

Envisioning a Lower-Carbon Economy:  
An Examination of the Economic Characteristics which Decrease Emissions in Vehicles,  
Residential Buildings, and Electricity Generation

by

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## DISSERTATION ABSTRACT

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Title: Envisioning a Lower-Carbon Economy: An Examination of the Economic Characteristics which Decrease Emissions in Vehicles, Residential Buildings, and Electricity Generation

Scholars, governments, and other policy analysts have made arguments about which characteristics in an economy will decrease fossil fuel use and resulting carbon emissions. In this dissertation, I examine empirical evidence from the United States to assess the actual effect of these characteristics on carbon emissions. In empirical chapter one, I run panel regression models to assess the effects of increased retail gasoline prices, increased vehicle fuel efficiency, an increased share of workers working from home, and an increased share of workers commuting on public transit on emissions from fossil fuel use in vehicles. In empirical chapter two, I run panel regression models to assess the effects of increased energy efficiency and increased residential natural gas retail prices on emissions from fossil fuel use in residential buildings. In empirical chapter three, I compare electricity consumption trends in Texas and California, over the period 2001 to 2021, to assess which characteristics of an economy (or of the surrounding society) decrease electricity demand – making it easier to meet demand entirely with non-carbon electricity supply.

I find that increased vehicle fuel efficiency and increased retail gasoline prices decrease vehicle emissions. Increased residential building energy efficiency and increased residential natural gas retail prices decrease residential building emissions. Finally, people living in more temperate climates, higher retail electricity prices for commercial and industrial use, and (possibly) increased residential building energy efficiency decrease demand for electricity.

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## DEDICATION

For humankind. We can stop climate change, together.

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## Introduction

Society must stop emitting greenhouse gases to avoid the worst possible effects of climate change. Such decarbonization involves several difficult steps. Large government outlays may be needed to change the economy to use less fossil fuels (Aronoff et al 2019). Potential changes to the economy must also be beneficial to a large enough subset of the population to mobilize a mass coalition which is supportive of, or at least neutral towards, the changes (Ibid; Cullenward and Victor 2020). Before even this, however, it is necessary to determine which changes to the economy would decrease emissions – and which policies would result in such changes.

People who are intent on decarbonizing the economy often skip over this first step – perhaps because, as I discuss below, most thinkers who are interested in decarbonizing the economy believe in one of a few paradigms concerning the causes of fossil fuel use. Each paradigm points to certain conclusions about which changes to the economy would reduce emissions, and about which policies would affect such changes. Adherents of any of the paradigms thus implicitly believe the policies necessary to decarbonize the economy have already been logically deduced -- even without extensive empirical evidence that these policies actually decarbonize the economy.

However, the fact that a story is *logical*, according to certain premises, does not make it *true*. Economies are complex and hard to fully predict (York and Bell 2019); thus, the effects of policies on the economy and, ultimately, emissions are hard to predict. Real-world evidence is necessary to determine the effect that particular policies actually have on the economy and emissions. Yet, with some notable exceptions (for example, Herring 2006; Prasad and Munch

2012; Greene 2012; York and McGee 2016; Szasz 2023), there has not been enough work done determining the actual effect of different policies, and/or changes to the economy, on emissions.

In this dissertation, I conduct new empirical research on the effect of certain characteristics of an economy, which policies might aim to induce, on emissions. My first empirical chapter uses panel regression models to test the effects of different characteristics of the vehicle transportation system on carbon emissions from fossil fuel consumption in vehicles. My second empirical chapter uses regressions models to test the effects of different characteristics of residential buildings on carbon dioxide emissions from fossil fuel use in buildings. My third empirical chapter compares the systems of electricity provision in Texas and California to determine which characteristics of California's system are limiting electricity demand in the state and, by extension, which characteristics of any economy will decrease electricity demand; this is an important question because electricity demand must be limited to levels which can be met entirely with supply from low-carbon sources. I hope my findings contribute to the empirical literature examining which policies, or which changes to an economy, actually result in lower emissions.

In the following pages, I discuss the existing literature on emission reduction in more detail and argue that more empirical literature is needed examining the effects of different policies on emissions. I then outline the studies undertaken in the dissertation's empirical chapters.

### [Literature on reducing emissions](#)

Literature on policies to reduce emissions can be separated into four categories. First, government agencies and policymakers have divided the task of decarbonizing into a series of specific technological or fiscal barriers that must be overcome and have theorized policies to

overcome these barriers. Second, economists have conceptualized economic activity as utility-maximizing behavior of rational actors on a market and have argued that climate change results from a “market failure” in which fossil fuel producers and consumers do not pay the full cost of their fossil fuel use. These economists argue that the ideal solution to decrease carbon use is to implement a tax or emission trading scheme which forces those using carbon to pay the full costs of its use. Third, left-wing social scientists have argued that the capitalist economic system, or other interlocking social systems, are to blame for climate change and other ecological problems. Some of these social scientists believe that these social systems will need to be abolished and replaced wholesale to stop climate change or other ecological problems. However, other left-wing social scientists believe that policies may be effective – if policymakers consider which behaviors are incentivized under current market conditions, within the capitalist economic system, and change market conditions to incentivize different behavior.

