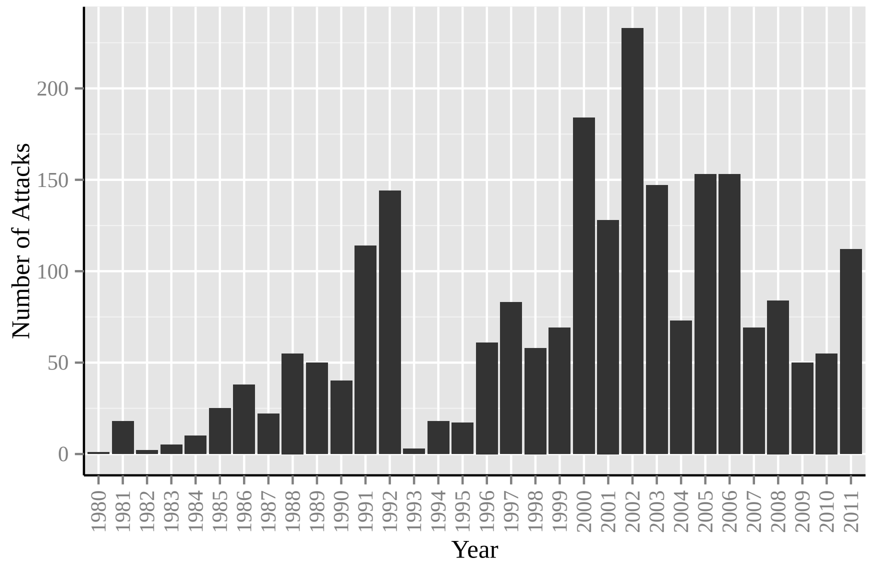
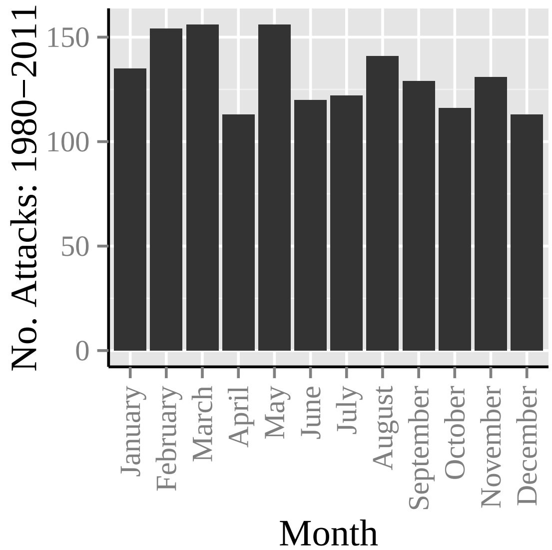


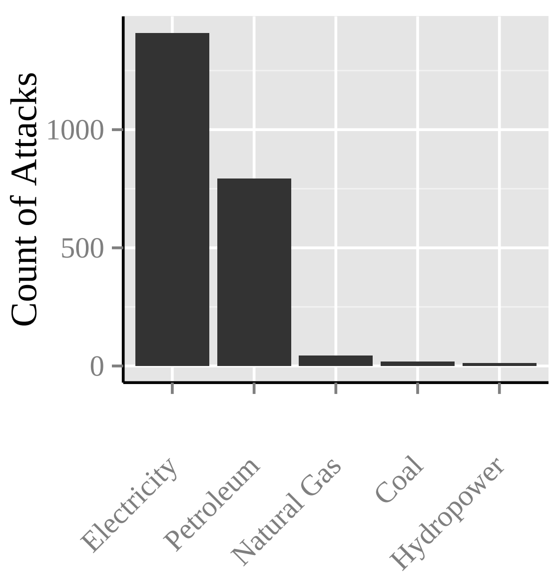
Figure 4.2: Histogram of attacks on energy infrastructures in Colombia 1980-2011.

Figure 4.2, shows the distribution of aggregated attacks over the 31-year observation period. There appear to be two peaks in intensity in the early 1990s and the early 2000s. Data from the year 1993 are conspicuously absent because the data entries from one of the main sources of the database, the Global Terrorism Database, were lost (2016). In Figure 4.3a, we see the number of attacks aggregated by each month. Over the 31-year period, some months experienced attacks more often than others, most clearly, February, March, and May, but there do not appear to be seasonal trends associated with the attacks. Of these observations, 60% target the electricity sector, 37% target the oil sector, and 3% are targeting coal, hydro and natural gas combined (Figure 4.3b). The attack data are visualized on the infrastructure maps of Colombia with 1980 municipality boundaries (Figure 4.4).

The election data are taken from the El Centro de Estudios sobre Desarrollo Económico (CEDE) election panel data-set and the supporting documents (Pachon and Sanchez, 2014). Election dates were taken from CEDE documents and Wikipedia entries. The predetermined and consistent schedule of particular local and national Colombian elections (presidential,



(a) Energy infrastructure attacks by month in Colombia



(b) Energy infrastructure attacks by sector in Colombia

Figure 4.3: Energy infrastructure attacks between 1980-2011 by month and sector.

presidential runoff, senate, national legislature, departmental assembly, and municipal council) makes these dates exogenous to insurgent attacks on energy infrastructure. Mayoral and gubernatorial elections do not follow a regular schedule.[9] For this reason, we exclude

[9] Atypical election data can be found at the National Election Registry: Registraduría Nacional del Estado

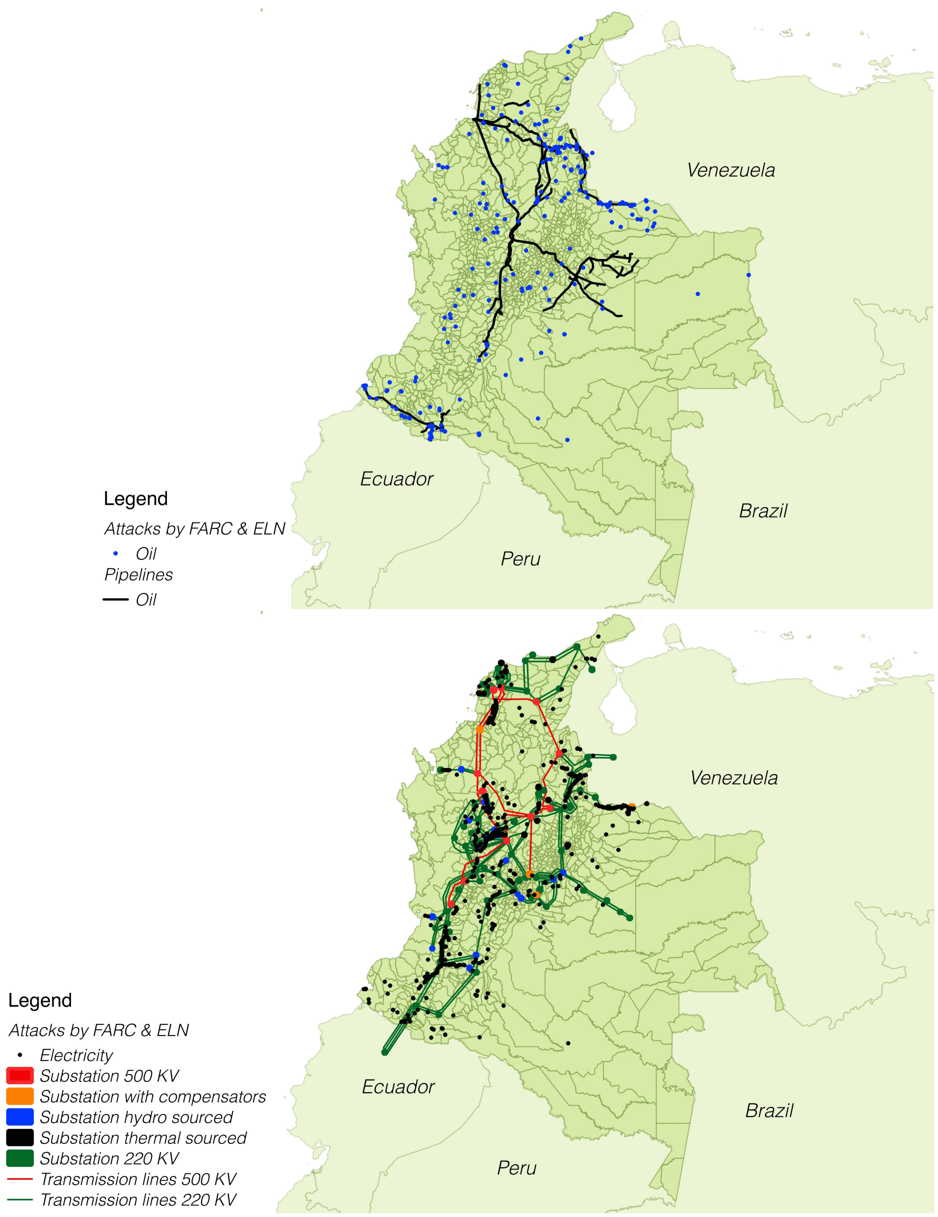


Figure 4.4: Maps of energy infrastructures in Colombia with EIAD attack data superimposed.

them from our estimation. The other covariates for our study are drawn from multiple sources: the CEDE panel of general characteristics for information about the municipalities, including population, area of the municipalities, and measures of poverty (Acevedo and Bornacelly, 2014); oil production by municipality in 1988 (Dube and Vargas, 2013); pipeline data (Burgherr and Hirschberg, 2014); oil prices (U.S. Energy Information Administration, 2017); and electricity data (Unidad de Planeacíon Minero Energética, 2015). In Table 4.2, we include the summary statistics for variables of interest and specifically the variables used during estimation.

Table 4.2: Summary statistics for entire panel (1980-2011).

	Mean	Std. Error	Min	Max
Conflict month	0.00342	0.0584	0	1
No. energy infrastructure attacks	0.00432	0.0812	0	6
Atks per million inhabitants	0.000600	0.0162	0	2.187
No. oil sector attacks	0.00113	0.0401	0	5
Oil atks per million inhabitants	0.000119	0.00714	0	2.187
No. electricity sector attacks	0.00309	0.0687	0	6
Electricity atks per million inhabitants	0.000470	0.0143	0	1.912
Population of municipality (ten thousands)	1783.6	10107.6	9.946	274754
WTI dollar per barrel oil	35.83	24.15	11.35	133.9
Oil production, hundred thousand barrels/day, 1988	0.00338	0.0544	0	1.627
Thousands of KM pipeline in muncipality	40.08	115.4	0	1578.2
Monetary value of oil production	0.121	2.353	0	217.8
Monetary value of 1000 KM oil pipeline	1436.0	5078.7	0	211294.8
Observations	367488			

Note: Statistics based on data from 1980-2011. Summary statistics calculation include all observations, including data not used in regression specific counterfactual samples. Summary statistics by counterfactual can be found in the Appendix Table B.24.

Civil.

4.6 Empirical Strategy

4.6.1 Testing the strategic timing of energy infrastructure attacks

To test our initial hypotheses, we estimate an Ordinary Least Squares (OLS) model using a fixed-effects framework. We exploit exogenously scheduled national elections to identify the causal, linear relationship between insurgent attacks on energy infrastructure and the timing of the election. To improve the accuracy of the estimates, we include other variables that could be correlated with energy infrastructure attacks, for example, the price of oil. As it is possible that attacks have a non-linear relationship with the timing of elections, we also consider a non-linear, zero-inflated model (Section B.1). Our linear model is shown below:

$$Y_{by}^{m} = \delta_1 elect_{by} + \delta_2 elect_{(b-x)y} + \lambda^m + \mathbf{X_{by}^{m}}\rho + \gamma_y + t\phi_1 + t^2\phi_2 + \epsilon_{by}^{m}, \tag{4.1}$$

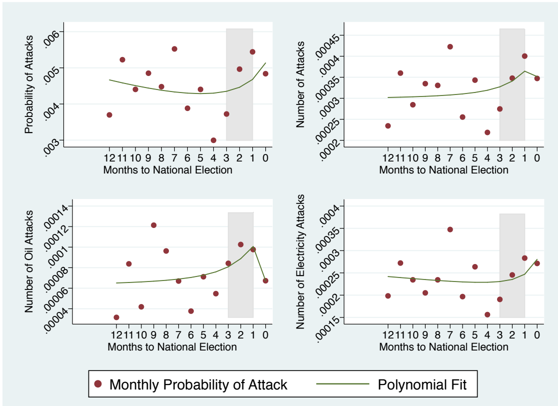
where our dependent variable, Y_{by}^{m}, is a measure of energy infrastructure attacks in municipality, m, during month, b, in year, y. The dependent variables include a binary variable indicating if there were any energy infrastructure attacks in the observed municipality during the observed month-year ('conflict month') and a discrete count variable of the number of energy infrastructure attacks in the observed municipality for each month-year per million inhabitants in that municipality ('number of attacks per million inhabitants'). We chose to scale the dependent variable to measure of each attack with the same unit. In doing so, we estimate coefficients with the correct interpretation and magnitude for average effects.

The variables of interest are $elect_{by}$, a binary variable indicating whether the month-year coincides with an election, and $elect_{(b-x)y}$, another binary variable that indicates whether the observation coincides with one of the three months preceding an election (i.e. $elect_{(b-x)y} =$

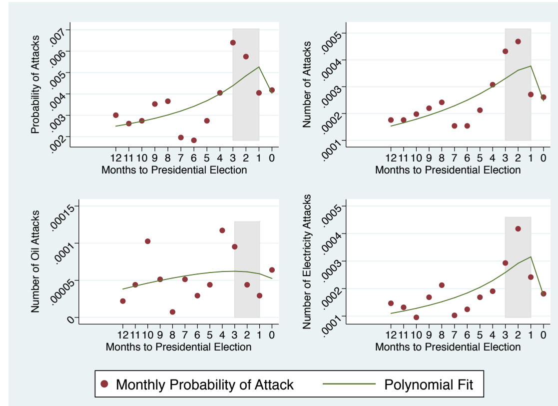
1 if $x \in [1,3]$ where $elect_{by} = 1$). This specification controls for the average trend in violence in the three months leading up to the election. Figure 4.5 shows the outcome variables plotted against the number of months before a national election. The graphs and the fractional polynomial fits of the data indicate a rise in violence roughly beginning three months before the election (depicted by the shaded bar on the graph), motivating our specification choice.[10] We specify the month variable to align with calendar months rather than the 30 days surrounding the election. Therefore, to the extent that the timing of the elections move around in the month, this specification will not capture the same window of time before an election across all lags. For example, if an election occurs on the first of the month, attacks that occur in the 30 days before that election will be coded as attacks in the month before the election rather than the month of the election. To show how this might make affect the significance of other lag variables and to offer alternative specifications, we consider other lags in the robustness section.

In our model, we include both time-invariant and time-varying controls to improve the precision of our estimates. Observable and unobservable time-invariant covariates are captured in the municipality fixed-effect, λ^m. Observable variables include topographical characteristics of the municipality or the distance of the municipality from Venezuela, for example. Unobserved and immeasurable, time-invariant variables include characteristics such as whether the municipality has a population sympathetic to the insurgents or not. We also control for some observable, time-invariant characteristics that are absorbed by the fixed effects: direct effects Oil^m_{1988} and $KMpipeline^m$, the average volume of oil produced (hundred thousand barrels/day) in the municipality during 1988 and the length of the pipeline (kilometers) that passes through the municipality, respectively. We are not able to identify the coefficients on the individual time-invariant variables, and indeed many variables captured in the fixed-

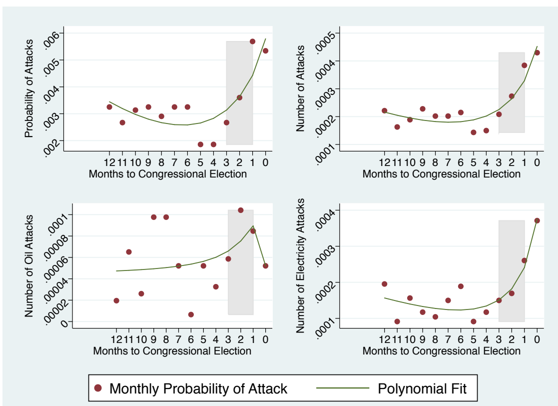
[10] We also considered lags including 6 months; however, controlling for 6 months reduces the size of our counterfactual to 6 months and can skew our results by overlapping with other elections and creating spurious significance.



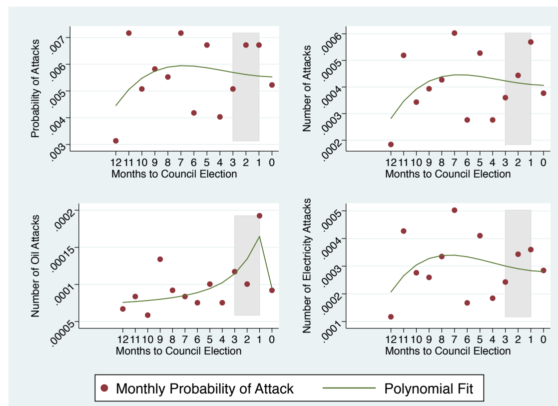
National elections include presidential, senate/national legislature, departmental assembly/council elections.



Presidential elections include main elections and runoff elections that occur in May and June, respectively.



Congressional elections include senate and national legislature elections that occur simultaneously in March.



Council elections include departmental assembly and municipality council elections that occur in October.

Figure 4.5: Scatter plots of monthly attack outcome means for 12 month election counterfactual 1980-2011.

effect may not be known or measurable; however, it is necessary to control for time-invariant characteristics to estimate our parameters of interest.

Time-varying attributes are captured in $\mathbf{X^m_{by}}$, the vector of time-varying controls. These controls include the West Texas Intermediate price of oil, WTI_{by}, a measure of the value of producing oil when the price of oil rises ($Oil^m_{1988} * WTI_{by}$), and the value of additional kilometers of pipeline when the price of oil rises, $(KMpipeline^m * WTI_{by})$. These variables control for any change in the probability or intensity of attacks due to increases in the economic value of oil and control for the effect of rapacity on attacks. We are able to identify the individual effects of these variables with our estimation strategy, though these variables are not the primary interest of our research.

Finally, we include year dummies, γ_y, to account for any latent annual trends in violence and the quadratic month time trend, $t\phi_1 + t^2\phi_2$, to control for any underlying trend in attacks over the span of the data-set (e.g., an increase in the use of violence on energy infrastructure since the 1990s). We use a flexible quadratic specification to allow for non-linear trends in violence over time rather than assuming a linear relationship. We do not use month-year dummies as doing so would control for the effects of specific month-year events that occur, such as elections. The idiosyncratic municipal-month-year errors, ϵ_{by}^m, are clustered in all the model specifications at the municipality level to account for correlation between the errors within the municipality.[11]

To establish the correct inference of our estimated coefficients and to improve efficiency, we estimate our standard errors using a paired, cluster bootstrap at the municipality level with 500 replications. Bootstrapping generates a distribution of errors that approximates the true distribution of errors when the true distribution is unknown; bootstrapping also can asymptotically improve the standard error estimates (Cameron and Trivedi, 2005). We chose to bootstrap because calculating the standard errors for panels with a large number of zeros as well for models with binary outcome variables can result in biases from estimating on the boundaries. As with robust-White-style standard errors, bootstrapping also accounts for heteroskedasticity and correlation within the municipality. As a check of robustness, we estimate our standard errors with White-style robust standard errors (see Sections 4.8 and B.1).

[11] We also tested our results with clusters at the department level, as discussed in the robustness section.

To test our initial research question — do insurgents target energy infrastructure strategically around elections? — we use exogenously scheduled elections (presidential, senate, national legislature, departmental assembly and municipality council elections) and the entire panel of attack data: 1980-2011. We subsequently consider each election type (e.g., presidential) individually.

The observations of month-years when an election occurs are the "treated" observations. The treated observations are compared to counterfactual or "control" observations of the same municipalities without an election in the twelve months prior to an exogenously scheduled election. The counterfactual is limited to twelve months before the election for a few reasons. First, the counterfactual should include enough observations to avoid making comparisons from anomalous months without elections. However, the counterfactual should not include so many observations that it no longer captures the municipality without an election but rather the municipality in all other states of the world. Second, choosing the twelve months prior to an election removes possible seasonal and election-year trend effects. Finally, the counterfactual is limited to months before, as opposed to after, the election in order to observe the municipalities under the same political regime for treatment and control. For example, we look at the municipality of Medellin in October of 1994 when there was an election; the counterfactual for this observation would be Medellin, every month from October 1993 to September 1994. When testing individual election effects, we construct election specific counterfactuals. That is, the 12 month window of month-year observations is measured from the specific election backwards (e.g., 12 months prior to a presidential election for the presidential counterfactual). We control for other elections occurring during the election-specific counterfactual. For example, in some municipalities a mayoral election may occur in the 12 month counterfactual for national elections — this control is captured in $\mathbf{X^{m}_{by}}$, the vector of time-varying controls. In our robustness checks, we change the counterfactual, ranging from 10 months to 14 months before the election to ensure the counterfactual specification is not driving our results (Section B.1, Table B.5).

Using model 4.1 and the covariates outlined in this section, we test whether a significant relationship exists between elections and the likelihood of attacks ('conflict month') on energy infrastructure by insurgent groups. If the insurgents do attack disproportionately during elections months, we expect the coefficient on the $elect_{by}$, δ_1, to be positive and significant. We also expect the coefficient on the $elect_{(b-x)y}$, δ_2, to be positive and significant if insurgents are more likely to attack in the three months before an election. Likewise with the outcome variable 'number of attacks per million in habitants,' if the insurgents launch more attacks during a national election month, we expect the coefficient on the $elect_{by}$, δ_1, to be positive and significant. We also expect a positive and significant coefficient on the $elect_{(b-x)y}$ if the insurgents increase the number of attacks on energy infrastructure in the three months leading up to an election.