Fourth, there is a scholarly literature which empirically evaluates the effect of previously adopted climate policies on energy use or emissions. This literature finds that carbon taxes and emission trading schemes decrease emissions, if only marginally. The efficacy of other climate policies varies. This literature is essentially the empirical check on the three theoretical literatures above – checking whether their theoretical claims about which policies will decrease emissions are borne out. Given its importance, this literature is currently too small: too few studies have examined existing empirical evidence to evaluate which types of policies actually reduce emissions, in practice. My dissertation helps to rectify this problem by empirically examining the effect of different characteristics of an economy, which policies could aim to induce, on emissions. Below, I briefly discuss the reasons many policymakers and academics are

interested in reducing carbon emissions, the four literatures concerning emission reduction policies, and the need for more scholarship empirically testing such policies.

### Reasons to reduce emissions

Burning fossil fuels for energy produces gaseous carbon molecules as a byproduct; as global society has burned ever more fossil fuels for energy, ever more carbon molecules have been released into the atmosphere. This has increased the concentration of carbon molecules in the atmosphere. Gaseous carbon molecules in the atmosphere increase “radiative forcing” – the amount of solar radiation hitting any spot on Earth at any moment in time – increasing Earth’s surface temperature. The greater the concentration of carbon molecules in the atmosphere, the greater the “radiative forcing”, and the more surface temperature increases. Thus, as global society has burned steadily more carbon emissions, Earth’s surface temperature has risen – and the temperature will continue to rise as long as we continue to burn fossil fuels and put more gaseous carbon molecules into the atmosphere (Pachauri et al 2014).

Human-induced increases in average surface temperatures – generally called “global warming” or “climate change” – will have potentially dire effects on global society. If society is sensitive to changes in ecological conditions, as a large literature suggests (Hsiang et al 2013, Burke et al 2015), then we would expect that the more climate change happens, the larger the effects will be on society. Already, climate change may have caused natural disasters (Klinenberg et al 2020), which in turn may have played a role in instances of social collapse and conflict such as the Syrian Civil War (Kelley et al 2015). Projections suggest that enough warming, relative to present, could make it impossible to grow staple crops such as wheat, rice, and corn in traditional breadbaskets and could leave areas such as southeastern China, the southeastern United States, and northern India seasonally too hot for human habitation. Such

changes could cause conflict (King et al 2015) or mass migration. One study finds that, without significant reductions in greenhouse gas emissions, “accounting for expected demographic developments... ~3.5 billion people (roughly 30% of the projected global population...) would have to move to other areas” in the next 50 years to continue living in humans’ usual ecological niches (Xu et al 2020: 11352).

What would be the effect on society of global disruptions in the production of staple crops, of increased extreme weather events, of increased conflicts, and of mass migrations of billions of people? It is hard to imagine anything but catastrophic results. Many scientists, governments, and social movements have come to similar conclusions, leading them to advocate for massive reductions in fossil fuel use. If society reduces fossil fuel use enough, they hope, we can avoid catastrophic climate change.

Many policymakers and academics view targeted economic and energy policies as a potential avenue to reduce fossil fuel emissions – though, as we will see, policymakers and academics disagree about which policies are effective at decreasing fossil fuel use. In the sections below, I discuss the policymaker and academic literatures on policy options to reduce carbon emissions.

### Policy literature on emissions reduction

Some city, regional, and state governments have created emission reduction goals for their jurisdictions. These goals are generally declarations that the jurisdiction will reduce emissions x amount, by y year, relative to emissions in some reference year. For example, a city might aim to reduce emissions 90% by 2035, relative to a 2005 baseline. These jurisdictions will sometimes produce documents which outline policies which could be adopted to decrease fossil

fuel use, and resulting carbon emissions, in their jurisdictions. This is the first literature about policies to reduce carbon emissions.

When discussing decarbonization, this first literature often separates energy generation and consumption into several “sectors”:

- “Vehicle transportation” – energy use in vehicles.
- “Buildings” – energy use in buildings. This category is sometimes further separated into energy use in “residential buildings,” where people live, and “commercial buildings,” where businesses operate.
- “Industry” – energy use in industrial processes, such as the production of plastic, cement, steel, and glass.
- “Electricity generation” – the various processes which produce electricity, including renewable generation and the burning of fossil fuels to generate electricity.

For an example of this categorization system, see the Obama White House’s “Vision for 2050”, chapter four (US White House 2016).

The policymaker literature considers how each sector must change if our economy is to stop burning fossil fuels for energy. Policy specialists generally believe emissions from on-location energy use in vehicles, residential and commercial buildings, and industrial processes must be reduced to zero – a goal which, they hypothesize, might be achieved by electrifying energy uses which can be powered with electricity (Ibid), and by finding creative workarounds for other energy uses.

In addition to electrifying energy uses, climate policy specialists also aim for all electricity to be generated by low-carbon sources, such as wind and solar power (Ibid).

Electrification is only a means of decarbonizing the economy if few emissions are created while generating electricity.

Although policymakers in states like California are aiming to electrify energy use as fast as possible, in the meantime they are also trying to reduce on-location fossil fuel use in buildings, vehicles, and industry through other means, such as making cars and appliances more energy efficient, and capping fossil fuel use or increasing its price (for examples, see policies discussed in Taylor 2017, Taylor 2018).

This literature makes comprehensive lists of the technical or fiscal problems which (policymakers believe) must be solved, in each sector, to achieve the sectoral goals explained above. For example, to eliminate on-site emissions in buildings, buildings must be transitioned from using fossil fuels to using electricity for heating, and this goal must be achieved using available government funds. Potential policies are seen as “solutions” to one or more of these “problems” (for examples, see Lovins 2004 or Massachusetts 2022). To return to our previous example, instituting building codes which require new buildings to only have electric building appliances might induce building electrification, and scaling electrification through these means, rather than government spending, fits within government’s limited budget.

#### [Economists’ theory of emission reduction](#)

Academics have also written about which policies might facilitate decarbonization, but they think about the problem very differently. Academics generally think about the people or institutions that consume fossil fuels: companies seeking to maximize profits and individuals seeking maximum comfort at minimum cost. Academics have models of how companies and people behave, and therefore, how the same will respond to different types of policies. Therefore,

academics often debate which *types of policies* will induce companies and people to burn fewer fossil fuels.

The second literature concerning options for emission reduction comes from a subset of academics: economists using the neo-classical model of an economy. These economists believe the most efficient, and therefore optimal, outcomes are achieved when the firms producing a good have to bear the full cost of production, and then are allowed to sell the good at any price. In such a situation, there will be some price at which the amount the firm supplies exactly matches the demand for the good. At this price point, the firm produces some number of goods and sells them for more than the full cost of production, making a return on investment. The consumers, collectively, decide it is worthwhile to trade some amount of money for the good, taking into account the full costs of production. There is neither a shortage of goods, relative to demand, nor a surplus that cannot be sold to anyone. In such a situation, the economists believe, optimal efficiency has been achieved, leading to the best possible outcome for the market and society as a whole.

The issue with fossil fuel use, in this view, is that the producers do not have to pay the full cost of burning fossil fuels, or of selling the consumer products which burn fossil fuels. Firms can make and sell goods at below their full cost, allowing them to sell more goods and profit more. Meanwhile, consumers pay less for the good, which, again, incentivizes more consumption. Instead, many of the “costs” of producing the good – the negative effects of climate change – will be borne by other people who neither made nor bought the good. This is what economists call an “externality.” (Nordhaus 2008; Stern 2007).

Economists’ solution to this problem is to “internalize” the “externality” by increasing the market price of fossil fuel use to match the “true” cost of fossil fuel use. Economists believe

any climate policy will necessarily increase or decrease the cost of using fossil fuels to some extent, but they generally believe that the best policy is one that directly changes the price of fossil fuel use – either through a tax on fossil fuel use or through an emissions trading scheme (colloquially called “cap and trade”; Tietenberg, 2013). Of course, economists debate both the ideal stipulations of an actual carbon pricing policy (Ibid) and the externalized “cost” of emitting a unit of carbon (Nordhaus 2008; Stern 2007).

### Left-wing social science theories

The third literature concerning emission reduction comes from other academics: left-wing social scientists who blame the economic system of capitalism – or another, interlocking social system such as “patriarchy” or “settler-colonialism” –for environmental problems. Marxist scholars have argued for decades that, in a capitalist society, decisions about production of goods are mostly made by companies whose goal is to maximize profit. These companies will cause environmental harm if doing so increases their short-term profit margin – which it often does. Thus, environmental harms in our society are not incidental, but rather, are often a result of the capitalist economic system through which we produce and distribute goods (Schnaiberg and Gould 1994; O’Connor 1988, 1998; Foster 2000; Clark and York 2008; Foster, Clark, and York 2011).

Other left-wing academics argue that capitalism is tied up with other social systems which, they believe, are just as much to blame for environmental harm in our society. Ecofeminists argue that modern capitalist societies’ destruction of the environment is intimately tied to the oppression of women (Merchant 1980; Bell et al 2020). Environmental humanities scholars have argued that the social institutions of the slave trade and the plantation were crucial to the creation of capitalism and the subsequent environmental harm capitalism created (Murphy

and Schroering 2020). Theorists of settler-colonialism argue that settlers in the Americas and elsewhere, beyond being capitalists, also believed in settler-colonialist ideology – which included a willingness to destroy nature (McKay et al 2020).