4.6.2 Testing the impact of energy infrastructure attacks on voter turnout

To test whether energy infrastructure attacks impact voter turnout, we estimate an OLS model using a fixed-effects framework. Unfortunately, we do not have a source of exogenous variation to identify the causal relationship between insurgent attacks on energy infrastructure and voter turnout. Instead, we estimate the correlation between voter turnout and these attacks. The model is shown below:

$$VT_e^m = \beta_1 energyatk_e^m + \beta_2 energyatk_e^m + \lambda^m + \gamma_y + t\phi_1 + t^2\phi_2 + \varepsilon_e^m, \qquad (4.2)$$

where our dependent variable, VT_e^m, is an approximate measure of voter turnout in municipality, m, during election, e. We estimate voter turnout by aggregating the votes in each municipality and normalizing by the 2005 municipal population. The variables of interest are $energyatk_e^m$ and $energyatk_{(e-x)}^m$. Each take on different measures of energy infrastructure attacks in each specification: conflict month as well as counts normalized by the municipality population of all attacks, oil attacks, and electricity attacks. $energyatk_e^m$ captures the aggregate measures of violence during the election month in the municipality while $energyatk_{(e-x)}^m$ includes the aggregated attacks in the three months before an election (i.e. $energyatk_{(e-x)}^m = \sum energyatks^m$ if $x \in [1, 3]$ where $elect_e = 1$).

As in model 4.1, we include a municipality fixed-effect, λ^m, to control for observable and unobservable, time-invariant covariates, a year fixed-effect, γ_y, and the quadratic time trend, $t\phi_1 + t^2\phi_2$. The idiosyncratic errors, ε_e^m, are clustered at the municipality level, using the 1980 boundary approximation, and calculated with a paired bootstrap method, replicated 500 times.

We test whether attacks influence voter turnout with Equation 4.2 with election specific subsets of the data: presidential, presidential runoff, senate, national legislature, departmental assembly, and municipal council. We measure the effect of the attacks on presidential elections generally by combining presidential and presidential runoff elections into one. In the case of congressional elections, senate and national legislature elections occur on the same day, at the same polling stations but voters cast individual ballots for each office. This arrangement is also the case for the local elections, departmental assembly and the municipal council elections (Taylor, 2011). In theory, the effect on turnout should be the same for those races occurring on the same day, unless voters in large numbers decided to only vote for one office while at the polling station. If the occurrence of insurgent attacks on energy infrastructure is correlated with reduced voter turnout as we hypothesize, we expect the coefficient on the $energyatk_e^m$, α_1, to be negative and significant. We also expect the coefficient on the $energyatk_{(e-x)}^m$, α_2, to be negative and significant if the insurgent attacks during the three months before an election are correlated with reduced turnout.

4.7 Results

As an initial test of our research question, we estimate the regression given by Equation 4.1 with a series of attack outcome measures and a binary election variable indicating whether one of the regularly scheduled elections (presidential, upper and lower national legislature, and departmental assembly and council elections) occurs. In Table 4.3 (column (1)) we test a binary energy infrastructure attack outcome, “conflict month,” that takes on the value one if any attacks are launched during the month-year observation and takes on the value of zero if no attacks occur. In column (2), the measure of attacks is a scaled count variable, attacks per million inhabitants. Columns (3) and (4) are scaled count variables of the distinct targets, oil and electricity, respectively. Columns (1) and (2) show that during the month when a national election takes place, the average municipality[12] is 0.11% more likely to experience a positive number of insurgent attacks and that the intensity of attacks on energy infrastructure increases by 0.00038 attacks per one million inhabitants. These results are significant at the 5% and 1% confidence levels, respectively. Put into context, these results mean that during an election month Colombia as a whole will experience at least one attack on its energy infrastructure. And, in a city the size of Bogotá (with approximately 7 million inhabitants), there is an increase of 0.0027 attacks. This represents a 234% increase in the number of attacks per million inhabitants relative to the mean number of attacks in Bogotá during the 12 month counterfactual — 0.0000116. Also, comparing these results to the mean in an average municipality during control months (non-election and not a month during the three months before an election) (see Table 4.3), we find that an average municipality is 25% more likely to have an attack and the number of attacks per million inhabitants increases by 51%. These results are consistent with our hypothesis that FARC and ELN strategically attack energy infrastructure during elections.

[12] That is, a municipality that takes on the mean values of all the covariates.

It is important to consider these coefficients in context as the small magnitudes may be difficult to translate into "real world" examples and the coefficients do not reflect the severity of the attack. In reality, an increase of one energy attack across Colombia could have a significant impact on society and the economy. In the case of an electricity attack, consider an attack like the one on Buenaventura in July 2014 causing a blackout that lasted only a day (Dugdale, 2014). Even a short electricity interruption causes ripples through the local economy and society from lost revenues and suspended public services such as potable water. In the oil sector, consider an attack on a pipeline such as the one that occurred in the summer of 2016. That attack halted 6% of the national oil production, reducing output by 56,000 barrels of crude oil per day (Willis and Kassai, 2016). That amounts roughly to a loss of $2,340,800 USD per day.[13]

Table 4.3: Impact of national elections on the likelihood, intensity, and nature of energy infrastructure attacks by insurgent groups, FARC and ELN.

	Conflict Month	Atks	Oil Atks	Electricity
Nat'l election month	0.00109*	0.00038**	0.00015	0.00023
	(0.00055)	(0.00015)	(0.00009)	(0.00014)
Nat'l election next 3 months	0.00097*	0.00043**	0.00005	0.00038**
	(0.00040)	(0.00015)	(0.00005)	(0.00014)
Observations	200013	200013	200013	200013
Control months mean	0.00438	0.00074	0.00011	0.00062
Standard errors	(0.06603)	(0.01671)	(0.00484)	(0.01573)
Number control months	121000	121000	121000	121000

Note: The dependent variables in these regressions are conflict month, number of attacks per million inhabitants, number of oil attacks per million inhabitants, and number of electricity attacks per million inhabitants. National elections include presidential, presidential runoff, national legislature, departmental assembly, and municipal council elections. Variables not shown are municipality fixed-effects, time-invariant controls, time-varying controls, quadratic time trend, and year fixed-effects. Standard errors, shown in parentheses, are calculated with a paired, municipality-cluster bootstrap method, replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

In the three months leading up to a national election there is an increase of 0.097% in the likelihood of an attack on energy infrastructure (column (1)). We also see an increase in the intensity of attacks three months ahead of the election month (column (2)) of 0.00043

[13] Assuming the price of oil from August 2016 at $41.80 USD/barrel.

attacks per million inhabitants. Relative to control months, that is a 22% and 58% increase, respectively. The coefficients on conflict month are statistically significant at the 5% level, while the coefficients for the attacks per million inhabitants are significant at the 1% level. In columns (3) and (4), the attacks are split according to target — oil and electricity, respectively. These results indicate that the increase in attacks is driven by attacks on electricity infrastructure and not driven by attacks on oil infrastructure. The number of attacks on the electricity sector do not significantly increase the month of the national election despite the overall number of attacks on both infrastructure increasing during that time. The lack of statistical significance is likely due to the fact that we reduce our power to estimate when we split out according to target. Interestingly, the number of electricity attacks increases by 61% during the three months before a national election month relative to non-election months, significant at the 1% confidence level. These results are consistent with an intimidation strategy, though the audience of the attacks is not clear. The trend of increasing attacks prior to an election could logistically interrupt elections by preventing people from registering to vote, but these attacks also could be seen as a warning to deter would-be voters or to influence incoming politicians. By causing power outages and service disruptions, FARC and ELN demonstrate their ability to undercut government services, undermining the government's legitimacy for voters and investors. Intimidating voters has been found in many cases to be an effective strategy to disrupt elections (e.g., Höglund, 2009). In the next section, we test whether FARC and ELN are targeting voters effectively with attacks prior to the election.

Oil attacks neither increase during a national election month nor in the months prior to a national election. Based on the central role that oil plays in the Colombian economy and civil conflict, our initial hypothesis was that FARC and ELN would disproportionately target oil infrastructure. In order to explain this somewhat surprising result, we generated a few non-mutually exclusive hypotheses, some testable and some not testable. The first hypothesis is that the EIAD database is missing oil infrastructure attack observations. If this were true, as we suspect, we would expect access to more data would show that oil infrastructure are targeted more frequently and strategically around elections. It would be possible to test this hypothesis were we to gain access to all the multinational and domestic oil company infrastructure attack data. A second hypothesis is that FARC and ELN target electricity infrastructure as an indirect way to attack oil infrastructure by cutting power to oil production and refining equipment (Maher, 2015). Though currently we do not have access, it would be possible to test for disruptions using oil production data at the municipality level. Until now, we have not found any official records or estimates of how power outages have influenced oil production. A third possibility is that an extensive effort by the paramilitary (with funding from the United States government) to protect the pipelines incentivized FARC and ELN to substitute oil targets for electricity targets. As with the first hypothesis, it would be necessary to have additional oil attack data to test it. Finally, a fourth, testable hypothesis is that attacks on electricity are an indirect way to target and intimidate voters without direct, interpersonal violence. By using indirect force, the insurgents may be trying not to alienate their support base. One testable implication of a successful intimidation strategy would be a reduction in voter turnout, which we investigate with municipality level voting data.

Assuming the observations are accurately reported, the quality and completeness of the electricity data appear superior to the data we have on oil infrastructure attacks, which were taken from a variety of sources, including the media.[14] For example, some of the oil data from media reports do not include precise locations (some only at the department level), whereas all of the electricity data from the private source include precise geographical coordinates. We must also consider the possibility that data from both electricity and oil attacks are systematically censored during election months for political reasons, which we would not be able to control for. While we find no evidence of systematic censoring, Colombia has a long

[14] Electricity data were provided by a private industry source on the condition of anonymity.

history of violence against journalists and reporters (Taylor, 2009). As a result, we cannot say with certainty that the EIAD includes the universe of electricity attacks; however, the results would change only if enough attack observations occurred during non-election months relative to the counterfactual period. In the case of oil, we cannot conclude there is no effect on oil infrastructure. Given more data from the oil companies an effect might be more apparent.

Next, we subset the data by election type in Table 4.4 though we realize we reduce our power to estimate substantially. Panel A contains the presidential election results (main and runoff); Panel B contains the national legislature results (congressional elections); Panel C shows the departmental assembly and municipal council elections (council elections). Each of the three panels is organized identically, though the number of observations differs by election type due to the election-specific counterfactual we generated (see Empirical Strategy in Section 4.6). In column (1), we test our binary outcome variable, "conflict month." Split out by election, there is neither an increase in the likelihood of an attack on energy infrastructure during an election month, nor an increase in the three months leading up to an election.

Table 4.4: Impact of each election separately on the likelihood, intensity, and type of infrastructure attack by insurgent groups, FARC and ELN.

Panel A: Presidential Elections				
	Conflict Month	Atks	Oil Atks	Electricity
Presidential election month	0.00105	-0.00010	-0.00003	-0.00009
	(0.00088)	(0.00022)	(0.00005)	(0.00021)
Presidential election next 3 months	0.00085	0.00051**	-0.00004	0.00055***
	(0.00076)	(0.00019)	(0.00006)	(0.00017)
Observations	102399	102399	102399	102399
Control months mean	0.00290	0.00045	0.00007	0.00039
Standard errors	(0.05380)	(0.01384)	(0.00320)	(0.01343)
Number control months	68900	68900	68900	68900
Panel B: Congressional Elections				
	Conflict Month	Atks	Oil Atks	Electricity
Congressional election month	0.00030	0.00035	0.00013	0.00024
	(0.00093)	(0.00034)	(0.00021)	(0.00025)
Congressional election next 3 months	-0.00026	0.00004	0.00003	0.00001
	(0.00044)	(0.00017)	(0.00007)	(0.00016)
Observations	111969	111969	111969	111969
Control months mean	0.00283	0.00043	0.00008	0.00035
Standard errors	(0.05308)	(0.01223)	(0.00422)	(0.01145)
Number control months	77500	77500	77500	77500
Panel C: Council Elections				
	Conflict Month	Atks	Oil Atks	Electricity
Council election month	-0.00023	-0.00008	0.00036*	-0.00035
	(0.00140)	(0.00032)	(0.00018)	(0.00026)
Council election next 3 months	0.00068	-0.00004	0.00017	-0.00014
	(0.00099)	(0.00023)	(0.00009)	(0.00021)
Observations	87087	87087	87087	87087
Control months mean	0.00542	0.00097	0.00015	0.00080
Standard errors	(0.07345)	(0.01974)	(0.00660)	(0.01817)
Number control months	60300	60300	60300	60300

Note: The dependent variables in these regressions are conflict month, number of attacks per million inhabitants, number of oil attacks per million inhabitants, and number of electricity attacks per million inhabitants. Variables not shown are municipality fixed-effects, time-invariant controls, time-varying controls, quadratic time trend, and year fixed-effects. Standard errors, shown in parentheses, are calculated with a paired, municipality-cluster bootstrap method, replicated 500 times.*p<0.05, ** p<0.01, ***p<0.001

In Panel A, columns (2)-(4), we find that the number of attacks per million inhabitants increases in the three months leading up to a presidential election but not during the actual election month. We see this increase in attacks is driven by the electricity sector rather than the oil sector, causing 0.00055 more attacks per million inhabitants. Relative to the mean number of electricity attacks during presidential election control months, this is an increase of over 100%. These results are significant at the 0.1% level. Attacking electricity infrastructure may be an effective strategy particularly to disrupt presidential elections because small attacks can affect a large number of people voting through a black out, for example. From a symbolic protest perspective, presidential elections offer a high-profile stage. Attacking electricity prior to the presidential election could be a message to the new administration as well as the population about foreign investment contracts. FARC and ELN do not appear to target these infrastructure during presidential election months, as opposed to before the election, which could be due to increased security. While the Colombian government has increased security to safeguard elections (Acevedo and Bornacelly, 2014), we find the security has no significant influence on attacks occurring during national elections (Section B.1.1) nor presidential elections (Section 4.8, Table B.2). It should also be kept in mind that presidential elections and congressional elections typically occur during the same year. As a result, the presidential counterfactual includes months that contain congressional elections, which likely increases the "control" level of violence.

In Panel B, columns (2)-(4), the congressional elections show no significant increase in the number of attacks across all types of outcome variables. Still, the mean number of attacks during congressional control months is roughly equivalent to presidential control means. Panel C, columns (2)-(4), shows the results for number of attacks per million inhabitants for the departmental assembly and municipal council elections. Like the congressional elections, we see neither an increase in the overall number of attacks nor the number of electricity attacks during an election month. Interestingly, however, we do see an increase in the number of attacks on oil infrastructure during an election month of 0.00036 attacks per million inhabitants, significant at the 5% level. This increase amounts to a 200% increase in the number of oil infrastructure attacks during a council election control month. This result is particularly interesting because these departmental and municipal elections occur during October, typically not within the same year as presidential and congressional elections. Furthermore, the mean levels of violence during council election control months are also higher than during congressional and presidential control months. This means that years that do not have presidential and congressional elections, on average, have a higher, overall intensity and likelihood of an energy infrastructure attack. This heightened level of violence makes additional attacks during council election months appear less anomalous. At the local level, targeting the oil infrastructure is in line with our initial hypotheses. Attacks are motivated by royalties from oil production that are distributed at the local level and dispensed by the local government (Echeverry et al., 2008). There is a history of the insurgent groups competing for these rents (Dunning and Wirpsa, 2004). As noted, we are confident that our database captures only a portion of the total oil attacks. Given additional data oil attacks, we might see a more significant effect, assuming that we have not unintentionally collected the majority of attacks occurring during election months.

4.7.1 Changes in Security

One concern is that the levels of violence were affected by changes in security around the elections. To test this concern, we include a dummy variable measure of 'democratic security' from the CEDE panel database spanning 1993-2011.[15] The indicator takes a value of one if a municipality had 'democratic security' during elections and zero otherwise. We expect that the coefficient on this variable would be negative (positive) and significant if the presence of security decreases (increases) the levels of violence. We find that democratic security reduces the intensity of energy infrastructure attacks; however, security does not have a significant effect on the likelihood of being attacked (see Table 4.5). Still, the point estimates on the election variables remain stable in magnitude after controlling for security when compared to the same timeframe without controlling for security (See Panel B). This confirms our intuition that security is launched to reduce attacks, but that the effect we estimate is not driven by changes in security. Ideally, we would like to have a measure of security at the month-year, municipality level that also includes a measure of security intensity. Given that level of detail, we would be able to determine whether local, timely changes in security

[15] Unfortunately, we were not able to find a measure of security that spanned the entire data-set.

influence violence. One might expect that attacks on energy infrastructure could increase if security efforts were directed at protecting populated targets (e.g., polling stations).

Table 4.5: Sensitivity analysis of main results controlling for 'democratic security'

Panel A: Sensitivity analysis of main results controlling for 'democratic security' (1993-2011)				
	Conflict Month	Atks	Oil Atks	Electricity
Nat'l election month	0.00151*	0.00051*	0.00014	0.00037
	(0.00075)	(0.00020)	(0.00010)	(0.00019)
Nat'l election next 3 months	0.00187***	0.00072**	0.00013	0.00060**
	(0.00056)	(0.00022)	(0.00008)	(0.00020)
Democratic security	0.00410	-0.00087*	0.00019	-0.00104***
	(0.00730)	(0.00037)	(0.00024)	(0.00027)
Observations	133023	133023	133023	133023

Panel B: Main results for comparison (1993-2011)				
	Conflict Month	Atks	Oil Atks	Electricity
Nat'l election month	0.00151*	0.00051*	0.00014	0.00037
	(0.00075)	(0.00020)	(0.00010)	(0.00019)
Nat'l election next 3 months	0.00187***	0.00072**	0.00013	0.00060**
	(0.00056)	(0.00022)	(0.00008)	(0.00020)
Observations	133023	133023	133023	133023

Note: Dependent variables are four measures of attack variable: conflict month and three scaled count variables, number of attacks (total, oil, and electricity) per million inhabitants. These results test the hypothesis that our results are driven by changes in security. The only measure of security around elections available to us is a dummy variable in the CEDE Violence and Conflict panel data-set, 'democratic security,' that indicates whether there was any security in that municipality during any elections during a particular year. When multiple municipalities were combined, the maximum value of the dummy variable was assumed. This table includes data from 1993-2011; this constraint is due to the democratic security dummy variable which was not available for the complete observation period. Therefore, we rerun the main results for the years 1993-2011 for comparison. National elections include presidential, presidential runoff, senate, national legislature, assembly, and council elections. Variables not shown are municipality fixed-effects, time-invariant and time-varying controls, and year fixed-effects. Standard errors are paired, cluster boostrapped, replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

4.7.2 Voter Turnout Results: Normalized Attack Variables

Determining whether the attacks had a causal influence on voter turnout poses many challenges empirically. Without an exogenous source of variation, we are not able to disentangle whether attacks reduce voter turnout or whether the expectation of voter turnout increases attacks. Instead, recognizing these results are not well-identified, we test whether attacks on energy infrastructure are correlated with voter turnout. If attacks on electricity infrastructure three months ahead of presidential elections are meant to intimidate the population, we expect attacks on the electricity sector three months prior to the election to be correlated with reduced voter turnout. For the council elections, we expect the oil attacks during the month of the election will have no effect on voter turnout.

Using equation 4.2, we test voter turnout, approximated by number of votes normalized by municipality population, for the presidential, municipal council, and departmental assembly elections. We find that electricity attacks during a presidential election month are not negatively correlated with voter turnout at a statistically significant level, though the sign of the coefficient is in the expected direction. However, we find that electricity attacks in the three months ahead of a presidential election are correlated with a reduction in voter turnout, significant at the 10% confidence level, see Table 4.6. Attacks launched during the municipal council elections and the departmental assembly elections do not show any significant correlation with voter turnout in those elections (Table B.22-B.23).

Table 4.6: Impact of likelihood and intensity of attacks on voter turnout for presidential elections.

	Voter Turnout			
Probability of atk	0.00002			
	(0.00004)			
Probability of atk 3 months to election	-0.00007			
	(0.00005)			
Atks per million inhabitants		-0.00009		
		(0.00021)		
Atks 3 months to election		-0.00020		
		(0.00010)		
Oil atks per million inhabitants			0.00108	
			(0.00078)	
Oil atks 3 months to election			-0.00035	
			(0.00025)	
Electricity atks per million inhabitants				-0.00024
				(0.00021)
Electricity atks 3 months to election				-0.00018
				(0.00010)
Observations	7656	7656	7656	7656

Note: Voter turnout is regressed on four measures of attacks: conflict month, total, oil and electricity attacks per million inhabitants. Variables not shown are municipality fixed-effects, quadratic time trend, and year fixed-effects. Paired, clustered at the municipality level bootstrapped standard errors in parentheses — replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

While these models are not well-identified, these results suggest that attacks on energy infrastructure have a marginal impact on voter turnout. In line with an alternative hypothesis, these attacks may be indirectly targeting oil infrastructure and other multinational investments. For FARC and ELN, launching these attacks near elections may be an effective way to disseminate their message to incoming administrations and potential foreign investors.

Taken together, these results suggest FARC and ELN use attacks on energy infrastructure to achieve both financial and political objectives. In interpreting all our results, we chose a conservative significance threshold relative to other papers in the related literature by using a 5% confidence level. At this threshold, our results confirm that FARC and ELN strategically time attacks on energy infrastructure to coincide with national elections. In particular, FARC and ELN appear to target energy infrastructure more during presidential elections, especially electricity infrastructure. Therefore, we believe presidential elections may have a greater symbolic value for the insurgents relative to other elections. We also find that departmental assembly and municipal council elections cause insurgents to increase the number of attacks on oil infrastructure. This result aligns with our prior that violence might break out to gain control of the oil royalties. Our main results are robust to changes in security around elections. Oil and electricity infrastructure attacks do not appear to have a strongly significant correlation with voter turnout. Though the specifications for voter turnout are not well-identified, these results suggest that attacking electricity and oil infrastructure may be targeting the government and multinational companies and investors more than the Colombian population. In the future, the impact on multinational companies, particularly oil companies, should be considered. Nevertheless, these results support our research hypothesis that insurgents also derive non-monetary value from attacking energy infrastructure, such as publicity for their ideological agenda and grievances.