Many of these left-wing scholars appear to believe that the economic system of capitalism – and possibly the social systems connected to it – will need to be completely abolished and replaced with new systems to stop environmental problems (e.g. Foster 1999; Bell et al 2020). For example, Bell et al (Ibid: 4) state it is an

*“[assumption] that [has] not thus far been empirically demonstrated: that authoritarian-, imperial-, and/or capital-led forces exist with sufficient motivation to lead a global decarbonization; that such pathways would in fact be easier and faster than more democratic and inclusive ones; and that a decarbonization effort brought about via hegemonic political styles could ever be truly sustainable from an ecological and social perspective.”*

However, some left-wing scholars are open to the possibility that, absent the total abolition of the capitalist economic system or associated social systems, policies may be effective at decreasing environmental harm, including fossil fuel use (see, for example, O’Connor 1988, 1998). These scholars generally believe that, to decrease emissions, policymakers will have to identify the mechanisms through which existing social systems cause emissions – and design interventions which affect these mechanisms to produce lower emissions (York 2012; York and Bell 2019).

For example, York and Bell (2019: 43) argue that as long as fossil fuel use is profitable, within a capitalist economy, companies and consumers will continue to use fossil fuels. They suggest that “Increasing the price of extracting and importing fossil fuels through a carbon fee and dividend”, or capping total energy use (thus increasing prices “due to scarcity”), may be effective at decreasing fossil fuel use – because, within a capitalist economic system, higher

fossil fuel prices may induce lower fossil fuel use. Alternatively, they suggest, restricting fossil fuel extraction may be effective, as this would necessarily limit fossil fuel use.

### Empirical literature

The fourth and final literature on policies to reduce emissions is the scholarly literature empirically evaluating the effects of different climate policies. This literature looks at particular cases and measures the effect of policies, implemented in those cases, on energy use or emissions (see, for example, Greene 2012; Prasad and Munch 2012; Murray and Maniloff 2015). This literature generally finds that carbon taxes and emission trading schemes are associated with emission reductions, while empirical results for other climate policies are more mixed (Sterner 2007; Tietenberg 2013; Szasz 2023).

There has also been scholarship concerning the effects of particular characteristics of an economy on emissions. For example, there are multiple works examining the effect of energy efficiency on aggregate energy use. Some of these works have noted that, over time, increases in energy efficiency coincide with increasing total energy use (Herring 2006; York and McGee 2016) – suggesting that energy efficiency may not be effective as a way to decrease aggregate energy use and resulting emissions.

The issue is that the above literature is still too small. As I have explained, above, policymakers and scholars have presented various theoretical arguments about which climate policies will decarbonize the economy. The task now is to bring the full weight of empirical evidence to assess which, if any, of these arguments are *correct*. Such a task requires that as many instances of climate policy adoption as possible be studied, to check, across many cases, which policies actually seem to reduce emissions. Yet, so far, only a small number of cases of climate policy adoption have been studied to see how effective these policies were at reducing

carbon emissions – and, therefore, to see which theories about climate policy are borne out empirically.

My dissertation research helps to address this gap. In the empirical chapters that follow, I leverage empirical evidence to evaluate the effect of different characteristics of the economy in reducing on-site emissions in vehicles, reducing on-site emissions in residential buildings, and limiting electricity demand.

### Organization of Dissertation

Below, I discuss how I evaluate the effect of economic characteristics on emissions or energy use in each empirical chapter. Empirical chapter one uses panel regression models to examine the effect higher retail gasoline prices, increased vehicle fuel economy, an increased share of workers who work from home, and an increased share of workers who commute on public transit, each have on emissions from fossil fuel use in vehicles. Empirical chapter two uses panel regression models to measure the effect of increased retail natural gas prices and increased building energy efficiency on emissions from fossil fuel use in residential buildings. In both empirical chapters one and two, the units of observation are state-years, for the fifty United States, for the years 2008-2019. Empirical chapter three is a comparative case study of electricity consumption in California and Texas over the period 2001-2021. Chapter three leverages this comparison to identify characteristics of an economy, and of the surrounding society, which can limit demand for electricity.

In the sections that follow, I first explain why I take this approach to evaluating the effects of climate policies. I then describe each of the empirical projects I undertake in more detail.

## Approach to studying climate policies

The motivation for this dissertation was my previous research project evaluating the effects of climate policies (Szasz 2023). In that previous research, I sought to leverage empirical data to study which climate policies could significantly decarbonize a modern, carbon-intensive economy like the United States. To answer this question, I ran fixed effect panel regression models. The units of observation were state-years, for the fifty United States, for the years 1997-2017. The dependent variable was carbon dioxide emissions from the consumption of fossil fuels for energy. The independent variables of interest were ten variables which each recorded whether a certain climate policy was in implementation in that state-year. The model included other independent variables to control for a variety of demographic factors which could affect energy use or emissions.

The logic of the regressions was to control for the effects of the various demographic factors on emissions, leaving some amount of the emissions which could not be explained by these factors. The computer is left with a math problem: the amount of emissions that cannot be explained by demographic factors, and information about which of the ten policies was in implementation, for each state-year. The computer solves the math problem to determine how much implementing each policy increased or decreased emissions, on average.

When I ran these regressions, I found that the most effective of the ten tested policies – cap and trade – was associated with about a 6-8% reduction in emissions, controlling for other factors. Others of the ten policies were associated with smaller emission reductions, on average, or even associated with increases in emissions (Ibid). In other words, none of the tested policies had caused significant decarbonization in any of the United States.

In retrospect, this result made sense. How could any of the tested policies cause significant decarbonization in the United States, when we know for a fact that all fifty states still have carbon intensive economies?

However, this line of thinking led me to a new problem. If no single climate policy *has* significantly decarbonized a US state's economy, how can we leverage empirical evidence to evaluate which policies *could* decarbonize an economy?

One possible approach is to measure the effects of characteristics of the economy on emissions, rather measuring than the effects of policies on emissions. No US state has largely decarbonized after adopting any particular climate policy. However, the goal of many climate policies is to change the economy to have various features – more energy efficient appliances, higher retail prices for fossil fuels, etc. – which, policymakers hope, will induce people to use fewer fossil fuels. We know that states vary widely on these structural characteristics and that states' emissions profiles vary widely as well. It is possible that differences in these structural characteristics are largely responsible for differences in states' emissions. By comparing different US states on structural characteristics which might affect emissions, controlling for other possible causes of emissions, and then comparing the states' emissions data, we can test this proposition ourselves.

Intuitively, this approach has a better chance of producing notable results than did my previous models. The problem we have identified with the previous models is that there is no instance in the US in which the passage of a single policy led to a drastic, sudden decrease in emissions; therefore, it makes sense that a model checking whether any policy had such an effect would come up empty-handed. However, as previously stated, emissions *do* vary a great deal, overall, across time and place. There is enough variance in structural characteristics of the

economy across time and space, as well as enough variance in emissions, that it is *possible* we could find that some structural characteristic or other is associated with much lower emissions, controlling for other factors. (If our models *do not* find any such association, that too is informative.)

This modeling approach can also produce results which are meaningful for policymakers. If the results suggest a particular characteristic is associated with much lower emissions, controlling for other factors, this indicates that policies which change an economy to have that characteristic would reduce emissions. For example, if the analysis finds that higher retail fossil fuel prices are associated with lower emissions, then policymakers should enact policies which aim to raise energy prices. In this way, the results can inform future decisions by policymakers.

In this dissertation, I take the above approach to the empirical study of emissions reduction. Empirical chapters one and two use panel regression models, similar to my previous research (Szasz 2023), to examine which factors can decrease emissions from consumption of direct fossil fuels for energy in vehicles and in residential buildings. However, instead of markers of which policies were implemented in which state-year, the independent variables of interest in these regression models are measurements of the structural characteristics of the economy which might affect fossil fuel use, such as the level of energy efficiency of fuel-consuming technologies, or the retail price of fossil fuels.

Empirical chapter three is a comparative case study of electricity consumption in California and Texas over the period 2001-2021. To decarbonize the economy, modern society will most likely need to switch out many technologies which currently burn fossil fuels for electric equivalents, and society will need to source that electricity entirely from low-carbon sources. Currently, a large share of electricity in the United States is produced by burning fossil

fuels. To switch electricity entirely to low-carbon sources, society will need to: generate large amounts of electricity from low-carbon sources, such as wind and solar power; limit electricity demand to a level that can be met entirely with available electricity from low-carbon sources; and ensure that electricity from low-carbon sources (rather than electricity from burning fossil fuels) is used to meet this demand.

The Texas-California comparison can be used to gain empirical leverage into the second of these three tasks: limiting electricity demand to a level that can be met entirely with electricity from low-carbon sources. Over the period 2001 to 2021, both Texas and California saw fairly consistent increases in population and GDP – both of which existing research (e.g. York 2007) has found to be positively correlated with energy consumption. (California’s population increases consistently until about 2017, when it levels out, then starts to decrease in 2021.) Furthermore, both states saw large increases in renewable electricity generation over this period and, again, existing research (York 2012) indicates that increased electricity generation from non-carbon sources generally results in increased overall electricity demand. Thus, we might expect that both Texas and California would see an increase in electricity consumption over the study period, and, indeed, in Texas electricity consumption steadily rose between 2001 and 2021. In California, too, electricity consumption increased between 2002 and about 2008. However, from 2008 to 2021, while GDP, population, and renewable generation in California all increased – which we might expect to cause more consumption – electricity consumption declined.

The purpose of the Texas-California comparison is to identify reasons why electricity consumption did not follow a similar trend in California, over the period 2001-2021, as in Texas. I may discover that the different consumption trends can be partly attributed to features of the states’ economies. If so, other jurisdictions could attempt to change their own economies to have

those features as well, to limit electricity demand. Limiting electricity demand, in turn, may make it easier for the jurisdictions to decarbonize electricity supply.

### Empirical Chapters 1 and 2

Empirical chapters one and two use fixed effect panel regression models to evaluate the effect of structural characteristics in energy-use “sectors” on those sectors’ on-location CO<sub>2</sub> emissions. I am specifically interested in characteristics of these sectors that climate policies aim to change, as an avenue to emissions reduction, such as the retail price of fossil fuels or the energy efficiency of buildings/vehicles. The dependent variables for these models are CO<sub>2</sub> emissions from the on-site consumption of fossil fuels for energy in vehicles and residential buildings, respectively. The models include independent variables to measure the different characteristics of these sectors which climate policies aim to affect; the variables test the effect of changes to these characteristics on sectoral emissions. The models also include independent variables which control for a variety of other characteristics of states which may affect emissions. I include these other variables so I can more accurately pinpoint the effects of the variables of interest on emissions.