4.8 Robustness

To verify the robustness of our results, we test some additional variables and specifications. First, we test whether our presidential election results are stable when controlling for changes in the presence of 'democratic security.' As discussed in the main results for national elections, one concern might be that security is an omitted variable that would affect both attacks and be correlated with the timing of elections, as security may be more widely deployed to ensure access to election polls. However, like during national elections, we find that controlling for democratic security during presidential elections does not change the number or likelihood of attacks on energy infrastructure (Section B.1.1). Next, we verify that our approximation of the 1980 boundaries does not strongly influence our results. This robustness check responds to a concern that approximating the municipality boundaries causes the results we find. In Section B.1.2, we show that our results are stable after excluding the 35 municipalities that had boundaries altered during our observation period. Also during the 31-year observation period, the laws in Colombia changed. In particular, a new constitution was implemented in 1991 that had effects on the democratic election process (see Section 4.4 for more details). Due to these changes, one might believe the estimation should run from 1991 forward to separate any influence caused by constitutional changes. In Section 4.5, the histogram of our attack data (Figure 4.2) shows that the majority of our attack data are documented following 1991. This could be either because more attacks occur or due to data availability. In Section B.1.3, we show that including the years before 1991, as we have in the main results, generates more conservative estimates. Both the likelihood and intensity of attacks on energy infrastructure increase when the observation window is limited to 1991-2011. To test our counterfactual assumption, we limit and extend the number of months we use as control months to show the stability and robustness of our result (Section B.1.4). The conclusions based on different counterfactual windows remain the same, though the magnitudes of the estimates fluctuate slightly.

Next, in order to test our specification, we build up our model from the naive to the full specification, demonstrating the influence of the individual covariates. We also consider a non-linear specification. In the build-up of the model, we control for each of the three months in the pooled lag variable separately. This specification shows that the significance of the three month lag variable, $elect_{(b-x)y}$, is mainly driven by the first month before the election (Section B.1.5). The pooled-lag specification that we use is therefore more conservative than the individual lags. It is also motivated by our raw data showing the increasing trend in violence leading up the elections (see Table 4.5). Responding to concerns of post-treatment bias, we also include our models run without the main election effect. Our treatment variable, $elect_{by}$, and the lag, $elect_{(b-x)y}$, are determined simultaneously and prior to the election, therefore, we do not have a post-treatment variable that can alter or enable manipulation of the "treatment;" nevertheless, we include these estimates as further evidence. For a non-linear specification, we used a zero-inflated count model (see Section B.1.9). Though we are not able to estimate this model for all of the specifications shown in the main results due to convergence issues, we estimate the main results and find supportive evidence for our linear results.

Finally, we check the robustness of our standard error specification. We rerun our main model 4.1 with robust, White-style standard errors and department level clusters. The main, bootstrapped results are mirrored with the robust standard errors and the more conservative department-level clustering (Section B.1.7-B.1.8). Following each robustness test, we see the results are stable and consistent to variations in specification, modifications to covariates, and alternative standard error calculations.

4.9 Conclusion

The results of our study confirm that the insurgent groups, FARC and ELN, strategically time attacks on energy infrastructure during the months before and the month of a national election. To arrive at this result, we take advantage of a novel data-set on energy infrastructure attacks, the Energy Infrastructure Attack Database (EIAD), containing over 2000 observations of attacks by FARC and ELN during the years 1980-2011. We estimate our results with a linear regression model in a fixed-effects framework and rely on the exogenously scheduled national elections in Colombia for identification. We find that the likelihood of an attack on energy infrastructure during an election month increases by 25% and that the intensity of attacks increases by 51%, both relative to control months. These results are driven by attacks on electricity infrastructure rather than oil infrastructure, particularly timed before and during presidential elections. Our findings verify that FARC and ELN leverage attacks for political gain, challenging the common 'greed' hypothesis that asserts the insurgents only launch attacks for financial gain. The political gain appears to be multipurpose. Not only do these attacks undermine the government's ability to provide basic services to their citizens, but the attacks also a way to disseminate FARC and ELN's opposition to democracy and capitalism.

Initially, we hypothesized that energy infrastructure attacks would be used as tactics to disrupt elections, preventing voting through intimidation. However, we find only marginally significant correlation with voter turnout during presidential elections. While these results are not well-identified, they suggest that energy infrastructure attacks are not a tactic intended to prevent democratic participation — after all, FARC and ELN could use direct violence to prevent voting, as evidenced by their demonstration of force in other contexts (Dube and Vargas, 2013). Rather, attacks on energy infrastructure before and during election months suggest that the insurgents leverage this tactic to publicize their anti-capitalist, anti-government message and to undermine the government and multinational corporations. Indeed, the audience may include the voting population as well as politicians and multinational investors, each receiving a distinct message from such attacks. To make an impression on a governmental or multinational corporation audience, these attacks are designed to inflict economic harm. For example, attacks on the electricity sector could be indirect attacks on oil infrastructure that rely on electricity. Alternatively, attacks on electricity infrastructure, which are increasingly constructed with foreign investment financing, could be attacks directly on multinational firms' profits. By attacking energy infrastructure, FARC and ELN inflict a large financial cost on these companies as well as the local economy. At the population level, energy infrastructure attacks, and in particular electricity attacks, can have a long-term chilling effect, as the presence of the insurgents extends into the home and society.

The messaging power of indirect attacks, as opposed to direct, interpersonal attacks, to undermine democratic institutions is an emerging security challenge for developed and developing democratic institutions. Indirect targets, such as critical infrastructure or shared public goods like the Internet, offer disproportionate leverage and audience to relatively weak terrorists, insurgents, and other non-state or state actors (Homer-Dixon, 2002). Furthermore, these targets assume a symbolic, anti-democratic and anti-establishment value when exploited to coincide with an election or to subvert the election results. Targeting critical infrastructure would appear to be a long-view strategy rather than a short-term strategy; that is, a strategy to plant doubts and fears in the government's legitimacy as opposed to achieving an election victory.

Ironically, in the case of Colombia, some research suggests that this strategy may ultimately fuel, finance, and embolden the insurgents' opponents: the government, the paramilitary, and the multinational companies investing in Colombia. Though, it is important to note that for this paper, we focused solely on physical attacks against the electricity and petroleum sectors rather than other possible indirect attacks using cyber warfare. Multinational companies have not reduced investments in Colombia in the face of the conflict. On the contrary, international investment has increased (Maher, 2015). Not only do multinationals negotiate better financial deals with the government to compensate for the difficult investment conditions, but they also engage foreign governments — specifically, the United States — to fund counterinsurgent operations. The counterinsurgent operations, intentionally or unintentionally, make large payments to the paramilitary and private security forces to protect their assets from the insurgents (Dube and Naidu, 2010). In the end, the insurgents may undermine the Colombian democratic institutions in short-term and long-term ways. Over the short-term, insurgents prevent the government and multinationals from daily operations and from providing services. Over the long-term, the insurgents may ultimately undermine the government by giving multinationals, the paramilitary, and foreign governments a lot more influence and latitude in Colombia. In fact, these attacks may bring FARC and ELN no closer to their desire for political change in Colombia but rather fuel the "War System" in Colombia (Richani, 2005).

These results prompt us to consider the extent to which our technology advancements and increasing development make us more vulnerable to our adversaries, what exactly is at stake, and how we will respond in the face of those vulnerabilities. From an energy policy perspective, these results suggest that infrastructure development or modernization projects must weigh the benefits, risks, and costs of interconnectedness, dependence, and vulnerability. These topics are well-researched and implemented in many engineering applications. For example, one of the many functions of Probabilistic Safety Assessment — a systematic method to determine and evaluate the safety of a complex technological system — is to identify and reduce critical dependencies that can lead to cascading failures in nuclear power plants. However, in a larger, societal system, some of these interconnections can be overlooked though they might end up becoming the sources of exploitable weaknesses. Of course, there is no way to eliminate all vulnerabilities. However, measures can be taken to address the most serious vulnerabilities, which are being identified more often in our critical infrastructure: energy technologies, the Internet, electricity grids, and telecommunications networks. Importantly, all of these critical infrastructure can be attacked indirectly. How should and can indirect attacks be responded to? What are the actual objectives of indirect attacks — assuming the infrastructure are incidental? Could a long-view, insurgent strategy to indirectly target the legitimacy of the government undermine democratic institutions in other countries?

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CHAPTER 5

CONCLUSION

In the papers of this dissertation, my coauthors and I investigate increased physical risks (e.g., accident, attack) associated with energy systems (e.g., nuclear, oil) in three contexts: nuclear fuel disposal, international oil transportation, and critical energy infrastructure vulnerability. These topics were motivated by the recognition that society is expanding its energy systems to an unprecedented scale and complexity, and in so doing, increases benefits for humans but also increases risks. Examples of risks might include vulnerability to attack, environmental spills or releases, and pollution. The social, political, and economic incentives that shape society's recognition of and response to these heightened risks often induce policymakers to take suboptimal policy decisions. Of course, all impacts and all risks from energy systems cannot be avoided completely; however, we show that, in specific policy contexts, policymakers can internalize underappreciated and emerging risks by identifying, quantifying, and including these new risks in decision- and policy-making.

In the first context, U.S.'s disposal of used nuclear fuel, we trace the historical policies, as well as the current political and economic incentives, that are hindering the construction of a permanent geological storage facility at Yucca Mountain. To assess the potential costs and risks of letting certain economic and political incentives shape disposal policy, we analyze the safety and security risks of the used fuel given the current storage methods and the used fuel inventories on reactor sites. We find that, without the permanent storage facility that the U.S. government committed to providing and never did, the industry resorted to high density, long-term storage of used fuel in pools that were designed only for temporary cooling (5-7 years) and, in some cases, subsequent dry cask storage. These de facto storage arrangements have increased the potential consequences associated with the used nuclear fuel. As an example, consider a blackout of an entire power plant. Without power to circulate and cool the water in the cooling pools, the heat from the fuel assemblies can boil off the water. In the worst case, this can melt the assemblies together, possibly releasing of harmful nuclear materials into the environment. The potential consequences — and the speed at which the accident would unfold — are increased by the sheer amount of used fuel stored in these pools.

The U.S. government has also breached its legal obligation to remove the used fuel from reactor sites, which enables the industry to sue for storing fuel on site. The longer used fuel remains on site, the larger the financial and political incentives are for both the industry and the government to maintain the status quo. Yet, doing nothing to change the current circumstances poses serious risks to human health and national security. We propose that the U.S. government create multiple, consolidated government-run storage sites where used fuel can be stored on an interim basis in robust concrete and steel dry casks. This proposal alleviates the safety and security concerns and begins to unwind the incentives working against proper disposal policy. First, the dry cask storage technique reduces the risks to health and security relative to storing the used fuel in cooling pools. Take, for example, our blackout scenario again. Since cooling is passive in dry casks, it requires no outside electrical power and a blackout would pose minimal risk. Second, the interim dry cask storage solution provides a transition between storage arrangements and reduces the risks of temporary on site storage. Furthermore, it enables the U.S. government to meet its obligation and take responsibility for the used fuel while a geological solution is renegotiated.

The second context in which policymakers can internalize underappreciated and emerging risks in their decision making is in the oil sector where we quantify the risks associated with international oil trade between the countries in the economic blocks: OECD and non-OECD. These two economic blocks are typically distinguished by disparities in environmental regulations, technological capacity, and development status. While these disparities incentivize trade between the two economic blocks, the risks associated with oil demand

and consumption are assumed by the countries that are least equipped to handle it — the non-OECD countries. Motivated by a sustainability perspective, we quantify the patterns of how oil-trade related to risk is distributed internationally. To do this, we isolate the contribution of trade-related risk, measured in fatalities, using data from the global and comprehensive *Energy-Related Severe Accident Database (ENSAD)*, and reassign the trade-related risks to OECD countries according to their oil consumption from imports. We borrow this "consumption-based" accounting method, as opposed to "production-based" method, from climate change literature to measure embodied greenhouse gas emissions. We find that shifting from a production-based accounting method to a consumption-based method quantifies risk that would otherwise go unnoticed or be disregarded by consuming countries: the risk associated with trading oil internationally. We categorize the OECD countries according to five patterns in oil trade that illustrate the source of the oil consumption risks: *net-exporting influence, non-OECD dominated influence, domestic influence, OECD influence, and multiple influences*. The first pattern corresponds to countries that import and re-export most of their oil, so their consumption-based fatality rate tends to be low. Countries that belong to the non-OECD dominated influence import the majority of their fatality risk from non-OECD countries. 40% of the OCED countries with positive oil consumption are in this category. A country with a *Domestic influence* designation produces its own oil and assumes its own fatality rate. This group is dominated by countries that joined the OECD recently, suggesting that these countries are not using the same technologies and not enforcing the same level of regulation as other OECD countries. Countries in the *OECD influence* group import their oil from other OECD countries. Finally, countries in the multiple influences category have fatality rates from many sources: their own, non-OECD, and OECD imports. Using these categories and the shift in analytical perspective from producer to consumer, we reframe the policy issue as one that needs coordinated and cooperative strategy between countries; a strategy in which consumer-countries coordinate their demand for a higher standard of production and export practices. By linking the reputation of the consumer-country to the producer-country, the consumer-country has an interest in choosing producer-countries with more sustainable practices.

Finally, we consider the vulnerability of critical energy infrastructure in Colombia as our third context in which policymakers can internalize underappreciated and emerging risks in their decision making. In this paper, we confirm that insurgent groups FARC and ELN have political incentives, as well as the already-known economic incentives, to attack oil pipelines and electricity transmission lines. To confirm FARC and ELN's political motivations, we use a novel dataset of attacks on energy infrastructure by non-state actors, the *Energy Infrastructure Attack Database (EIAD)*, and empirically test whether Colombian insurgents time attacks on energy infrastructure to coincide with elections. We overcome endogeneity issues that commonly undermine causal identification of empirical models in electoral violence papers by using a fixed, exogenously determined election schedule. According to our results, FARC and ELN increase attacks on energy infrastructure by 51% during the month of and 58% during the three months before an election. The rise in attacks is mainly directed at electricity infrastructure (e.g., transmission lines), which are long, linear structures that are hard to protect. We test the effectiveness of these attacks in disrupting the elections and find a marginally statistically significant correlation between heightened attacks and reduced voter turnout. These results are important for understanding how indirect attack strategies, as opposed to interpersonal attacks, could be used to undermine democratic institutions. Indirect attacks targeting critical infrastructure, including cyber attacks, can have far-reaching material consequences (e.g., blackouts that prevent voting) and immaterial consequences (e.g., intimidation, undermining confidence in democracy). Quantifying this risk in the Colombian context raises a larger security policy issue: how should policymakers weigh the benefits of increasing reliance on complex and interconnected infrastructure against the risks of creating opportunities and incentives for relatively weaker insurgent actors to gain leverage and influence?

These three papers expose, explain, and quantify unappreciated risks of energy technologies interfacing with society. Each paper contributes to an overall effort to internalize more risks into energy policy, but each paper also illustrates one particular step and method in moving risks from unappreciated to internalized. Establishing the existence of a risk is one of the first steps toward internalizing such a risk, and a step that must be iteratively revisited as technologies and society evolve. The paper on energy infrastructure attacks in Colombia quantifies an increased risk of attacks motivated by political incentives and substantiates the emerging risk to energy infrastructure that increasing complexity and vulnerability poses. We use an econometric method that allows us to determine a causal relationship between attacks and election timing. Such robust quantification is central to establishing credible evidence for policymaking. The second step toward internalizing a risk is determining the scope of the risk — who or what does the risk affect? What are the costs or benefits? In the paper quantifying the import-adjusted fatality rate associated with oil consumption, we calculate the unappreciated impact of the risk associated with international oil trade data about trading relationships across the world. To do this, we shift the frame of the policy analysis from production- to consumption-based accounting. This simple shift in framing alters the interpretation and the analysis of historical data and our quantitative research findings. In the case of Colombia, this second step toward internalization would involve quantifying the consequences of such attacks. Though we have anecdotal consequence estimations and showed some suggestive evidence of the impacts on voter turnout, we would need to quantify the material and immaterial impacts of attacks contained in the whole database more precisely, for example, financial losses, causal change in voter turnout, and environmental impacts.

Finally, in our paper on used nuclear fuel storage in the U.S., we come to the third step in internalizing risks (policy creation and communication) and propose an interim policy solution that takes the newly appreciated risks into account. To garner understanding of and support for such a policy, we translate the technical data and historical context that informed our policy recommendation for a broad audience and focus on communicating the risks to the public. The objective of good communication is to reduce the influence of decision-making biases with clear and informative language. Often neglected in practice, risk communication is essential to the policymaking process. For Colombia, this third step would entail communicating the drivers, risks, and the consequences of insurgents attacking energy infrastructure to the government and the group of companies affected by these attacks. When evaluated in aggregate, the government and the affected companies could be more poised to address the challenges they face to secure their infrastructure together.

Over the long-term (e.g., years), internalizing new risks in energy policy, whether through prices or regulations, promotes necessary adjustments to the evolving technological and social setting. Over the short-term, internalizing new risks in energy policy does not *necessarily* require a policy change or the addition of ever more variables in a policy objective function. Rather, over the short-term, internalization means engaging with the evolving technological and social setting, acknowledging the importance and influence of unpriced and unregulated risks, understanding how society responds to those risks, and communicating new information to the public. This broad definition of internalization suggests that what is not known about risks is informative too and should guide what to research or monitor, what data to collect, shared qualities with other already-known risks, and indicators of emerging risks. In other words, risk internalization is as much about adding new parameters to optimize as it is about truly understanding what has been left out of the optimization and why. We can see this internalization process already underway in the closely related policy realm of climate change. Decades were necessary to gather enough momentum, information, social and political support, and economic instruments and opportunities to begin to change the shape of global climate policy.

The realization that internalizing risk is a slow, iterative process is both reassuring and dissatisfying. While we require stable energy policies to make investments in critical energy systems and infrastructure to drive modern society, not having the will or ability to quickly respond to risks slows progress. Oftentimes, policymakers procrastinate making policy improvements until a major accident occurs. However, as energy systems become more complex, interconnected, and unwieldy, policymakers that procrastinate will be faced with policies that are even more complicated and difficult to negotiate. In this dissertation, we have considered settings where social and political incentives have hindered the internalization of risks. However, a future area of research should look at commonly used energy policy instruments (e.g., taxes, regulations, insurance) that unintentionally create conditions and incentives for risks to persist or worsen. One particularly rich area for this research is energy system insurance markets. For example, in many energy sectors, companies are required by law to have insurance to guarantee that they will reclaim the land they used and properly dispose of any waste generated during operations. However, as has been seen in the coal mining industry, despite having insurance, companies have been able to discharge these liabilities by going bankrupt. Ultimately the burden of the liability falls on the government, setting a precedent for other companies to also not internalize their risks, but rather to discharge them.

Risks in the energy sector are generated and aggravated by changes to both technical and social conditions. As societies have increased their reliance on energy resources, the scale and complexity of the energy systems and networks producing and distributing those resources have grown. As a result, policymakers are faced with a new, more complicated set of issues to address. First and foremost, policymakers are confronted with the increasing scale and complexity of consequences associated with generating and distributing enough energy to meet societal demands, not to mention disposing of the associated waste products. These consequences, including known effects such as resource depletion, increasingly detectable and measurable impacts such as pollution, and emerging risks such as climate change, arise for technical as well as political and economic reasons. Though more emphasis has historically been placed on technical risks, policymakers should be iteratively balancing costs, benefits, and risks arising from technical, political, or economic sources. In doing so, policymakers will ensure that while minimizing the harm done to the environment and human health, society has well-functioning, modern energy infrastructure necessary for growth and prosperity.

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APPENDIX A

A.1 Import-adjusted fatality rates for individual Organization for Economic Cooperation and Development (OECD) countries caused by accidents in the oil energy chain

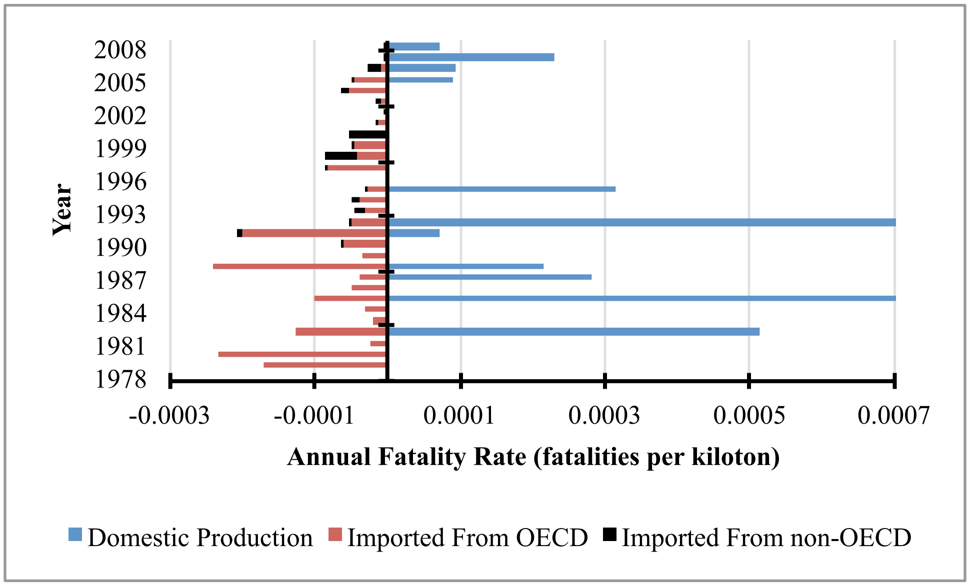

Figure A.1: The annual fatality rate of Mexico is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

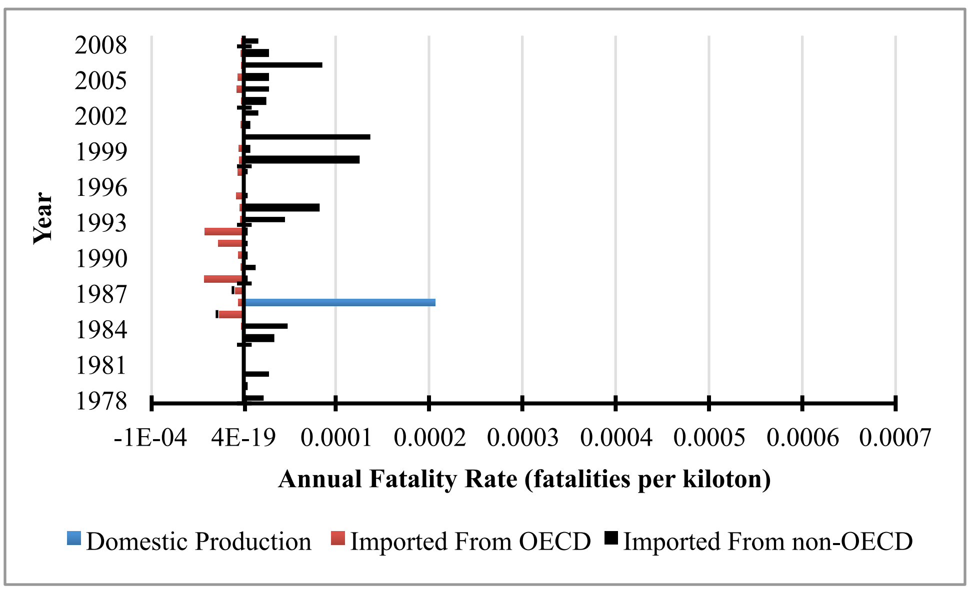

Figure A.2: The annual fatality rate of Australia is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

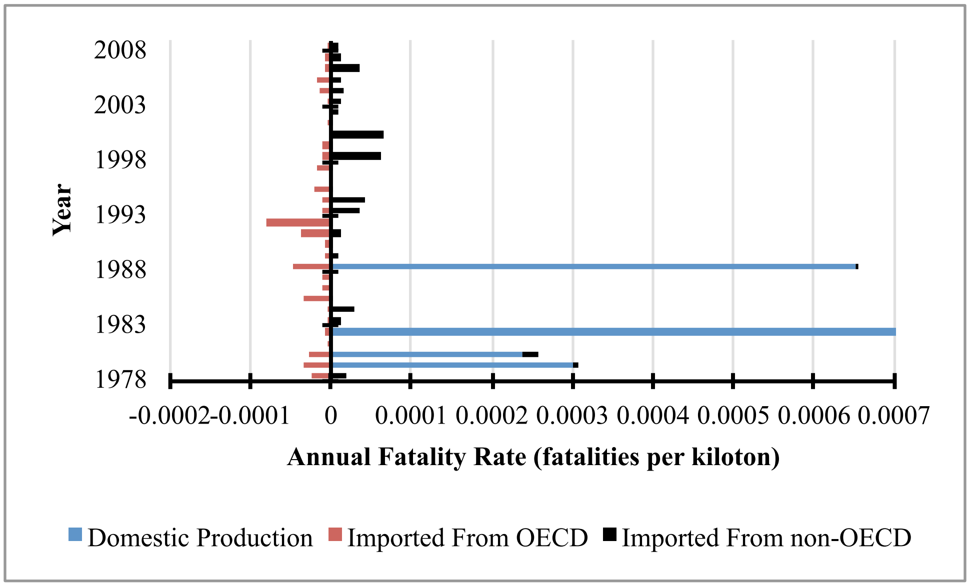

Figure A.3: The annual fatality rate of Canada is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

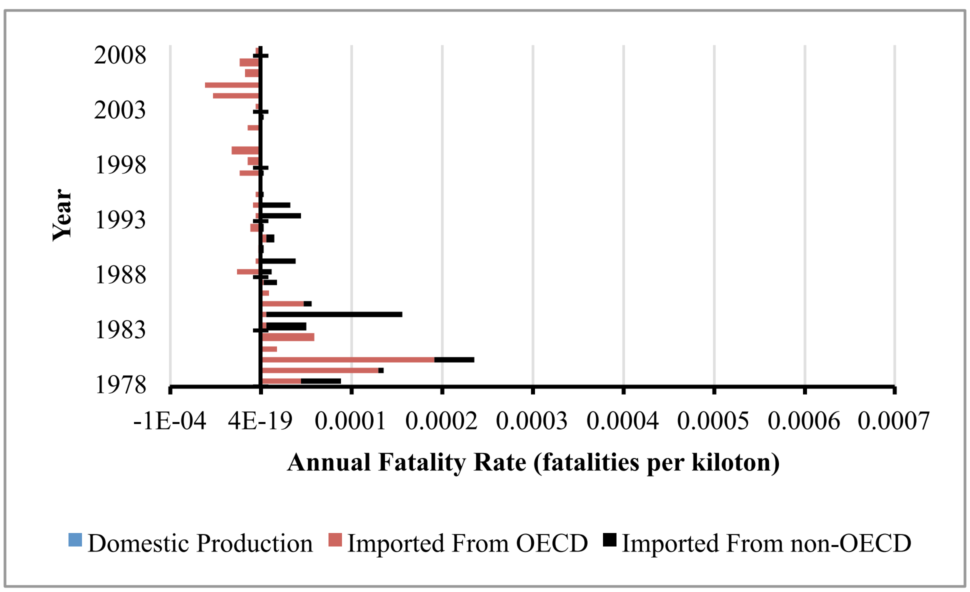

Figure A.4: The annual fatality rate of Denmark is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD and the black bars indicate a source from the non-OECD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

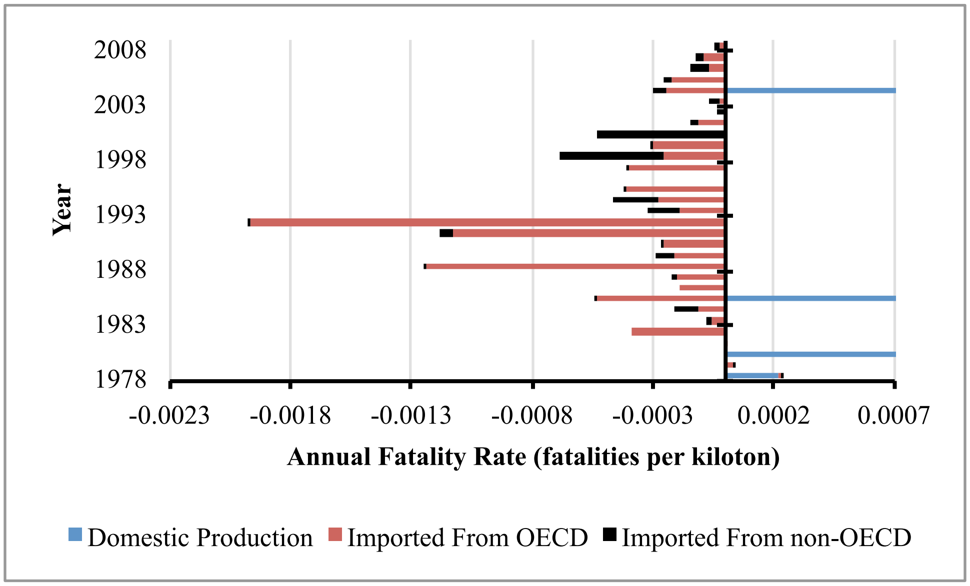

Figure A.5: The annual fatality rate of Norway is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

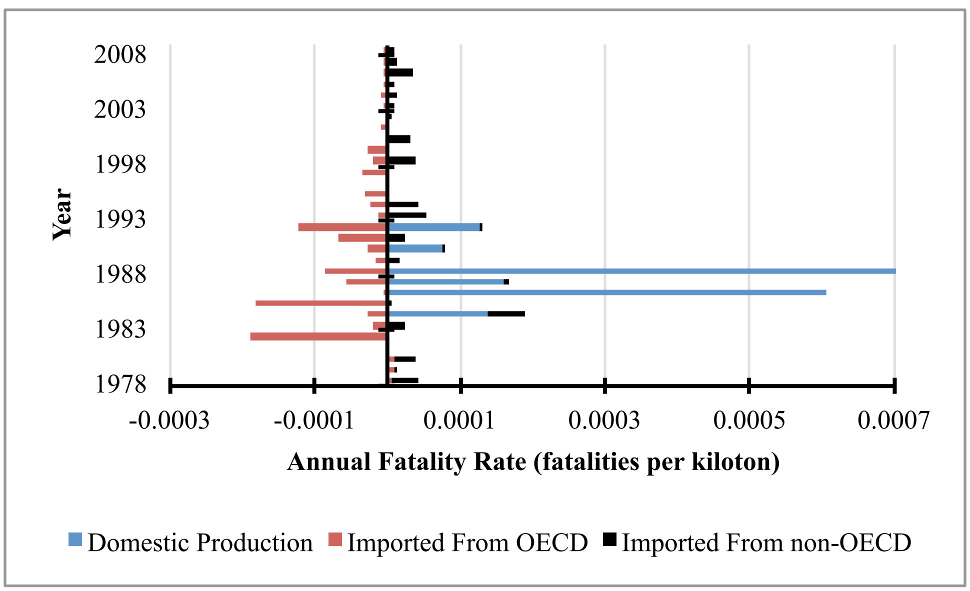

Figure A.6: The annual fatality rate of the United Kingdom is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

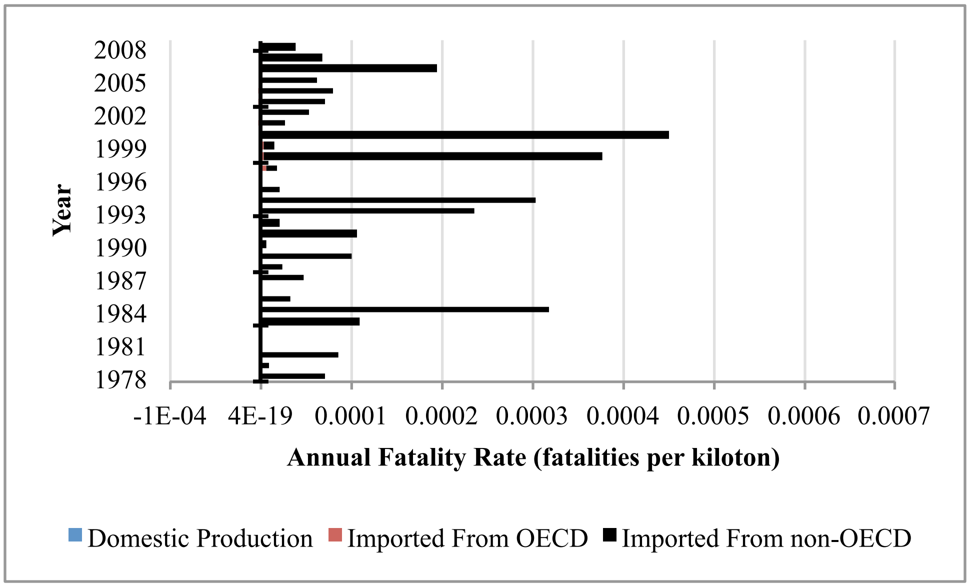

Figure A.7: The annual fatality rate of Poland is graphed for the years between 1978 and 2008. The black bars indicate a source from the non-OECD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

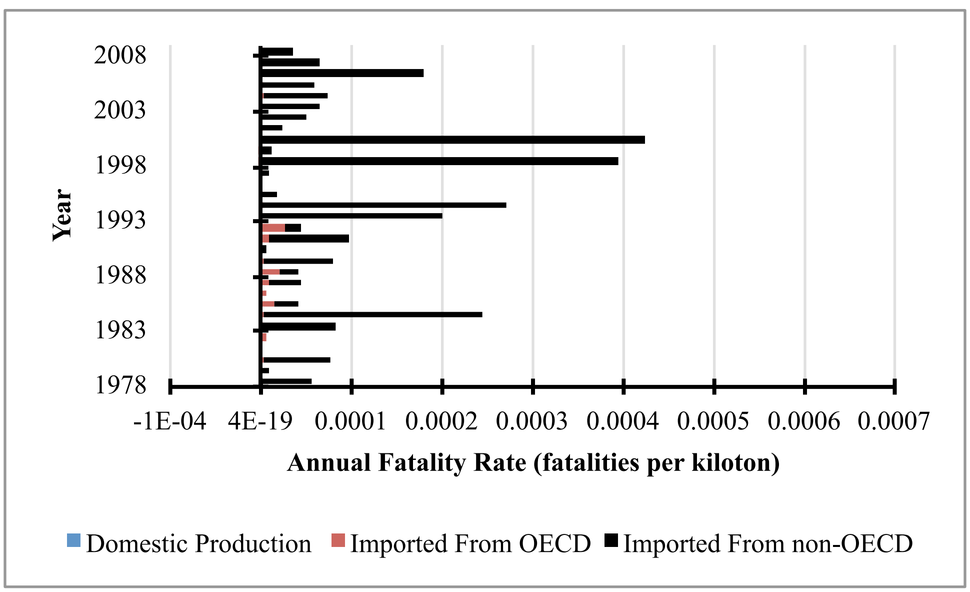

Figure A.8: The annual fatality rate of Austria is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD and the black bars indicate a source from the non-OECD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

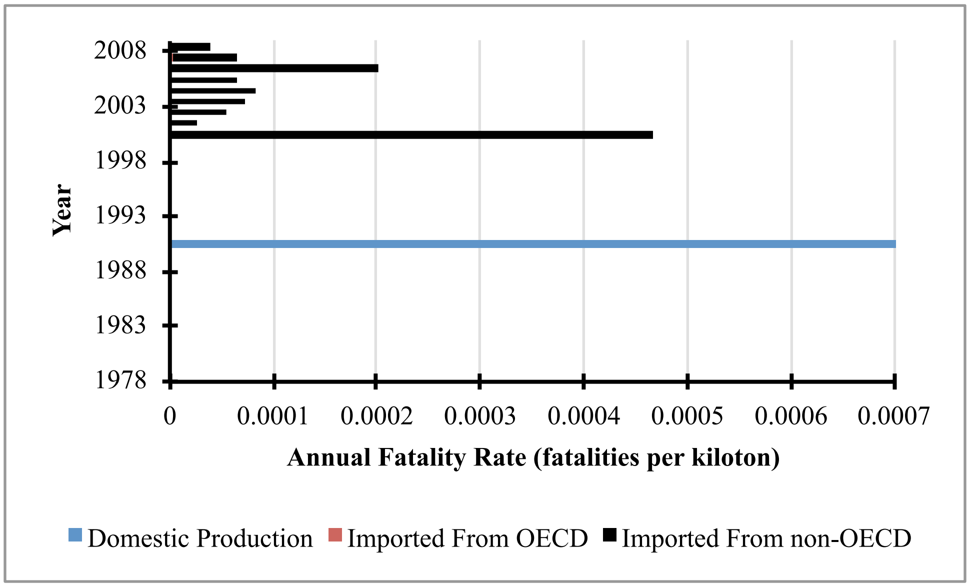

Figure A.9: The annual fatality rate of Chile is graphed for the years between 1978 and 2008. The black bars indicate a source from the non-OECD and the blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

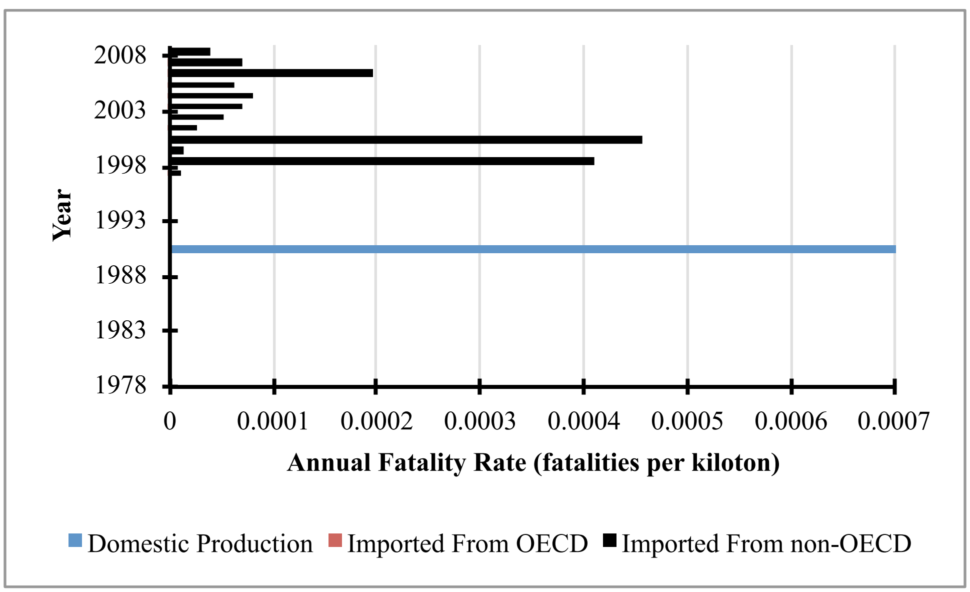

Figure A.10: The annual fatality rate of the Czech Republic is graphed for the years between 1978 and 2008. The black bars indicate a source from the non-OECD and the blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

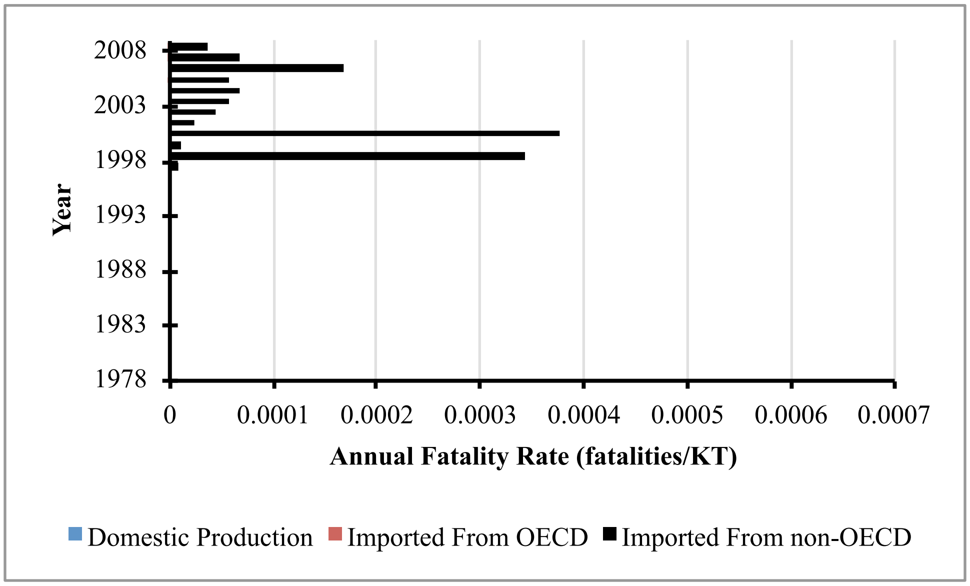

Figure A.11: The annual fatality rate of Hungary is graphed for the years between 1978 and 2008. The black bars indicate a source from the non-OECD — fatality rates from domestic production and those imported from OECD are not visible at this scale. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

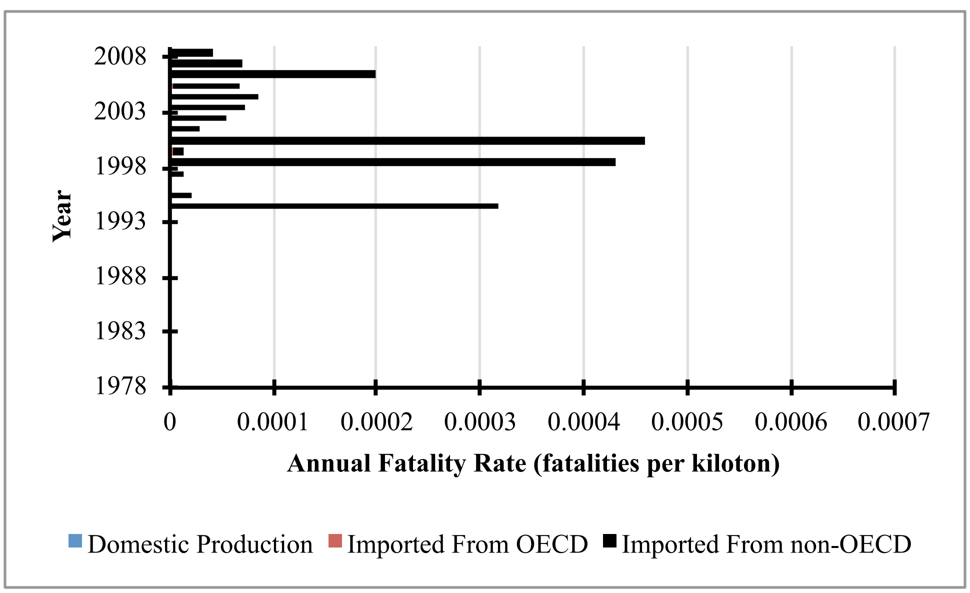

Figure A.12: The annual fatality rate of South Korea is graphed for the years between 1978 and 2008. The black bars indicate a source from the non-OECD; other fatality rate sources not visible at this scale. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