The units of observation are state-years, for the fifty United States, for the years 2008-2019. The key independent variables for the vehicle regression models are the real average retail gasoline price in a state-year, vehicles’ average miles per gallon when traveling on highways in the state-year (as a proxy for vehicle fuel efficiency), the percentage of workers who take public transit to work (as a proxy for overall public transit use), and the percentage of workers who work from home. The key independent variables for the residential building models are the real, average retail natural gas price in residential buildings in the state-year and the percentage of a

state's housing units which were built before the year 2000 (as a proxy for the residential building stock's overall energy efficiency).

Both regressions include independent variables to control for various demographic factors that may affect on-site energy use in these sectors, including the size of the population, the share of the population who are dependents, the median household income, the percentage of state residents who live in urban areas, the number of cooling and heating degree days, the percent of residents who believe in man-made climate change, and the cumulative amount of time Democrats have controlled state government since the turn of the century. The vehicle regression models include an independent variable to control for the amount of economic activity in the transportation and shipping sectors in a state-year, while the residential building models include independent variables to control for electricity's share of building energy use, the average number of people per occupied housing unit, and the median number of rooms per housing unit.

### Empirical Chapter 3

My comparative case study of electricity consumption in Texas and California has two components. First, I examine the existing literature to compile a list of reasons other commentators have suggested as to why the states have different electricity consumption trends.

Second, I subdivide electricity consumption in each state into consumption for residential, commercial, and industrial uses. For each category of electricity consumption, I visualize data concerning each characteristic that some commentators attribute the disparate consumption trends to, such as different industries' size over time in the two states, beliefs about man-made climate change, and retail electricity prices. I compare the trends in each of these characteristics to consumption trends to see which characteristics appear to be correlated with

consumption trends. If some characteristic is consistently correlated with consumption – for example, if higher electricity prices are consistently associated with lower electricity consumption – this is evidence that characteristic is driving consumption trends.

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# Empirical Chapter 1: Assessing Economic Determinants of Vehicle Emissions

## Introduction

Currently, most vehicles in the United States burn fossil fuels for energy; this reaction releases fossil fuels as a byproduct. Fossil fuel use in vehicles is one of the major sources of greenhouse gas emissions globally; in 2022, CO<sub>2</sub> emissions from fossil fuel use in vehicles accounted for roughly 34.66% of all carbon dioxide emissions in the United States (US EPA n.d.). Thus, if policymakers wish to greatly reduce total carbon dioxide emissions in the United States, they must find a way to decrease aggregate carbon dioxide emissions from fossil fuel use in vehicles.

Policymakers and scholars have proposed various changes to vehicle transportation which, advocates contend, may reduce fossil fuel combustion and resulting emissions from vehicle use. Four commonly proposed changes are increasing the price of gasoline, increasing the prevalence of working from home, increasing average vehicle miles per gallon (“vehicle fuel economy”), and increasing the prevalence of public transit use. There are theoretical reasons why each of these changes might, or might not, be effective in reducing vehicle emissions. Thus, empirical research is needed to determine which of these changes actually reduce emissions, in practice.

In this chapter, I conduct just such empirical research. I leverage the fact that these four characteristics have varied in the US across different states and years to measure the effect of changes to each of the four characteristics on vehicle emissions. More specifically, I run panel regression models, using data from all fifty United States, from the years 2008-2019, to measure the effects of changing each of the four characteristics on emissions, controlling for other factors. I find that increasing vehicle “fuel economy” (miles per gallon) reduces emissions more than increasing gasoline price, the share of people who work from home, or the share of people who

commute on public transit. That said, higher gasoline prices also reduce emissions, partly by inducing people to drive more fuel efficient vehicles, and partly through other means. On the other hand, my results indicate that increased public transit use for travel to and from work, and possibly increased transit use overall, have little impact on emissions.

### Approaches to reducing on-site emissions in vehicles

Multiple potential approaches to reducing on-site emissions in vehicle transit have been proposed. Proposed approaches include: increasing vehicles' average miles per gallon of gasoline, increasing public transit use, increasing the prevalence of remote work ("work from home"), raising the price of gasoline, and electrifying personal vehicles.

I will not examine the effect of electrifying a greater percentage of vehicles here. If an increasing share of the vehicle fleet is electrified, while the number and fuel efficiency of cars remains the same – and they are driven the same amount – on-location vehicle emissions will necessarily decrease. This is because all electricity to fuel the vehicles would be produced from a remote source, and any emissions associated with generating that electricity would occur remotely, where the electricity is produced. Therefore, electrifying a greater share of vehicles would of course be effective at reducing on-location emissions.

However, jurisdictions are interested in reducing emissions from vehicle transportation in other ways, on top of just electrifying vehicles. Among the proposed methods of decreasing emissions are the other four approaches listed above: increasing fuel efficiency, increasing public transit use, having more people work from home, and increasing the price of gasoline.