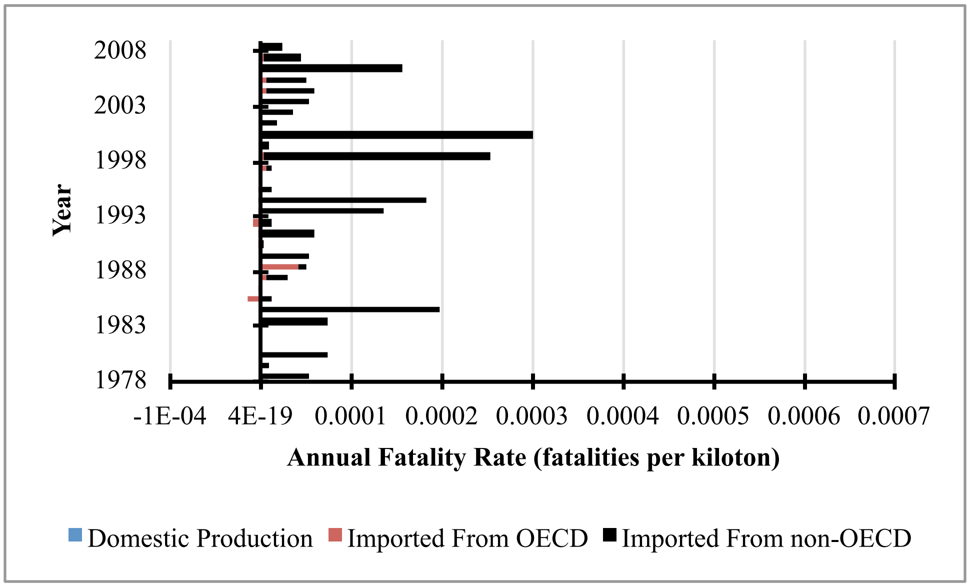

Figure A.13: The annual fatality rate of New Zealand is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD and the black bars indicate a source from the non-OECD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

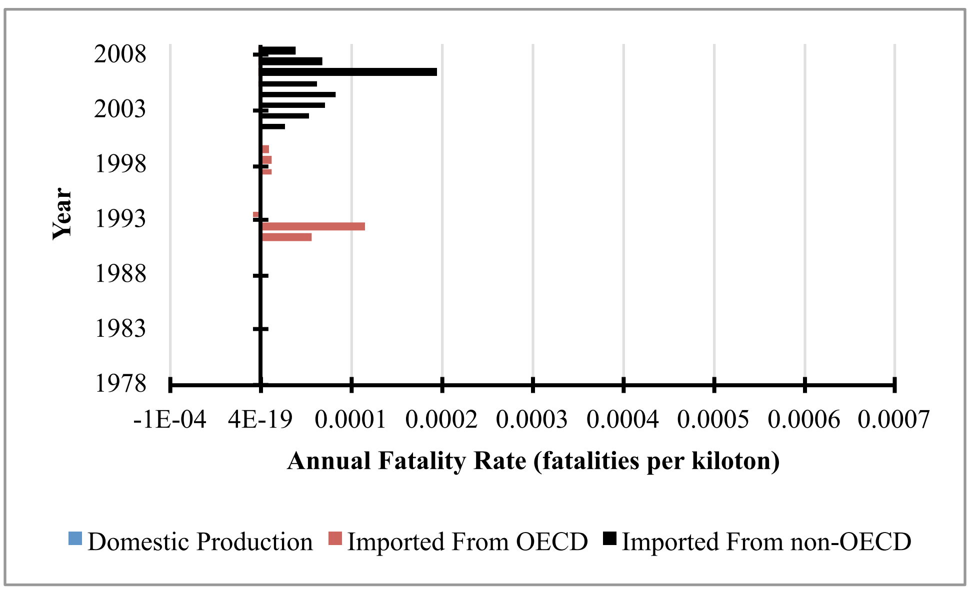

Figure A.14: The annual fatality rate of Slovakia is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD and the black bars indicate a source from the non-OECD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

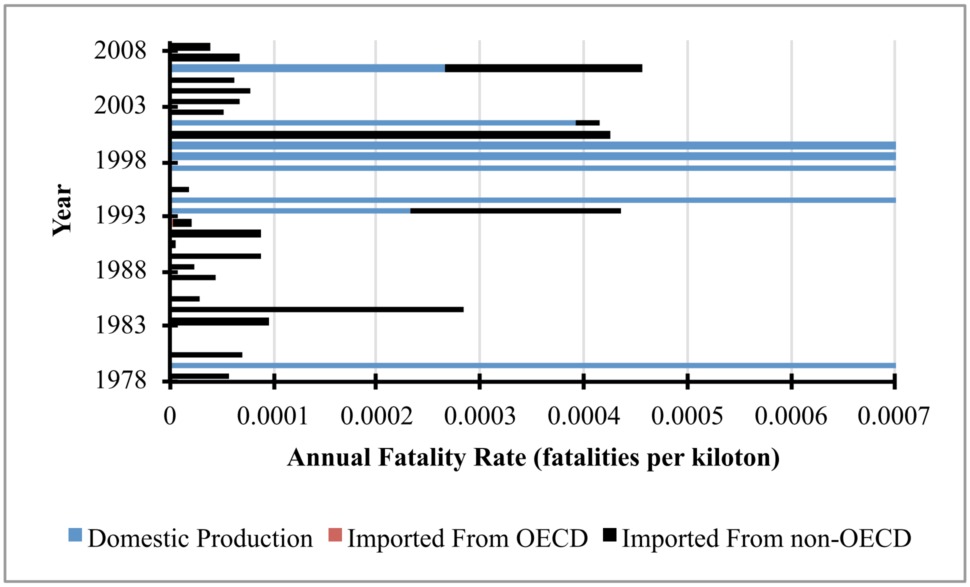

Figure A.15: The annual fatality rate of Turkey is graphed for the years between 1978 and 2008. The black bars indicate a source from the non-OECD and the blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

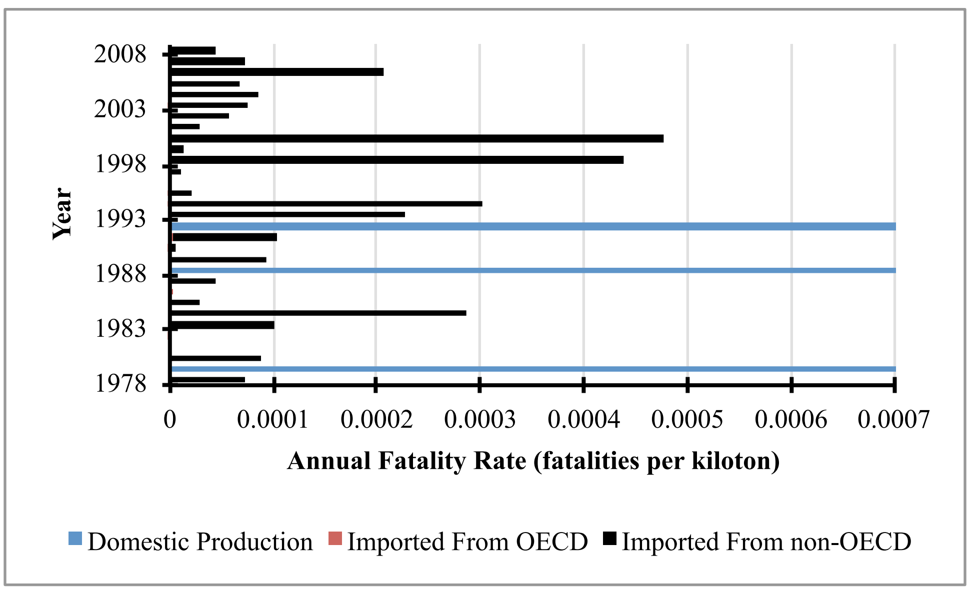

Figure A.16: The annual fatality rate of Greece is graphed for the years between 1978 and 2008. The black bars indicate a source from the non-OECD and the blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

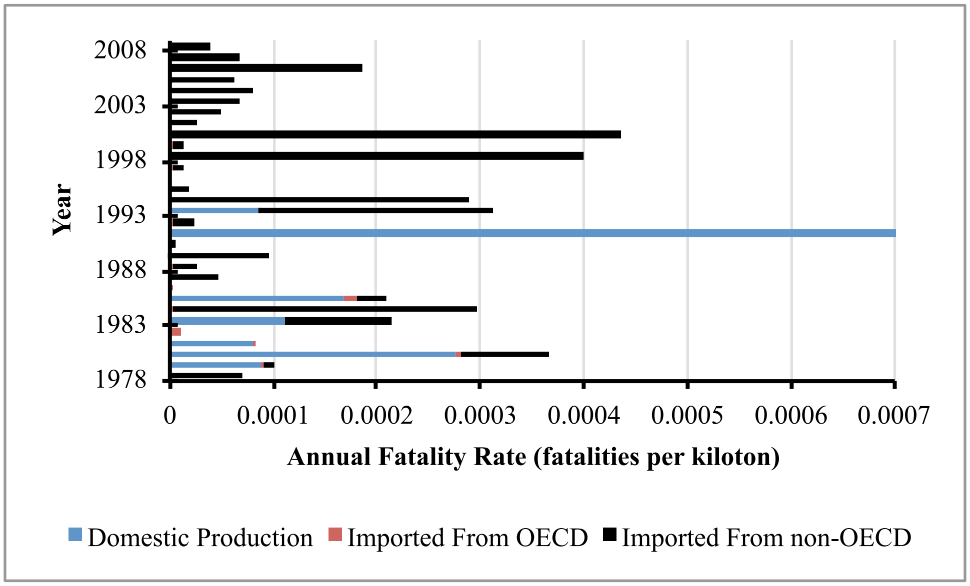

Figure A.17: The annual fatality rate of Italy is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

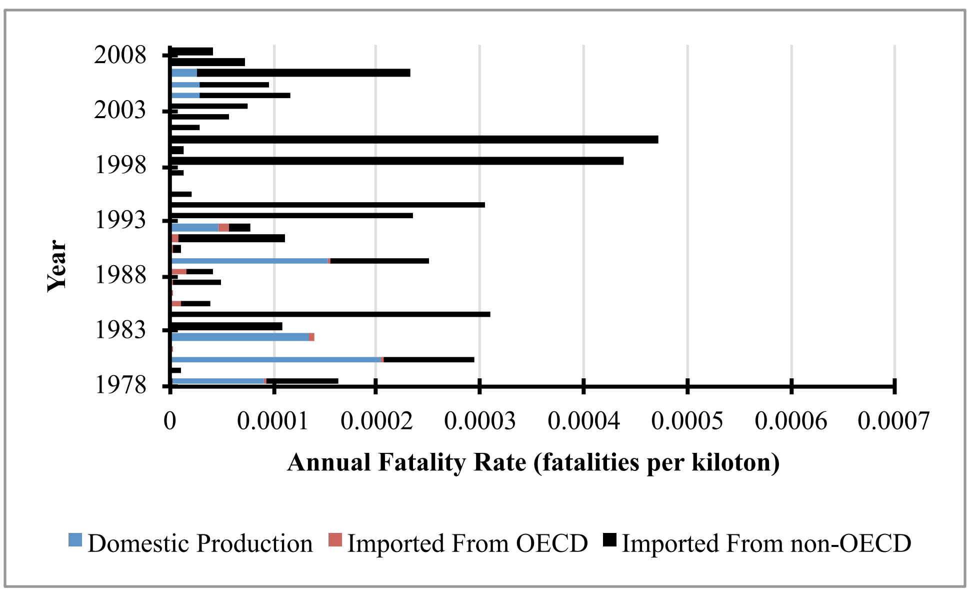

Figure A.18: The annual fatality rate of Japan is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

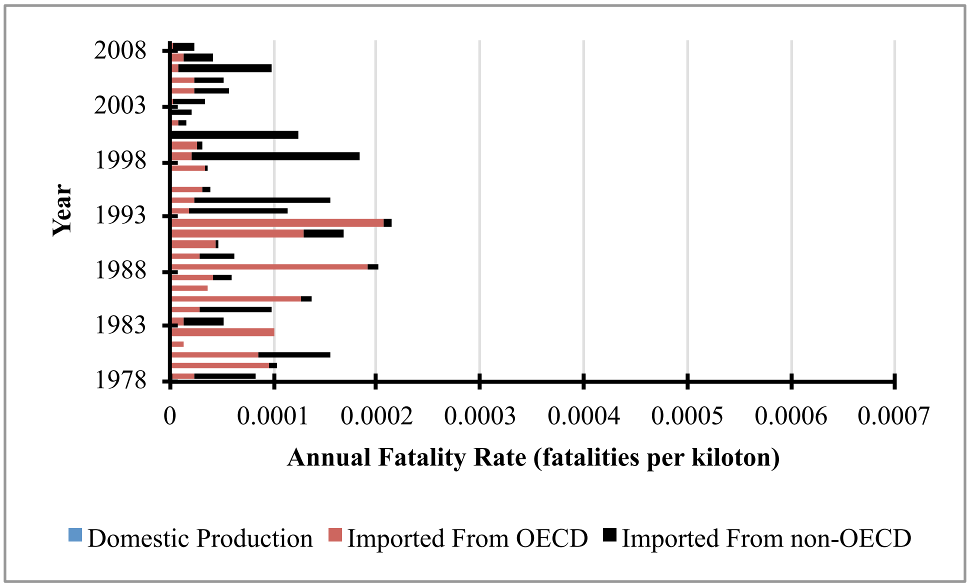

Figure A.19: The annual fatality rate of Sweden is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD and the black bars indicate a source from the non-OECD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

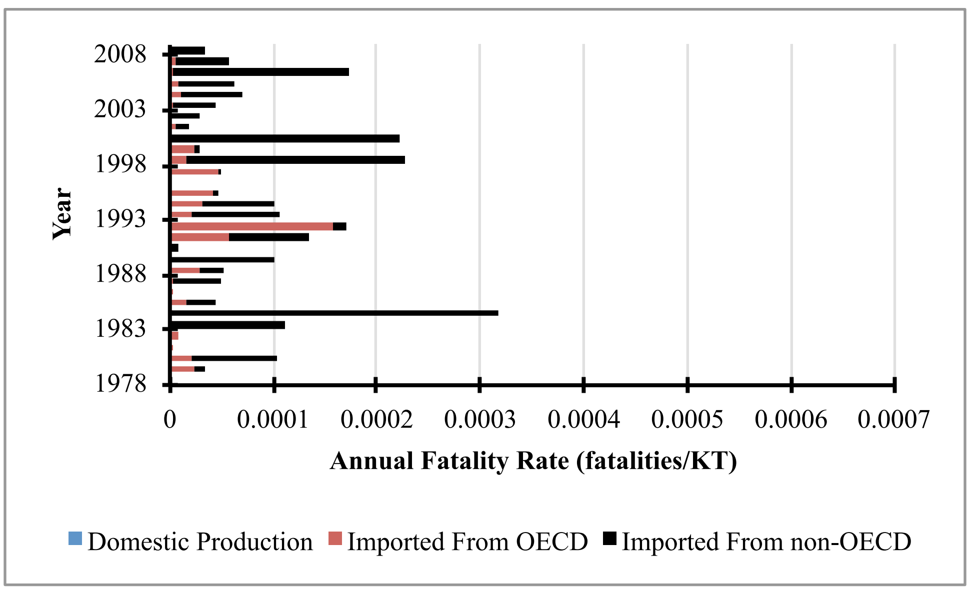

Figure A.20: The annual fatality rate of Finland is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD and the black bars indicate a source from the non-OECD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

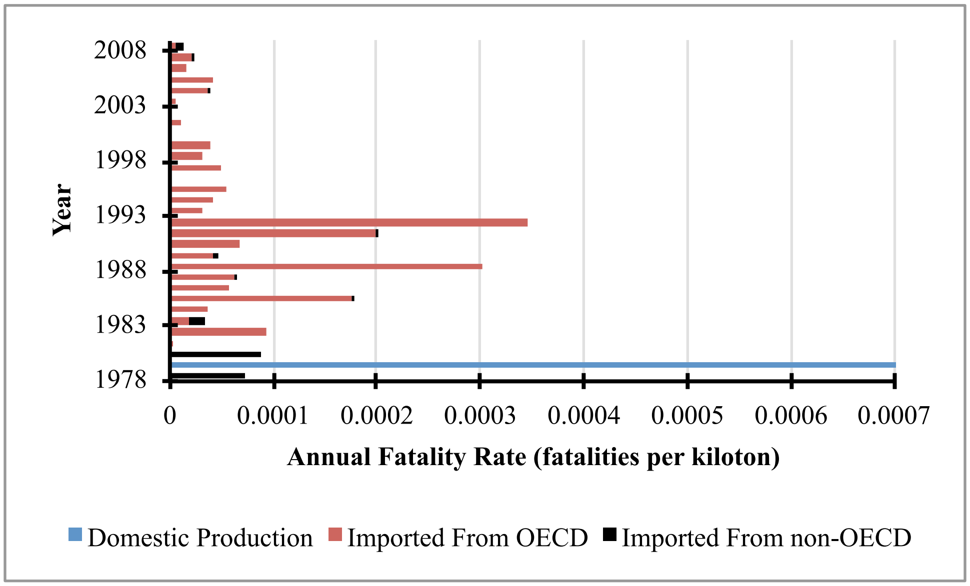

Figure A.21: The annual fatality rate of Ireland is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

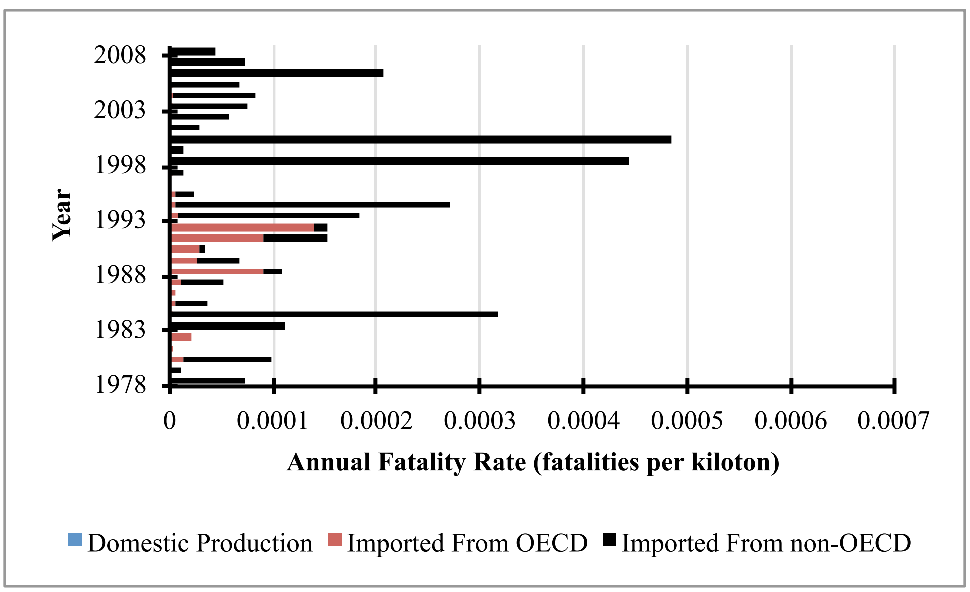

Figure A.22: The annual fatality rate of Switzerland is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD and the black bars indicate a source from the non-OECD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

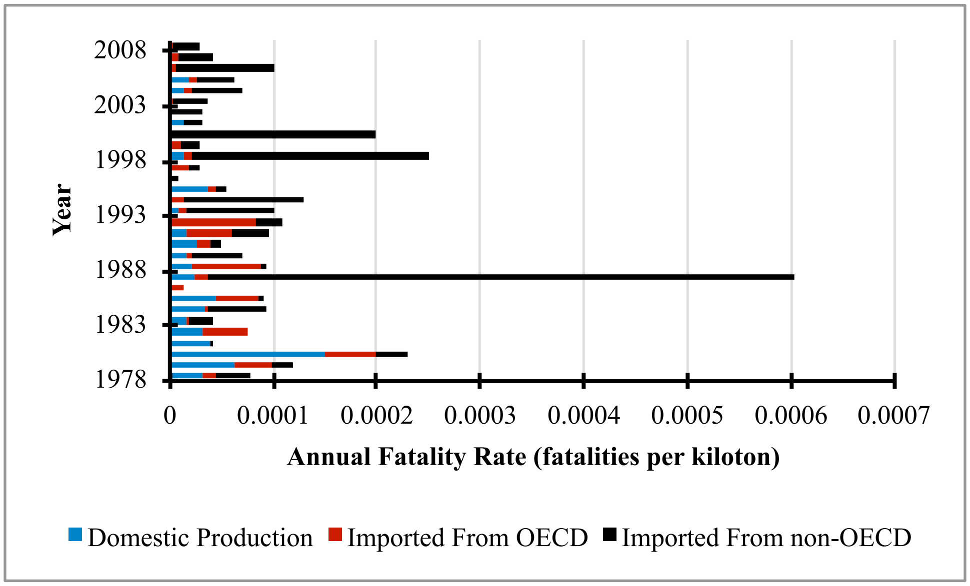

Figure A.23: The annual fatality rate of the United States is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

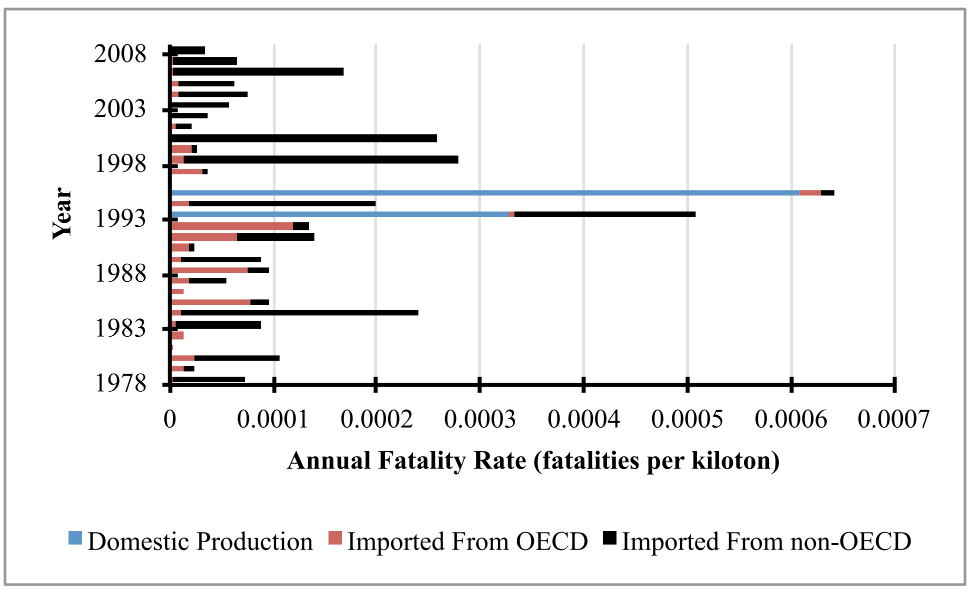

Figure A.24: The annual fatality rate of Belgium is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

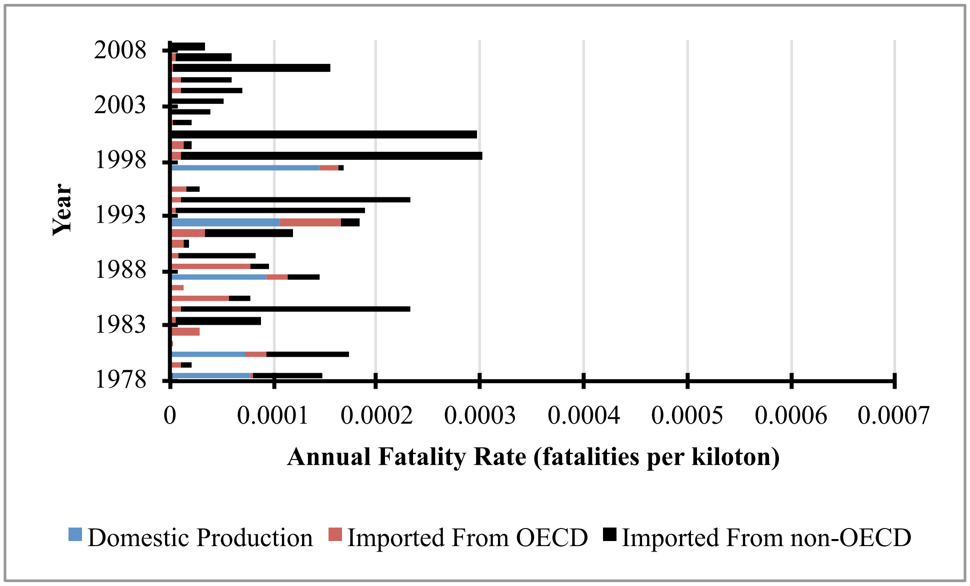

Figure A.25: The annual fatality rate of France is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

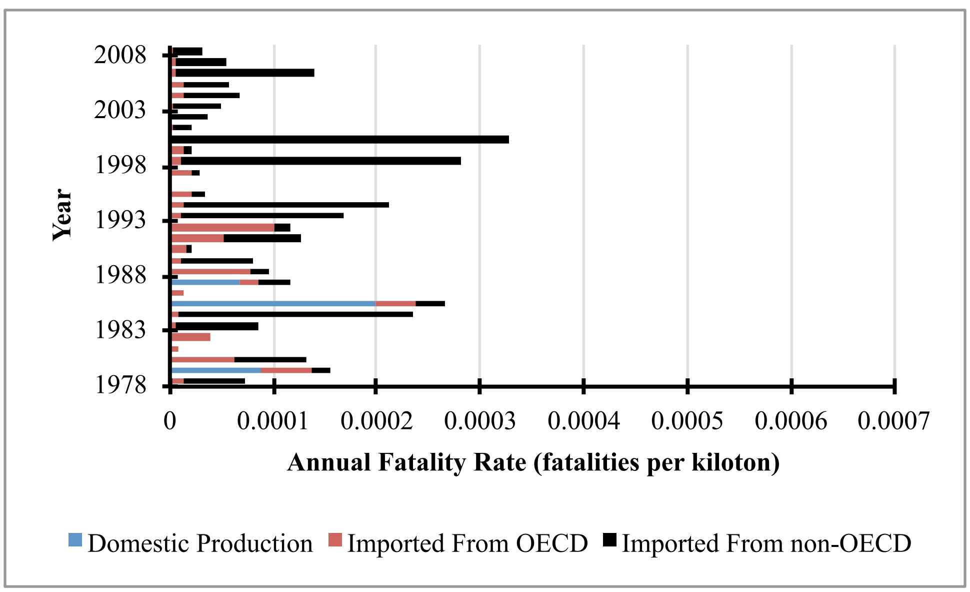

Figure A.26: The annual fatality rate of Germany is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

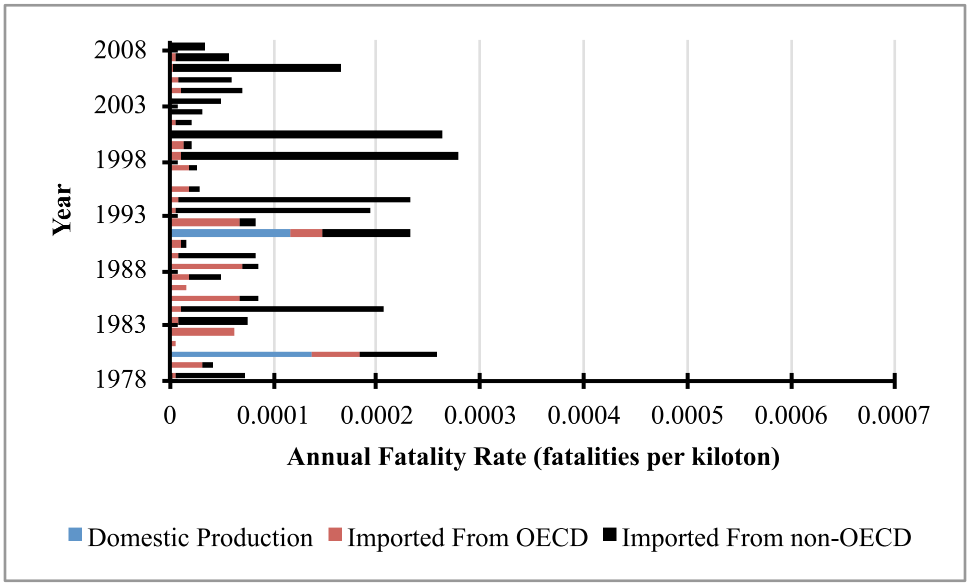

Figure A.27: The annual fatality rate of Netherlands is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

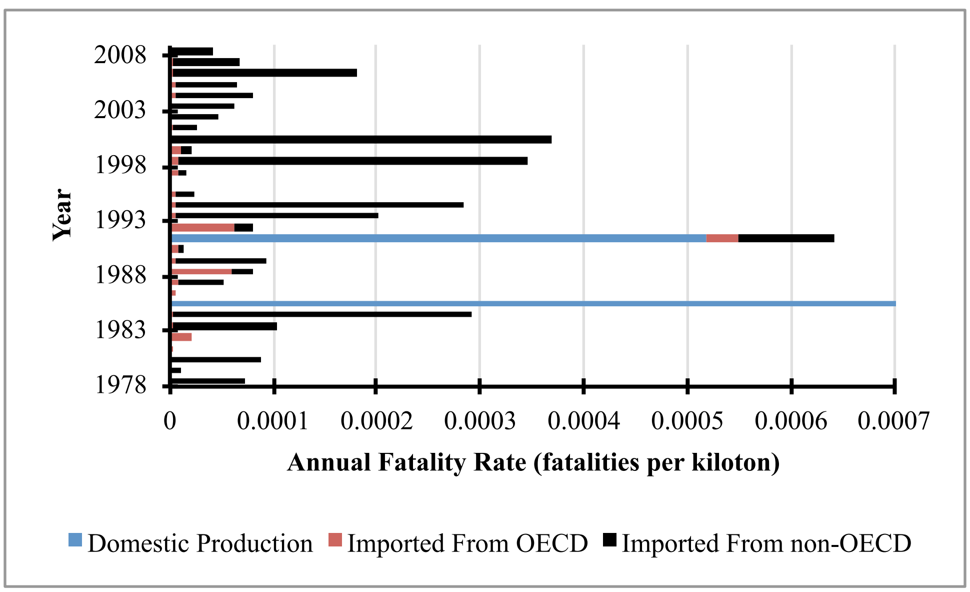

Figure A.28: The annual fatality rate of Portugal is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

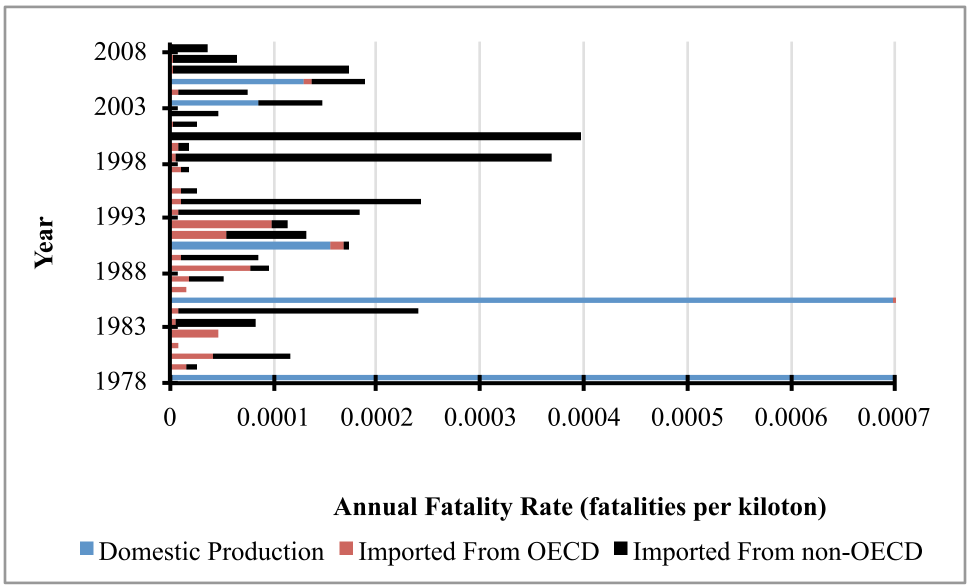

Figure A.29: The annual fatality rate of Spain is graphed for the years between 1978 and 2008. The red bars indicate a source from the OECD, black bars indicate a source from the non-OECD, and blue bars indicate the accidents are the result of domestic accidents. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Country	***Year***	***Group***
Denmark	*1961*	*Net Exporter*
Norway	*1961*	*Net Exporter*
United Kingdom	*1961*	*Net Exporter*
Austria	*1961*	*Non-OECD Dominated Influence*
Greece	*1961*	*Domestic Influence*
Turkey	*1961*	*Domestic Influence*
Ireland	*1961*	*OECD Influence*
Sweden	*1961*	*OECD Influence*
Switzerland	*1961*	*OECD Influence*
Belgium	*1961*	*Multiple Influences*
France	*1961*	*Multiple Influences*
Germany	*1961*	*Multiple Influences*
Netherlands	*1961*	*Multiple Influences*
Portugal	*1961*	*Multiple Influences*
Spain	*1961*	*Multiple Influences*
United States	*1961*	*Multiple Influences*
Canada	*1962*	*Net Exporter*
Italy	*1962*	*Domestic Influence*
Japan	*1964*	*Domestic Influence*
Finland	*1969*	*OECD Influence*
Australia	*1971*	*Net Exporter*
New Zealand	*1973*	*Non-OECD Dominated Influence*
Mexico	*1994*	*Net Exporter*
Czech Republic	*1995*	*Non-OECD Dominated Influence*
Hungary	*1996*	*Non-OECD Dominated Influence*
Korea	*1996*	*Non-OECD Dominated Influence*
Poland	*1996*	*Non-OECD Dominated Influence*
Slovak Republic	*2000*	*Non-OECD Dominated Influence*
Chile	*2010*	*Non-OECD Dominated Influence*

Figure A.30: Table of countries according to their accession into the OECD. Corresponds to Table 3.1 of OECD country grouping. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

APPENDIX B

B.1 Insurgent Attacks on Energy Infrastructures and Electoral Institutions in Colombia

B.1.1 Security during elections

One might be concerned that the levels of violence were affected by changes in security around the elections. To test this concern, we include a dummy variable measure of 'democratic security' from the CEDE panel database spanning 1993-2011.[1] The indicator takes a value of one if a municipality had 'democratic security' during elections and zero otherwise. We expect that the coefficient on this variable would be negative (positive) and significant if the presence of security decreases (increases) the levels of violence. We find that democratic security reduces the intensity of energy infrastructure attacks; however, security does not have a significant effect on the likelihood of being attacked (see Table B.1). Still, the point estimates on the election variables remain stable in magnitude after controlling for security when compared to the same timeframe without controlling for security (See Panel B). This confirms our intuition that security is launched to reduce attacks, but that the effect we estimate is not driven by changes in security. Ideally, we would like to have a measure of security at the month-year, municipality level that also includes a measure of security intensity. Given that level of detail, we would be able to determine whether local, timely changes in security influence violence. One might expect that attacks on energy infrastructure could increase if security efforts were directed at protecting populated targets (e.g., polling stations).

[1] Unfortunately, we were not able to find a measure of security that spanned the entire data-set.

Table B.1: Sensitivity analysis of main results controlling for 'democratic security'

Panel A: Sensitivity analysis of main results controlling for 'democratic security' (1993-2011)				
	Conflict Month	Atks	Oil Atks	Electricity
Nat'l election month	0.00151*	0.00051*	0.00014	0.00037
	(0.00075)	(0.00020)	(0.00010)	(0.00019)
Nat'l election next 3 months	0.00187***	0.00072**	0.00013	0.00060**
	(0.00056)	(0.00022)	(0.00008)	(0.00020)
Democratic security	0.00410	-0.00087*	0.00019	-0.00104***
	(0.00730)	(0.00037)	(0.00024)	(0.00027)
Observations	133023	133023	133023	133023

Panel B: Main results for comparison (1993-2011)				
	Conflict Month	Atks	Oil Atks	Electricity
Nat'l election month	0.00151*	0.00051*	0.00014	0.00037
	(0.00075)	(0.00020)	(0.00010)	(0.00019)
Nat'l election next 3 months	0.00187***	0.00072**	0.00013	0.00060**
	(0.00056)	(0.00022)	(0.00008)	(0.00020)
Observations	133023	133023	133023	133023

Note: Dependent variables are four measures of attack variable: conflict month and three scaled count variables, number of attacks (total, oil, and electricity) per million inhabitants. These results test the hypothesis that our results are driven by changes in security. The only measure of security around elections available to us is a dummy variable in the CEDE Violence and Conflict panel data-set, 'democratic security,' that indicates whether there was any security in that municipality during any elections during a particular year. When multiple municipalities were combined, the maximum value of the dummy variable was assumed. This table includes data from 1993-2011; this constraint is due to the democratic security dummy variable which was not available for the complete observation period. Therefore, we rerun the main results for the years 1993-2011 for comparison. National elections include presidential, presidential runoff, senate, national legislature, assembly, and council elections. Variables not shown are municipality fixed-effects, time-invariant and time-varying controls, and year fixed-effects. Standard errors are paired, cluster boostrapped, replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

We also check the effect of security specifically on presidential elections, as presidential elections appear to be targeted the most. Unlike democratic security around the national elections, democratic security does not reduce or increase attacks on energy infrastructure near presidential elections (see Table B.2). It is possible that the measure of democratic security we have does not capture security for presidential elections, or the security deployed is not effective in preventing the electricity attacks in the months proceeding the election.

Table B.2: Sensitivity analysis of presidential results controlling for 'democratic security'

Panel A: Sensitivity analysis of presidential results controlling for 'democratic security' (1993-2011)				
	Conflict Month	Atks	Oil Atks	Electricity
Presidential election month	0.00068	-0.00023	-0.00003	-0.00023
	(0.00112)	(0.00031)	(0.00006)	(0.00029)
Presidential election next 3 months	0.00193	0.00093***	-0.00000	0.00094***
	(0.00105)	(0.00027)	(0.00007)	(0.00027)
Democratic security	0.00956	-0.00020	0.00051	-0.00071
	(0.01101)	(0.00062)	(0.00049)	(0.00041)
Observations	65076	65076	65076	65076

Panel B: Presidential results for comparison (1993-2011)				
	Conflict Month	Atks	Oil Atks	Electricity
Presidential election month	0.00068	-0.00023	-0.00003	-0.00023
	(0.00106)	(0.00029)	(0.00006)	(0.00029)
Presidential election next 3 months	0.00193	0.00093***	-0.00000	0.00094***
	(0.00104)	(0.00026)	(0.00007)	(0.00025)
Observations	65076	65076	65076	65076

Note: Dependent variables are four measures of attack variable: conflict month and three scaled count variables, number of attacks (total, oil, and electricity) per million inhabitants. These results test the hypothesis that our results are driven by changes in security. The only measure of security around elections available to us is a dummy variable in the CEDE Violence and Conflict panel data-set, 'democratic security', that indicates whether there was any security in that municipality during any elections during a particular year. When multiple municipalities were combined, the maximum value of the dummy variable was assumed. This table includes data from 1993-2011; this constraint is due to the democratic security dummy variable which was not available for the complete observation period. Therefore, we rerun the main results for the years 1993-2011 for comparison. Variables not shown are municipality fixed-effects, time-invariant and time-varying controls, and year fixed-effects. Standard errors are paired, cluster boostrapped, replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

B.1.2 Municipality boundaries

During the 31-year observation period of our data, the boundaries of the municipalities in Colombia have changed, forming new municipalities as well as altering existing municipalities. As discussed in Section 4.6, to account for these changes, we approximated the boundaries of the municipalities in 1980. Since 1991, new municipalities have been formed based on a set of social and economic criteria; however, prior to any official guidelines, municipality territories were established by historical, social, and cultural forces (Departamento Administrativo Nacional de Estadistica (DANE), 2017). To rule out any underlying correlation between municipality boundary formation, energy infrastructure, and attacks, we run the main models excluding those municipalities affected in any way by changing boundaries (Table **??**). We see that our results remain stable and increase slightly in magnitude once we remove the approximated municipalities. Interestingly, we find the municipalities that had stable boundaries over time shape our finding. This makes sense if we believe well-established municipalities have more developed infrastructure.

Table B.3: Impact of national elections on likelihood and intensity of attacks against energy infrastructure excluding approximated 1980 municipalities.

	Conflict Month	Atks	Oil Atks	Electricity
Nat'l election month	0.00121*	0.00040**	0.00016	0.00025
	(0.00054)	(0.00016)	(0.00009)	(0.00013)
Nat'l election next 3 months	0.00099*	0.00043**	0.00006	0.00039**
	(0.00041)	(0.00015)	(0.00005)	(0.00015)
Observations	194370	194370	194370	194370

Note: Dependent variables are four measures of attack variable: conflict month and three scaled count variables, number of attacks (total, oil, and electricity) per million inhabitants. The municipalities with boundaries that were created or modified have been excluded from this estimation. Variables not shown are municipality fixed-effects, time-invariant and time-varying controls, and year fixed-effects. National elections include presidential, presidential runoff, national legislature, assembly, and council elections. Standard errors are replicated 500 times using a paired, cluster bootstrap. *p<0.05, ** p<0.01, ***p<0.001

B.1.3 Sensitivity on Constitutional Changes

To verify that our results are consistent following the change in the constitutions in 1991, we run our main models on a subset of the data: 1991-2011. We find that limiting the estimation window increases the magnitude of the effect we find with the complete set of data (Table B.4). Furthermore, the conclusions using the subset of years are consistent with those using the entire set of data.

Table B.4: Impact of national elections on the likelihood, intensity, and nature of energy infrastructure attacks by insurgent groups, FARC and ELN, post-constitutional change (1991-2011).

	Conflict Month	Atks	Oil Atks	Electricity
Nat'l election month	0.00150*	0.00059**	0.00023	0.00036*
	(0.00067)	(0.00022)	(0.00012)	(0.00017)
Nat'l election next 3 months	0.00148**	0.00060**	0.00009	0.00053**
	(0.00053)	(0.00020)	(0.00008)	(0.00018)
Observations	154077	154077	154077	154077
Control Month Mean	0.00552	0.00095	0.00013	0.00080
Standard Deviation	0.07408	0.01901	0.00525	0.01797
Number control months	91900	91900	91900	91900

Note: Dependent variables are four measures of attack variable: conflict month and three scaled count variables, number of attacks (total, oil, and electricity) per million inhabitants. National elections include presidential, presidential runoff, national legislature, departmental assembly, and municipal council elections. Variables not shown are municipality fixed-effects, time-invariant controls, time-varying controls, quadratic time trend, and year fixed-effects. Standard errors, shown in parentheses, are calculated with a paired, municipality-cluster bootstrap method, replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

B.1.4 Sensitivity analysis on counterfactual window

To create a counterfactual for our election-month data, we chose a 12 month window from which to draw our "control" observations (Section 4.6). We also consider 10, 11, 13 and 14 month counterfactuals. We find that the conclusions remain the same with this variation in the counterfactual window, though the magnitudes of the estimates fluctuate slightly (Table B.5). As we modify our counterfactual window, we must keep in mind that other elections may overlap. As a result, the levels of violence for the counterfactual and the election month converge in some cases when the counterfactual becomes too small, masking the effect of the election on attacks. In addition, because congressional elections occur in March and the first round of presidential elections occur in May, March could be coded as two months prior to an election or it could be coded as an election month. We choose to code it as an election month, making there fewer observations of the two and three individual months prior to an election relative to the number of observations one month before the election. This is the more conservative specification since it associates the attacks to the closest election. The summary statistics for each of the counterfactuals appear in Table B.24.