Below, I will explain the scholarly arguments for why each approach might or might not be reduce vehicle emissions. Then, in later sections of the chapter, I use empirical methods to test the actual effect of each approach on emissions.

## Fuel efficiency

One proposed method of decreasing on-site vehicle emissions is to increase vehicles' fuel efficiency: their average miles per gallon (US White House 2016; Taylor 2018). The argument for fuel efficiency is simple. Most cars burn gasoline to create energy, which moves the car. If people continue to drive the same distance in cars, but cars need less energy to drive that distance, aggregate energy use in cars will decrease – and, with energy, gasoline use and vehicle emissions. Therefore, increasing vehicles' average miles per gallon may decrease emissions.

However, there is reason to question whether increasing average vehicle miles per gallon would actually decrease gasoline use and emissions. The above reasoning assumes that the amount people drive is constant, while the amount of energy used to drive that distance is potentially variable. What if the amount people drive is not constant, but is instead a trade-off between the amount of time and money people have to spend driving versus the benefits of a trip?

Economists and Sociologists have noted that increasing the energy efficiency of an appliance – the amount it can do with any given energy input – decreases the energy costs associated with one use of the appliance. Because the cost of any one use of the appliance has decreased, people and companies may choose to use more of the product. This has been termed the “rebound effect” or the “Jevons paradox” (Herring 2006, York 2006, Saunders 2013, York and McGee 2016).

According to this logic, increasing vehicles' miles per gallon decreases the amount of fuel needed to make a trip – decreasing the monetary cost of driving. If this is the case, then increasing vehicle fuel efficiency may change people's calculus about the costs and benefits of a trip, pushing people to drive more. This, in turn, would cause fuel efficiency to reduce emissions less than we would expect, based on per-mile energy savings.

## Public transit

A second proposed method of decreasing on-site vehicle emissions is to increase public transit use (see, for example, Aronoff et al 2019). Vehicle travel in personal vehicles, with (at most) a few people inside, is a highly inefficient energy use. Theoretically, energy use from vehicle transportation could be decreased if people used public transportation such as subways, trains, or buses for most vehicle trips. For example, the same bus might be able to transport thirty people, rather than all thirty making the same trip in their own personal vehicles. Their personal vehicles will use less fuel to make that trip than a bus, but not thirty times less – so all thirty people traveling together on a bus rather than driving their own cars will decrease net energy use.

The potential issue with this logic is that public transit use might be added on top of personal vehicle use, rather than replacing it. York (2006; 2012; 2017) has discussed the phenomenon in which the provision of a new energy source does not replace an old energy source; instead, overall energy consumption increases, as people continue to use the old energy source at the previous rate and also begin using the new energy source. The idea is that, within a capitalist market economy, firms' production decisions are made not to minimize energy use, but rather, to maximize profit (Clark and York 2008). Similarly, individual consumers may not make consumption decisions with the aim of minimizing energy consumption, but instead, with some other aim such as maximizing comfort. York (2021: 766) calls these phenomena the “displacement paradox.”

This logic may apply to public transit use. The proponents of public transit use see it as a substitute for personal vehicle use. However, it may be that people who gain access to public transit continue to use personal vehicles for the trips they were previously taking and use public transit to do additional trips. Alternatively, they might switch over to public transportation for some trips, such as going to school or work, but if transit is cheap, this may save the traveler

money – money they spend on additional trips in a personal vehicle. In these ways, it is possible that public transit use will not “displace” personal vehicle use, but rather, be added on top of it.

### Work from home

A third proposed method to decrease on-site emissions from personal vehicle use is to have a larger percentage of the workforce work from home. Travel to and from work accounts for a large proportion of all personal vehicle trips in the United States – about 17% as of 2017 (US Bureau of Transportation Statistics, n.d.). Therefore, theoretically, if a large portion of workers switched from in-person to remote work modalities, total vehicle use in the United States could be reduced significantly.

This potential approach to emission reduction was discussed during the early Covid pandemic, when many people switched to work from home arrangements for the first time. Some of those who made the switch wondered if people being switched to remote work might be decreasing vehicle emissions, and if so, whether maintaining remote work arrangements post-pandemic might be a way to decrease carbon emissions from vehicle transportation long-term (Shreedhar et al 2022).

The worry, once again, is that a switch to remote work might change people’s behavior such that they take more trips for other reasons. This could lead to smaller decreases in the total amount of driving than we would expect, based on the number of people switching to remote work (Ibid). For example, workers who are “working” remotely may take advantage of the remote modality to stop working early and drive somewhere else for some other reason.

### Higher gasoline prices

A fourth proposed method to decrease on-site emissions from personal vehicles is to increase the price of the fossil fuels these vehicles run on. The logic of this method is simple: all else being equal, if the price of a good increases, consumers buy less of it. If we increase the

price of gasoline, people will buy less gasoline and, consequently, use less gasoline in their cars. Carbon emissions from personal vehicle use will decrease (Stern 2007; FHWA 2008; Szasz 2023).