Table B.5: Sensitivity analysis on counterfactual window

	Conflict Month	Atks	Oil Atks	Electricity
Panel A: 10 month counterfactual				
Nat'l election month	0.00113*	0.00033*	0.00014	0.00019
	(0.00056)	(0.00015)	(0.00009)	(0.00014)
Nat'l election next 3 months	0.00096*	0.00037**	0.00004	0.00034**
	(0.00045)	(0.00013)	(0.00004)	(0.00012)
Observations	174174	174174	174174	174174
Panel B: 11 month counterfactual				
	Conflict Month	Atks	Oil Atks	Electricity
Nat'l election month	0.00083	0.00032*	0.00015	0.00017
	(0.00058)	(0.00015)	(0.00009)	(0.00014)
Nat'l election next 3 months	0.00073	0.00037*	0.00005	0.00033*
	(0.00042)	(0.00014)	(0.00005)	(0.00013)
Observations	187572	187572	187572	187572
Panel C: 12 month counterfactual				
	Conflict Month	Atks	Oil Atks	Electricity
Nat'l election month	0.00109*	0.00038**	0.00015	0.00023
	(0.00055)	(0.00015)	(0.00009)	(0.00014)
Nat'l election next 3 months	0.00097*	0.00043**	0.00005	0.00038**
	(0.00040)	(0.00015)	(0.00005)	(0.00014)
Observations	200013	200013	200013	200013
Panel D: 13 month counterfactual				
	Conflict Month	Atks	Oil Atks	Electricity
Nat'l election month	0.00119*	0.00037*	0.00014	0.00023
	(0.00055)	(0.00015)	(0.00009)	(0.00014)
Nat'l election next 3 months	0.00110**	0.00042**	0.00005	0.00039**
	(0.00040)	(0.00014)	(0.00005)	(0.00013)
Observations	212454	212454	212454	212454
Panel E: 14 month counterfactual				
	Conflict Month	Atks	Oil Atks	Electricity
Nat'l election month	0.00116*	0.00033*	0.00012	0.00020
	(0.00056)	(0.00015)	(0.00009)	(0.00014)
Nat'l election next 3 months	0.00111**	0.00040**	0.00003	0.00037**
	(0.00040)	(0.00015)	(0.00005)	(0.00013)
Observations	224895	224895	224895	224895

Note: Dependent variables are four measures of attack variable: conflict month and three scaled count variables, number of attacks (total, oil, and electricity) per million inhabitants. Results correspond to varying the counterfactual window from 10 to 14 months. Our main results use a 12 month counterfactual, shown in Panel C. Variables not shown are municipality fixed-effects, time-invariant and time-varying controls, and year fixed-effects. Paired, cluster bootstrapped standard errors in parentheses, replicated 500 times.*p<0.05, ** p<0.01, ***p<0.001

B.1.5 Lag Specification and Naive Models

In the main models, we use a three month lag to indicate whether an observation is in one of the three months leading up to the election. This aggregated variable captures any possible trend in attacks prior to the election. Still, one might also be interested to see the contribution of those three months individually.

In Tables B.6-B.9, we show the build up of our model from the first-cut, naive regression to the full model with different lag specifications. The additional model specifications demonstrate that our results are not driven by the specification of our lag variable, and in fact, that controlling for the trend in attacks ahead of the election is more conservative than controlling for the three months ahead. In each of the four tables column (1) shows the naive regression of attack outcomes on the election month. Moving across from column (2) to (6), the coefficients on the national election month remain consistent. The individual coefficients indicate an increase in the number of attacks or probability of an attack during the month prior to the election. The pooled specification smooths the short-term variation in attacks at the month level and provides a better description of the trend in attacks. However, splitting the individual months out shows that the greatest increase in attacks and probability of attacks occurs during the month prior to the election.

Table B.6: Model specification construction for conflict month

	Conf. Mnth	Conf. Mnth	Conf. Mnth	Conf. Mnth	Conf. Mnth	Conf. Mnth
Nat'l election month	0.00085	0.00084	0.00114*	0.00117*	0.00122*	0.00109*
	(0.00052)	(0.00053)	(0.00054)	(0.00053)	(0.00056)	(0.00054)
Nat'l election next month			0.00115*	0.00133*	0.00128*	
			(0.00051)	(0.00053)	(0.00050)	
Nat'l election in 2 months				0.00066	0.00069	
				(0.00056)	(0.00057)	
Nat'l election in 3 months					0.00050	
					(0.00040)	
Nat'l election next 3 months						0.00097*
						(0.00043)
KM pipeline in municipality		0.00000	0.00000	0.00000	0.00000	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
WTI dollar per barrel oil		-0.00002	-0.00001	-0.00001	-0.00001	-0.00001
		(0.00004)	(0.00004)	(0.00004)	(0.00004)	(0.00004)
Monetary value of oil production		0.00041	0.00041	0.00041	0.00041	0.00041
		(0.00392)	(0.00384)	(0.00419)	(0.00411)	(0.00452)
Monetary value of KM pipeline		-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Other election in obs window		0.00000	0.00000	0.00000	0.00000	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Linear month trend	-0.00025**	-0.00026**	-0.00027**	-0.00026**	-0.00027**	-0.00029**
	(0.00008)	(0.00009)	(0.00009)	(0.00009)	(0.00009)	(0.00009)
Quadratic month trend	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Observations	200013	200013	200013	200013	200013	200013

Note: The dependent variable in these regressions is always conflict month, the binary indicator of whether there were any attacks on energy infrastructure. The variable controlling for the months leading up to the election is specified in two ways: an indicator variable for the three months prior to an election and three separate indicator variables for each of the three months prior to an election. Bootstrapped standard errors in parentheses, clustered by municipality and replicated 500 times.*p<0.05, ** p<0.01, ***p<0.001

Table B.7: Model specification construction for attacks per million inhabitants

	Atks	Atks	Atks	Atks	Atks	Atks
Nat'l election month	0.00028	0.00027	0.00042**	0.00043**	0.00045**	0.00038*
	(0.00014)	(0.00014)	(0.00015)	(0.00016)	(0.00016)	(0.00016)
Nat'l election next month			0.00056***	0.00062**	0.00059**	
			(0.00017)	(0.00020)	(0.00020)	
Nat'l election in 2 months				0.00021	0.00023	
				(0.00015)	(0.00015)	
Nat'l election in 3 months					0.00023	
					(0.00015)	
Nat'l election next 3 months						0.00043**
						(0.00015)
KM pipeline in municipality		0.00000	0.00000	0.00000	0.00000	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
WTI dollar per barrel oil		-0.00001	-0.00001	-0.00001	-0.00001	-0.00001
		(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)
Monetary value of oil production		0.00003	0.00003	0.00003	0.00003	0.00003
		(0.00030)	(0.00039)	(0.00032)	(0.00033)	(0.00036)
Monetary value of KM pipeline		-0.00000*	-0.00000*	-0.00000*	-0.00000*	-0.00000*
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Other election in obs window		0.00000	0.00000	0.00000	0.00000	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Linear month trend	-0.00003	-0.00004	-0.00004	-0.00004	-0.00004	-0.00005
	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00003)
Quadratic month trend	-0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Observations	200013	200013	200013	200013	200013	200013

Note: The dependent variable in these regressions is a scaled, count variable of the attacks per million inhabitants. The variable controlling for the months leading up to the election is specified in two ways: an indicator variable for the three months prior to an election and three separate indicator variables for each of the three months prior to an election. Bootstrapped standard errors in parentheses, clustered by municipality and replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

Table B.8: Model specification construction for oil attacks per million inhabitants

	Oil Atks	Oil Atks	Oil Atks	Oil Atks	Oil Atks	Oil Atks
Nat'l election month	0.00014	0.00014	0.00018	0.00018	0.00018	0.00015
	(0.00009)	(0.00008)	(0.00011)	(0.00010)	(0.00010)	(0.00009)
Nat'l election next month			0.00016	0.00017	0.00017	
			(0.00012)	(0.00012)	(0.00013)	
Nat'l election in 2 months				0.00001	0.00001	
				(0.00005)	(0.00005)	
Nat'l election in 3 months					0.00001	
					(0.00004)	
Nat'l election next 3 months						0.00005
						(0.00005)
KM pipeline in municipality		0.00000	0.00000	0.00000	0.00000	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
WTI dollar per barrel oil		-0.00001	-0.00001	-0.00001	-0.00001	-0.00001
		(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)
Monetary value of oil production		-0.00001	-0.00001	-0.00001	-0.00001	-0.00001
		(0.00008)	(0.00011)	(0.00009)	(0.00009)	(0.00008)
Monetary value of KM pipeline		-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Other election in obs window		0.00000	0.00000	0.00000	0.00000	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Linear month trend	-0.00003	-0.00003	-0.00003	-0.00003	-0.00003	-0.00003
	(0.00002)	(0.00002)	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Quadratic month trend	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Observations	200013	200013	200013	200013	200013	200013

Note: The dependent variable in these regressions is a scaled, count variable number of oil attacks per million inhabitants. The variable controlling for the months leading up to the election is specified in two ways: an indicator variable for the three months prior to an election and three separate indicator variables for each of the three months prior to an election. Bootstrapped standard errors in parentheses, clustered by municipality and replicated 500 times.*p<0.05, ** p<0.01, ***p<0.001

Table B.9: Model specification construction for electricity attacks per million inhabitants

	Elec. Atks	Elec. Atks	Elec. Atks	Elec. Atks	Elec. Atks	Elec. Atks
Nat'l election month	0.00014	0.00013	0.00023	0.00024*	0.00027*	0.00023
	(0.00011)	(0.00011)	(0.00012)	(0.00012)	(0.00013)	(0.00012)
Nat'l election next month			0.00039**	0.00045**	0.00043**	
			(0.00013)	(0.00015)	(0.00015)	
Nat'l election in 2 months				0.00023	0.00024	
				(0.00013)	(0.00014)	
Nat'l election in 3 months					0.00022	
					(0.00016)	
Nat'l election next 3 months						0.00038**
						(0.00014)
KM pipeline in municipality		0.00000	0.00000	0.00000	0.00000	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
WTI dollar per barrel oil		-0.00001	-0.00000	-0.00000	-0.00000	-0.00000
		(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)
Monetary value of oil production		0.00004	0.00004	0.00004	0.00004	0.00004
		(0.00024)	(0.00025)	(0.00030)	(0.00028)	(0.00024)
Monetary value of KM pipeline		-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Other election in obs window		0.00000	0.00000	0.00000	0.00000	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Linear month trend	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001	-0.00002
	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00002)	(0.00002)
Quadratic month trend	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Observations	200013	200013	200013	200013	200013	200013

Note: The dependent variable in these regressions is a scaled, count variable number of electricity attacks per million inhabitants. The variable controlling for the months leading up to the election is specified in two ways: an indicator variable for the three months prior to an election and three separate indicator variables for each of the three months prior to an election. Bootstrapped standard errors in parentheses, clustered by municipality and replicated 500 times.*p<0.05, ** p<0.01, ***p<0.001

B.1.6 Sensitivity on Treatment Specification

A concern that all of these model specifications are potentially biased by post-treatment bias must also be addressed. Post-treatment bias arises when a covariate that is influenced by the treatment is controlled for in the regression (Acharya et al., 2016). In our example, the suspect post-treatment covariates are the election lags and pooled lags because the rise in attacks during those months is caused by the insurgents anticipation of the election — the treatment. A sign of possible post-treatment bias is that the effect of the elections is not significant prior to conditioning on the lag variables. According to Acharya et al. (2016), if we are indeed conditioning on variables determined by the treatment, we are breaking the 'statistical independence' between the treatment variable and the outcome: the timing of the election and the attack outcome variable.

However, we show that these lags are not post-treatment variables for two main reasons. First, we can think of the lag variables as additional treatments. We could have easily chosen to specify our treatment differently showing that the treatment lasts more than the month of the election (Wooldridge, 2010) — for example, the first few months prior to an election and including the election month. In that case, the treatment would be independent of the covariates — satisfying ignorability of treatment conditions — as the timing of the election is exogenous to violence. In fact, we run the regressions using the lags as the treatment and find no change in the estimated coefficients (see Table B.10-B.13). Second, while the timing of the election lag variables is determined by the election treatment, they are determined simultaneously rather than sequentially and are related to the treatment mechanically in the same way. According to Angrist and Pischke (2009), "Good controls are variables that we can think of as having been fixed at the time the regressor of interest [or treatment] was determined." Whether we consider the lag variables treatments or controls, they are determined with the treatment and themselves are independent of the other covariates, including the municipality fixed-effect. In other words, the lag variables do not differentially influence elections, and therefore do not violate the strict exogeneity condition (Wooldridge, 2010).

Table B.10: Treatment Specification Sensitivity: Conflict Month

	Conf. Mnth	Conf. Mnth	Conf. Mnth	Conf. Mnth	Conf. Mnth
Nat'l election next month			0.00115*	0.00133*	0.00128*
			(0.00051)	(0.00053)	(0.00050)
Nat'l election in 2 months				0.00066	0.00069
				(0.00056)	(0.00057)
Nat'l election in 3 months					0.00050
					(0.00040)
Nat'l election next 3 months	0.00082*	0.00097*			
	(0.00039)	(0.00044)			
KM pipeline in municipality		0.00000	0.00000	0.00000	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)
WTI dollar per barrel oil		-0.00001	-0.00001	-0.00001	-0.00001
		(0.00004)	(0.00004)	(0.00004)	(0.00004)
Monetary value of oil production		0.00041	0.00041	0.00041	0.00041
		(0.00392)	(0.00384)	(0.00419)	(0.00411)
Monetary value of KM pipeline		-0.00000	-0.00000	-0.00000	-0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)
Other election in obs window		0.00109	0.00114*	0.00117*	0.00122*
		(0.00057)	(0.00054)	(0.00053)	(0.00056)
Linear month trend	-0.00025**	-0.00029**	-0.00027**	-0.00026**	-0.00027**
	(0.00008)	(0.00009)	(0.00009)	(0.00009)	(0.00009)
Quadratic month trend	0.00000	0.00000	0.00000	0.00000	0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Observations	200013	200013	200013	200013	200013

Note: The dependent variable in these regressions is always conflict month, the binary indicator of whether there were any attacks on energy infrastructure. We leave out the indicator variable for the election-month treatment to test for post-treatment bias. The variable controlling for the months leading up to the election is specified in two ways: an indicator variable for the three months prior to an election and three separate indicator variables for each of the three months prior to an election. Bootstrapped standard errors in parentheses, clustered by municipality and replicated 500 times.*p<0.05, ** p<0.01, ***p<0.001

Table B.11: Treatment Specification Sensitivity: Attacks per Million Inhabitants

	Atks	Atks	Atks	Atks	Atks
Nat'l election next month			0.00056***	0.00062**	0.00059**
			(0.00017)	(0.00020)	(0.00020)
Nat'l election in 2 months				0.00021	0.00023
				(0.00015)	(0.00015)
Nat'l election in 3 months					0.00023
					(0.00015)
Nat'l election next 3 months	0.00038**	0.00043**			
	(0.00014)	(0.00015)			
KM pipeline in municipality		0.00000	0.00000	0.00000	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)
WTI dollar per barrel oil		-0.00001	-0.00001	-0.00001	-0.00001
		(0.00001)	(0.00001)	(0.00001)	(0.00001)
Monetary value of oil production		0.00003	0.00003	0.00003	0.00003
		(0.00030)	(0.00039)	(0.00032)	(0.00033)
Monetary value of KM pipeline		-0.00000*	-0.00000*	-0.00000*	-0.00000*
		(0.00000)	(0.00000)	(0.00000)	(0.00000)
Other election in obs window		0.00038*	0.00042**	0.00043**	0.00045**
		(0.00015)	(0.00015)	(0.00016)	(0.00016)
Linear month trend	-0.00004	-0.00005	-0.00004	-0.00004	-0.00004
	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00003)
Quadratic month trend	0.00000	0.00000	0.00000	0.00000	0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Observations	200013	200013	200013	200013	200013

Note: The dependent variable in these regressions is a scaled, count variable of the attacks per million inhabitants. The variable controlling for the months leading up to the election is specified in two ways: an indicator variable for the three months prior to an election and three separate indicator variables for each of the three months prior to an election. Bootstrapped standard errors in parentheses, clustered by municipality and replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

Table B.12: Treatment Specification Sensitivity: Oil Attacks per Million Inhabitants

	Oil Atks	Oil Atks	Oil Atks	Oil Atks	Oil Atks
Nat'l election next month			0.00016	0.00017	0.00017
			(0.00012)	(0.00012)	(0.00013)
Nat'l election in 2 months				0.00001	0.00001
				(0.00005)	(0.00005)
Nat'l election in 3 months					0.00001
					(0.00004)
Nat'l election next 3 months	0.00004	0.00005			
	(0.00005)	(0.00005)			
KM pipeline in municipality		0.00000	0.00000	0.00000	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)
WTI dollar per barrel oil		-0.00001	-0.00001	-0.00001	-0.00001
		(0.00001)	(0.00001)	(0.00001)	(0.00001)
Monetary value of oil production		-0.00001	-0.00001	-0.00001	-0.00001
		(0.00008)	(0.00011)	(0.00009)	(0.00009)
Monetary value of KM pipeline		-0.00000	-0.00000	-0.00000	-0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)
Other election in obs window		0.00015	0.00018	0.00018	0.00018
		(0.00009)	(0.00011)	(0.00010)	(0.00010)
Linear month trend	-0.00003	-0.00003	-0.00003	-0.00003	-0.00003
	(0.00002)	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Quadratic month trend	0.00000	0.00000	0.00000	0.00000	0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Observations	200013	200013	200013	200013	200013

Note: The dependent variable in these regressions is a scaled, count variable number of oil attacks per million inhabitants. We leave out the indicator variable for the election-month treatment to test for post-treatment bias. The variable controlling for the months leading up to the election is specified in two ways: an indicator variable for the three months prior to an election and three separate indicator variables for each of the three months prior to an election. Bootstrapped standard errors in parentheses, clustered by municipality and replicated 500 times.*p<0.05, ** p<0.01, ***p<0.001

Table B.13: Treatment Specification Sensitivity: Electricity Attacks per Million Inhabitants

	Elec. Atks	Elec. Atks	Elec. Atks	Elec. Atks	Elec. Atks
Nat'l election next month			0.00039**	0.00045**	0.00043**
			(0.00013)	(0.00015)	(0.00015)
Nat'l election in 2 months				0.00023	0.00024
				(0.00013)	(0.00014)
Nat'l election in 3 months					0.00022
					(0.00016)
Nat'l election next 3 months	0.00035**	0.00038**			
	(0.00014)	(0.00013)			
KM pipeline in municipality		0.00000	0.00000	0.00000	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)
WTI dollar per barrel oil		-0.00000	-0.00000	-0.00000	-0.00000
		(0.00001)	(0.00001)	(0.00001)	(0.00001)
Monetary value of oil production		0.00004	0.00004	0.00004	0.00004
		(0.00024)	(0.00025)	(0.00030)	(0.00028)
Monetary value of KM pipeline		-0.00000	-0.00000	-0.00000	-0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)
Other election in obs window		0.00023	0.00023	0.00024*	0.00027*
		(0.00013)	(0.00012)	(0.00012)	(0.00013)
Linear month trend	-0.00001	-0.00002	-0.00001	-0.00001	-0.00001
	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00002)
Quadratic month trend	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Observations	200013	200013	200013	200013	200013

Note: The dependent variable in these regressions is a scaled, count variable number of electricity attacks per million inhabitants. We leave out the indicator variable for the election-month treatment to test for post-treatment bias. The variable controlling for the months leading up to the election is specified in two ways: an indicator variable for the three months prior to an election and three separate indicator variables for each of the three months prior to an election. Bootstrapped standard errors in parentheses, clustered by municipality and replicated 500 times.*p<0.05, ** p<0.01, ***p<0.001

B.1.7 Weighted Least Squares Models and Least Squares Models with Robust Standard Errors

Next, we tested the specification of our standard errors and we assign weights our observations by the log population to account for measurement error in the dependent variable. We find the results are consistent with the bootstrapped errors for both the national and presidential elections (Table B.14-B.15). Robust, White-style standard errors account for serial correlation and heteroskedasticity of the error term. An example of a possible source of serial correlation would be when a location (e.g., a pipeline) is attacked multiple times during the period observed; if we have not controlled for all the time-varying covariates contributing to such attacks (e.g., changing levels of surveillance), the effect of those covariates will remain in the error term and be correlated over time, as the choice of surveillance levels are correlated over time. An example source of heteroskedastic errors arising from the outcome variable of the number of attacks could be that the accuracy of attack reporting on a pipeline or electricity line decreases with the length of the pipeline or electricity line, meaning that longer pipelines, for example, have less accurate attack data and the variance of the observed attacks on longer pipelines would therefore be larger. In the case of the linear probability model — a binary model — our errors are by definition heteroskedastic.

Table B.14: Impact of national elections on the likelihood and intensity of energy infrastructure attacks by insurgent groups using robust standard errors and population weighting.

Panel A: Conflict Month and All Attacks				
	Conflict Month	Conflict Month (weighted)	Atks	Atks (weighted)
Nat'l election month	0.00109*	0.00110	0.00038*	0.00036*
	(0.00054)	(0.00057)	(0.00015)	(0.00015)
Nat'l election next 3 months	0.00097*	0.00095*	0.00043**	0.00040**
	(0.00041)	(0.00043)	(0.00015)	(0.00014)
Observations	200013	200013	200013	200013

Panel B: Oil and Electricity Attacks				
	Oil Atks	Oil Atks (weighted)	Electricity Atks	Electricity Atks (weighted)
Nat'l election month	0.00015	0.00013	0.00023	0.00023
	(0.00009)	(0.00008)	(0.00013)	(0.00012)
Nat'l election next 3 months	0.00005	0.00005	0.00038**	0.00036**
	(0.00005)	(0.00005)	(0.00014)	(0.00013)
Observations	200013	200013	200013	200013

Note: The dependent variables in the regressions in Panel A are a binary indicator of attacks, conflict month, and a scaled, count variable of the number of attacks per million inhabitants. The dependent variables in Panel B are two scaled, count variables oil and electricity attacks per million inhabitants. Variables not shown are municipality fixed-effects, time-invariant and time-varying controls, and year fixed-effects. Columns (2) & (4) in Panel A and B are weighted by the natural log of the population to offset possible measurement error in the reporting of violence variables. In Panel B, the outcome variable for columns (1)-(2) is the number of oil infrastructure attacks per million inhabitants; for columns (3)-(4), the outcome variable is number of electricity infrastructure attacks per million inhabitants. Columns (2) & (4) are weighted by the natural log of the population to offset possible measurement error in the reporting of violence variables. Robust standard errors in parentheses, clustered by municipality. *p<0.05, ** p<0.01, ***p<0.001

Assigning weights to observations is a method to account for measurement error. In municipalities with larger populations, it is likely that the reporting of attacks and incidents is more accurate because more people observe the incidents. This is a type of endogenous sampling when the probability of observing the outcome is correlated with the covariates (Solon et al., 2015). Using Weighted Least Squares (WLS), we are able place more weight on those observations we believe are more accurately estimated to achieve consistent estimates and improve efficiency (Solon et al., 2015). Using the natural log of the municipal populations as weights provides efficiency gains from smoothing the population distribution relative to using population alone. Without taking the log of the population, the population distribution is skewed right. Again, we find no significant change in our conclusions, only small efficiency gains (see Tables B.14-B.15).

Table B.15: Impact of presidential elections on the likelihood and intensity of energy infrastructure attacks by rebel groups using robust standard errors and population weighting.

Panel A: Conflict Month and All Attacks				
	Conflict Month	Conflict Month (weighted)	Atks	Atks (weighted)
Presidential election month	0.00105	0.00124	-0.00010	-0.00009
	(0.00086)	(0.00092)	(0.00022)	(0.00021)
Presidential election next 3 months	0.00085	0.00075	0.00051**	0.00047**
	(0.00080)	(0.00085)	(0.00018)	(0.00017)
Observations	102399	102399	102399	102399

Panel B: Oil and Electricity Attacks				
	Oil Atks	Oil Atks (weighted)	Electricity Atks	Electricity Atks (weighted)
Presidential election month	-0.00003	-0.00003	-0.00009	-0.00008
	(0.00005)	(0.00005)	(0.00021)	(0.00020)
Presidential election next 3 months	-0.00004	-0.00005	0.00055**	0.00051**
	(0.00006)	(0.00006)	(0.00017)	(0.00016)
Observations	102399	102399	102399	102399

Note: The dependent variables in the regressions in Panel A are a binary indicator of attacks, conflict month, and a scaled, count variable of the number of attacks per million inhabitants. The dependent variables in Panel B are two scaled, count variables oil and electricity attacks per million inhabitants. Presidential elections include normal and run-off elections. Variables not shown are municipality fixed-effects, time-invariant and time-varying controls, and year fixed-effects. Columns (2) & (4) are weighted by the natural log of the population to offset possible measurement error in the reporting of violence variables. Robust standard errors in parentheses, clustered by municipality. *p<0.05, ** p<0.01, ***p<0.001

B.1.8 Sensitivity Analysis: Department Level Clustered Standard Errors

Much of the cross-sectional variation in our explanatory variables is at the municipality level, which is the reason why we cluster our standard errors at the municipality level. However, there is also correlation between the municipalities within departments, so we also cluster our standard errors at the departmental level as another check of our results (see Table B.16). Clustering at the department level will increase our standard errors relative to the standard errors clustered at the municipality level as it assumes that each observation and the observations from one department provide less information due to a lack of independence. The standard errors clustered at the municipality level assume that observations within a municipality are correlated and therefore provide less information than individual, independent observations. Therefore, clustering at the department level is more restrictive, and so a good test of our result. We see that our results are consistent with both clustering schemes.

Table B.16: Sensitivity analysis: department level clustered standard errors

	Conflict Month	Atks	Oil Atks	Electricity
Nat'l election month	0.00109	0.00038**	0.00015	0.00023
	(0.00056)	(0.00013)	(0.00011)	(0.00012)
Nat'l election next 3 months	0.00097*	0.00043***	0.00005	0.00038**
	(0.00043)	(0.00012)	(0.00005)	(0.00012)
Observations	200013	200013	200013	200013

Note: The dependent variables are the binary indicator of attacks, conflict month, and three scaled count variables indicating the number of attacks per million inhabitants: total, oil, and electricity attacks. Standard errors are bootstrapped with a paired-cluster at the department level and replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

B.1.9 Additional, Non-Linear Specifications

Over the course of the observational period, in multiple years some municipalities do not experience any attacks on energy infrastructure. In fact, there are municipalities that do not have any attacks during the observation period. Observations without attacks appear as zeros. As these zeros are numerous, OLS can predict values outside of the [0,1] interval. In the case of the linear probability model (LPM), OLS can also predict values less than zero. Our outcome variable logically cannot take on negative integer values, so we use a non-linear count model to verify the results of our linear model. Theoretically, the zero-inflated count model fits the data better as it models zeros and positive outcomes with separate distributions. For example, in municipalities without energy infrastructure, we expect zero attacks. However, those zeros are a result of a lack of targets to attack and do not represent the decision by insurgents to attack or not to attack. Since the decision to attack or not to attack interests us the most, we want to model that decision separately. Nevertheless, the OLS model provides a parsimonious estimation of the conditional mean function and marginal effects of the relationship between elections and energy sector attacks.

The zero-inflated negative binomial model is a two part model

$$g(y) = \begin{cases} f_1(0) + (1 - f_1(0))f_2(0) & \text{if } y = 0 \\ (1 - f_1(0))f_2(y) & \text{if } y \geq 1, \end{cases}$$

where the first density function, f_1, models the zeros generated and the second density function, f_2, models the non-zero observations. The count density, f_2, is modeled with a negative binomial distribution. There are also Poisssonian zero-inflated models; however, in the Poisson model, the mean and variance are restricted to the same value. In the negative binomial model, the data can be "over dispersed," meaning the variance can be larger than the mean. Our data display over dispersion; therefore, a Poisson model would not theoretically be the correct specification. These densities are estimated with maximum likelihood (MLE); the density of zeros, f_1, is predicted with a Logit function of the variables for oil production, Oil^m_{1988}, and pipeline length in the municipalities, $KMpipeline^m$. Logically, if there are no infrastructure in the municipalities to attack, we expect zero attacks.[2] The Logit model is given below:

$$P(Y^m_{by} = 1|X^m_{by}) = \frac{exp(Oil^m_{1988}\rho + KMpipeline^m\phi)}{1 + exp(Oil^m_{1988}\rho + KMpipeline^m\phi)} \equiv \Lambda(Oil^m_{1988}\rho + KMpipeline^m\phi) \tag{B.1}$$

The density of positive attacks, f_2, is predicted with a negative binomial model using the the same covariates as in the linear regressions.

$$P(Y^m_{by} = 1|X^m_{by}) = \frac{\Gamma(\alpha^{-1} + y)}{\Gamma(\alpha^{-1})\Gamma(y + 1)} \left(\frac{\alpha^{-1}}{\alpha^{-1} + \mu}\right)^{-1} \left(\frac{\mu}{\mu + \alpha^{-1}}\right)^{y},$$

where $\Gamma(\cdot)$ is the gamma integral, α^{-1} is a count of attacks, and $\mu = exp(\delta_1 elect_{by} +$

[2] We do not currently have a good measure of electricity infrastructure by municipality.

$\delta_2 elect_{(b-x)y} + \mathbf{X^m_{by}}\rho + \lambda^m + \gamma_y + t\phi_1 + t^2\phi_2 + \epsilon^m_{by})$ specifies the covariates.

Our estimation of this model is complicated by our desire to include fixed-effects. We choose a Logit link to do this over the Probit link as Logit is better suited to estimate fixed-effects; according to Cameron & Trivedi (2005),"[f]ixed effects estimation is possible for the panel Logit model, using the conditional MLE, but not for other binary panel models such as panel Probit." There is a debate in the econometrics literature regarding the estimation of fixed-effects parameters with count models because of "incidental parameters." According to Hausman et al. (1984), the Poisson count model estimates unbiased coefficients with fixed-effects, but the data must not be over dispersed. Allison and Waterman (2002) and Guimaraes (2008) show, when estimating a negative binomial model with conditional MLE, the time-invariant effects are not accounted for in the traditional way, which biases the estimates. However, Hausman et al. (1984) suggest the bias is small.

B.1.10 Zero-Inflated Count Model Results

Estimating Equation B.1, we find that an average municipality in the three months before a national election is $e^{(0.18194)} = 1.1995$ times more likely to experience an attack (Table B.17). In other words, there is a 20% increase in the number of attacks on energy infrastructure. This result is reinforcing of the results we find using the OLS specification. However, unlike our main OLS specification, we find no effect during the month of a national election nor during the individual elections. Unfortunately, our panel contains mostly zeros, so estimating by MLE poses some challenges to get the model to converge. The models do not converge when we try to split the models out by attack type. The models do not converge because there are too few positive attacks to estimate using MLE. For example, there are only 70 observed oil infrastructure attacks in a panel of over 300,000 observations. The large number of zeros also creates a problem for the bootstrap command. In cases where the bootstrap sample does not capture all of the attacks, or the majority, the sample does not converge. For this reason, we use robust standard errors again, clustered at the municipality level.

Table B.17: Non-Linear Model Specification Results

Panel A: National Elections Pooled	
	Atks
No. energy infrastructure attacks	
Nat'l election month	0.17169
	(0.11564)
Nat'l election next 3 months	0.18194*
	(0.08503)
Observations	200013

Panel B: Presidential Elections	
	Atks
No. energy infrastructure attacks	
Presidential election month	0.23984
	(0.28363)
Presidential election next 3 months	0.16483
	(0.24725)
Observations	102399

Panel C: Congressional Elections	
	No. Atks
No. energy infrastructure attacks	
Congressional election month	-0.07777
	(0.32761)
Congressional election next 3 months	-0.19881
	(0.24184)
Observations	111969

Panel D: Council Elections	
	Atks
No. energy infrastructure attacks	
Council election month	-0.15904
	(0.31471)
Council election next 3 months	0.02724
	(0.18452)
Observations	87087

Note: The dependent variables are the binary indicator of attacks, conflict month, and three scaled count variables indicating the number of attacks per million inhabitants: total, oil, and electricity attacks. Robust standard errors are clustered at the municipality level. *p<0.05, ** p<0.01, ***p<0.001

B.1.11 Sensitivity analysis on Measure of Violence

We used a scaled measure of attacks in our main results, attacks per million inhabitants to put all of the observed attacks in the same relative unit. To demonstrate that this result does not drive our result, we also estimate the main result using an unscaled measure of attacks (Table B.18).

Table B.18: Impact of national elections on the likelihood, intensity, and nature of energy infrastructure attacks by insurgent groups, FARC and ELN, using an unscaled measure of attacks.

	Atks	Oil Atks	Electricity
Nat'l election month	0.00159	-0.00014	0.00173*
	(0.00092)	(0.00026)	(0.00084)
Nat'l election next 3 months	0.00169**	0.00030	0.00142*
	(0.00063)	(0.00023)	(0.00056)
Observations	200013	200013	200013
Control months mean	0.00074	0.00011	0.00062
Standard errors	(0.01671)	(0.00484)	(0.01573)
Number control months	121000	121000	121000

Note: The dependent variables are count variables (unscaled) of the number of attacks: total, oil, and electricity. National elections include presidential, presidential runoff, national legislature, departmental assembly, and municipal council elections. Variables not shown are municipality fixed-effects, time-invariant controls, time-varying controls, quadratic time trend, and year fixed-effects. Standard errors, shown in parentheses, are calculated with a paired, municipality-cluster bootstrap method, replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

B.1.12 Supplementary Voter Turnout Results

To test the effect of the increased attacks on the oil sector that we found in our main results, we consider the vote data from the municipal council and departmental assembly elections. Though municipal council and departmental assembly elections occur on the same day in the same location, ballots for each race are cast separately (Taylor, 2011). We test turnout for each election against the attacks that took place on that day. Tables B.19-B.20 show that oil attacks occurring during the month of an election are not significantly correlated with voter turnout. The sign on the coefficient is positive, suggesting a possible increase in voter turnout, but again, we do not find a significant relationship.

Table B.19: Impact of likelihood and intensity of normalized attacks on voter turnout for municipal council elections.

	Voter Turnout			
Probability of atk	0.00000			
	(0.00004)			
Probability of atk 3 months to election	0.00001			
	(0.00002)			
Atks per million inhabitants		-0.00004		
		(0.00014)		
Atks 3 months to election		-0.00007		
		(0.00007)		
Oil atks per million inhabitants			0.00003	
			(0.00040)	
Oil atks 3 months to election			-0.00016	
			(0.00028)	
Electricity atks per million inhabitants				-0.00001
				(0.00020)
Electricity atks 3 months to election				-0.00003
				(0.00009)
Observations	6699	6699	6699	6699

Note: The dependent variable used is voter turnout, approximated as the number of votes scaled by the municipal population, for municipal council. Variables not shown are municipality fixed-effects, quadratic time trend, and year fixed-effects. Paired, cluster bootstrapped standard errors in parentheses — replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

Table B.20: Impact of likelihood and intensity of normalized attacks on voter turnout for departmental assembly elections.

	Voter Turnout			
Probability of atk	-0.00001			
	(0.00004)			
Probability of atk 3 months to election	0.00003			
	(0.00003)			
Atks per million inhabitants		-0.00002		
		(0.00016)		
Atks 3 months to election		-0.00008		
		(0.00008)		
Oil atks per million inhabitants			0.00012	
			(0.00042)	
Oil atks 3 months to election			-0.00019	
			(0.00032)	
Electricity atks per million inhabitants				-0.00006
				(0.00020)
Electricity atks 3 months to election				-0.00004
				(0.00009)
Observations	6699	6699	6699	6699

Note: The dependent variable used is voter turnout, approximated as the number of votes scaled by the municipal population, for departmental assembly.Variables not shown are municipality fixed-effects, quadratic time trend, and year fixed-effects. Paired, cluster bootstrapped standard errors in parentheses — replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

B.1.13 Sensitivity analysis on vote counts

In this section we show the correlation regressions between vote count against normalized attack variables (e.g., attacks per million inhabitants). We find no significant correlation between the electricity attacks and reduced vote count for the presidential and municipal council elections (Tables B.21-B.22). We do see a significant negative correlation between vote count and electricity attacks three months prior to departmental assembly elections (Table B.23). This result indicates that we may not have had enough power to estimate an increase in electricity attacks in our main specification. However, since we do not see a symmetric reduction in vote count for municipal council elections, which occur on the same day in the same location though on a different ballot, we are cautious to make any strong conclusions.

Table B.21: Impact of likelihood and intensity of attacks on vote counts for presidential elections.

	Vote Count			
Probability of atk	-10059.9			
	(11021.1)			
Probability of atk 3 months to election	-19430.6			
	(15169.9)			
Atks per million inhabitants		-4216.0		
		(3874.2)		
Atks 3 months to election		-283.1		
		(1614.8)		
Oil atks per million inhabitants			11955.0	
			(15208.3)	
Oil atks 3 months to election			3418.8	
			(7573.6)	
Electricity atks per million inhabitants				-6142.7
				(4010.9)
Electricity atks 3 months to election				-347.8
				(1667.9)

Note: The dependent variable used is raw vote counts for presidential elections.Variables not shown are municipality fixed-effects, quadratic time trend, and year fixed-effects. Paired, cluster bootstrapped standard errors in parentheses — replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

Table B.22: Impact of likelihood and intensity of normalized attacks on vote counts for municipal council elections.

	Vote Count			
Probability of atk	6281.6			
	(6116.6)			
Probability of atk 3 months to election	-13583.8			
	(14716.7)			
Atks per million inhabitants		4225.1		
		(3625.7)		
Atks 3 months to election		-627.8		
		(1288.2)		
Oil atks per million inhabitants			4131.2	
			(8799.5)	
Oil atks 3 months to election			2870.6	
			(4988.9)	
Electricity atks per million inhabitants				-928.1
				(5034.4)
Electricity atks 3 months to election				-2293.7
				(1284.5)

Note: The dependent variable used is raw vote counts for municipal council.Variables not shown are municipality fixed-effects, quadratic time trend, and year fixed-effects. Paired, cluster bootstrapped standard errors in parentheses — replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

Table B.23: Impact of likelihood and intensity of normalized attacks on vote counts for departmental assembly elections.

	Vote Count			
Probability of atk	283.9			
	(1376.3)			
Probability of atk 3 months to election	480.7			
	(2677.4)			
Atks per million inhabitants		3440.7		
		(3044.9)		
Atks 3 months to election		-544.5		
		(1164.7)		
Oil atks per million inhabitants			3168.9	
			(6348.2)	
Oil atks 3 months to election			2984.7	
			(3956.9)	
Electricity atks per million inhabitants				-1491.3
				(4449.9)
Electricity atks 3 months to election				-2186.2*
				(985.6)

Note: The dependent variable used is raw vote counts for departmental assembly. Variables not shown are municipality fixed-effects, quadratic time trend, and year fixed-effects. Paired, cluster bootstrapped standard errors in parentheses — replicated 500 times. *p<0.05, ** p<0.01, ***p<0.001

B.1.14 *Summary Statistics for Additional Counterfactual Windows*

Table B.24: Summary Statistics for Counterfactuals

Panel A: 10 month counterfactual				
	Mean	Std. Dev	Min	Max
Conflict month	0.00456	0.0674	0	1
No. energy infrastructure attacks	0.00586	0.0958	0	6
Atks per million inhabitants	0.000843	0.0195	0	2.187
No. oil sector attacks	0.00138	0.0440	0	3
Oil atks per million inhabitants	0.000152	0.00860	0	2.187
No. electricity sector attacks	0.00433	0.0823	0	6
Electricity atks per million inhabitants	0.000677	0.0173	0	1.912
Population of municipality (ten thousands)	1783.6	10107.6	9.946	274754
WTI dollar per barrel oil	37.07	23.93	12.61	109.5
Oil production, hundred thousand barrels/day, 1988	0.00338	0.0544	0	1.627
Thousands of KM pipeline in muncipality	40.08	115.4	0	1578.2
Monetary value of oil production	0.125	2.403	0	178.2
Monetary value of 1000 KM oil pipeline	1485.9	5180.9	0	172864.6
Observations	174174			
Panel B: 11 month counterfactual				
	Mean	Std. Dev	Min	Max
Conflict month	0.00461	0.0678	0	1
No. energy infrastructure attacks	0.00590	0.0959	0	6
Atks per million inhabitants	0.000847	0.0193	0	2.187
No. oil sector attacks	0.00139	0.0439	0	3
Oil atks per million inhabitants	0.000150	0.00838	0	2.187
No. electricity sector attacks	0.00437	0.0827	0	6
Electricity atks per million inhabitants	0.000683	0.0173	0	1.912
Population of municipality (ten thousands)	1783.6	10107.6	9.946	274754
WTI dollar per barrel oil	37.03	23.55	12.61	109.5
Oil production, hundred thousand barrels/day, 1988	0.00338	0.0544	0	1.627
Thousands of KM pipeline in muncipality	40.08	115.4	0	1578.2
Monetary value of oil production	0.125	2.390	0	178.2
Monetary value of 1000 KM oil pipeline	1484.4	5151.3	0	172864.6
Observations	187572			
Panel C: 12 month counterfactual				
	Mean	Std. Dev	Min	Max
Conflict month	0.00455	0.0673	0	1
No. energy infrastructure attacks	0.00579	0.0946	0	6
Atks per million inhabitants	0.000825	0.0190	0	2.187
No. oil sector attacks	0.00133	0.0429	0	3
Oil atks per million inhabitants	0.000145	0.00817	0	2.187
No. electricity sector attacks	0.00431	0.0818	0	6
Electricity atks per million inhabitants	0.000667	0.0169	0	1.912
Population of municipality (ten thousands)	1783.6	10107.6	9.946	274754
WTI dollar per barrel oil	37.07	23.23	12.61	109.5
Oil production, hundred thousand barrels/day, 1988	0.00338	0.0544	0	1.627
Thousands of KM pipeline in muncipality	40.08	115.4	0	1578.2
Monetary value of oil production	0.125	2.382	0	178.2
Monetary value of 1000 KM oil pipeline	1485.8	5132.9	0	172864.6
Observations	200013			
Panel D: 13 month counterfactual				
	Mean	Std. Dev	Min	Max
Conflict month	0.00452	0.0671	0	1
No. energy infrastructure attacks	0.00572	0.0935	0	6
Atks per million inhabitants	0.000819	0.0188	0	2.187
No. oil sector attacks	0.00131	0.0425	0	3
Oil atks per million inhabitants	0.000144	0.00804	0	2.187
No. electricity sector attacks	0.00426	0.0808	0	6
Electricity atks per million inhabitants	0.000663	0.0169	0	1.912
Population of municipality (ten thousands)	1783.6	10107.6	9.946	274754
WTI dollar per barrel oil	37.02	22.89	12.61	109.5
Oil production, hundred thousand barrels/day, 1988	0.00338	0.0544	0	1.627
Thousands of KM pipeline in muncipality	40.08	115.4	0	1578.2
Monetary value of oil production	0.125	2.370	0	178.2
Monetary value of 1000 KM oil pipeline	1483.6	5104.8	0	172864.6
Observations	212454			
Panel E: 14 month counterfactual				
	Mean	Std. Dev	Min	Max
Conflict month	0.00450	0.0669	0	1
No. energy infrastructure attacks	0.00567	0.0929	0	6
Atks per million inhabitants	0.000820	0.0192	0	2.187
No. oil sector attacks	0.00131	0.0424	0	3
Oil atks per million inhabitants	0.000146	0.00817	0	2.187
No. electricity sector attacks	0.00421	0.0802	0	6
Electricity atks per million inhabitants	0.000662	0.0173	0	1.912
Population of municipality (ten thousands)	1783.6	10107.6	9.946	274754
WTI dollar per barrel oil	36.96	22.68	12.61	109.5
Oil production, hundred thousand barrels/day, 1988	0.00338	0.0544	0	1.627
Thousands of KM pipeline in muncipality	40.08	115.4	0	1578.2
Monetary value of oil production	0.125	2.361	0	178.2
Monetary value of 1000 KM oil pipeline	1481.3	5084.7	0	172864.6
Observations	224895			

Note: Statistics based on data from 1908-2011 using a different national election counterfactual sample constructed.