There is, however, a reason that increasing the price of fossil fuels consumed in vehicles might not decrease vehicle use and emissions as much as expected, at least in the US: the country is built out in a way that often forces residents to drive. Metropolitan areas are often divided into residential neighborhoods, where people live, and commercial or business districts, where people work and shop for goods. Walking from the residential neighborhoods to the business neighborhoods is often not feasible, and many metropolitan areas have insufficient public transportation for travel between neighborhoods. Public transit is often even sparser between cities, making it difficult to reach many cities without a car.

In this context, it is not clear how much increasing gasoline prices will decrease personal vehicle use. Presumably, residents would respond to higher prices by buying more fuel efficient cars (FHWA 2008) and by decreasing vehicle use when they can. However, if the built environment makes it difficult for residents to shop, get to school or work, or see friends or family without driving, residents may be forced to continue driving even if gasoline becomes more expensive.

## Data and Methods

In this chapter, I test the effect of the four approaches on emissions from fossil fuel use in vehicles. I use fixed effect panel regression models. The data are US state-years, for all fifty states, for the years 2008-2019. The dependent variable is a measure of emissions from the consumption of fossil fuels for energy in vehicles. The key independent variables of interest are measures of real gasoline prices, average vehicle fuel efficiency, the percentage of workers who

take public transit to work (a proxy for overall public transit use), and the percentage of workers who work from home. The models include controls for a variety of other factors that may affect emissions. The models also control for the the time-invariant effect of being in a certain state, and the location-invariant effect of being in a certain year, on emissions.

The logic of the modeling is that the differences in emissions from fossil fuel use in vehicles between the fifty United States may be partly caused by differences in fuel efficiency, public transit use, the prevalence of working from home, and the price of gasoline, as well as by a variety of demographic factors. After controlling for the other demographic factors we might expect to have an effect on emissions, we are left with state years that have different average vehicle fuel efficiency, different gas prices, different rates of public transit use and working from home, and unexplained differences in vehicle emissions. The computer solves this math problem to determine the average effect of each of these four characteristics of the economy on vehicle emissions.

My models include multiple independent variables of interest in the same model. If I only include one of independent variables of interest at a time, the models may misattribute increases or decreases in emissions to the wrong variable of interest.

Below, I discuss the empirical models in more detail.

#### Units of observation and dependent variable

The units of observation are state-years, for the fifty United States, for the years 2008-2019. The dependent variable is transportation energy-related carbon dioxide emissions: an estimate of the total carbon dioxide emissions in a state-year from consumption of fossil fuels for energy in vehicles, calculated by the US Energy Information Administration.

### Independent variables of interest

My models include four independent variables of interest. The first independent variable of interest is the average, real retail price of gasoline, in 2012 dollars per million BTU, in each state-year, including state and federal fuel taxes but not including sale taxes. The second independent variable of interest is an estimate of the percentage of workers who work from home in each state-year.

The third independent variable of interest is an estimate of the percentage of workers who take public transit to work. I use this variable as a proxy for public transit use. I expect that, in states where a larger share of people commute on public transit, public transit is available and affordable enough that it would also be used for other trips.

The fourth independent variable of interest is vehicles' average miles per gallon when traveling on highways in the state-year. I use this metric as a proxy for average fuel efficiency of cars in the state-year.

### Control variables

My models include independent variables to control for other potential determinants of vehicle use. I include controls for population, because total vehicle use will likely correlate with the size of the population, and percentage of residents living in urban areas, since personal vehicle use will likely vary between urban and rural areas. I control for the age structure of the population – the ratio of children and seniors to adults aged 18 to 64 – because working age people are likely to have different driving habits, compared with seniors or people under 18. I control for mean household income, in 2012 dollars, because households with more disposable income may choose to drive more. I control for heating degree days and cooling degree days because people might respond to very cold or hot temperatures by walking and biking less and driving more.

Another factor that could affect driving behavior is whether states' residents believe in, and worry about, man-made climate change. Residents who believe in the reality of man-made climate change, and are concerned about it, may make lifestyle decisions to limit their carbon footprint – such as cutting down on the amount they drive gas-powered vehicles. To control for the effect of belief in climate change on driving behavior, I include an independent variable estimating the percentage of people who believe climate change is mostly caused by human activities.

Over my study period, states might have passed other climate policies which reduced carbon emissions in vehicle transportation through some other means than pricing, public transit, working from home, or fuel economy. Thus, I also include a variable to control for cumulative Democratic control of a state's government over time, as a proxy for a state's likelihood to pass climate policies – since the Democratic party is far more concerned than the Republican party with reducing carbon emissions (McCright et al 2016).

It is not clear how much control of state government Democrats must have to pass climate policies. It is conceivable that Democrats controlling a state's House, Senate, or Governorship, even without the other two, increases the likelihood of the state passing climate policies. It is also conceivable that control of one house of the legislature, or of the governorship, is not enough. Instead, Democrats might need to control the state House, Senate, and Governorship – what is sometimes termed a “government trifecta” (Ballotpedia n.d.) – to pass climate policies.

Because I do not know which of these possibilities is correct, I create two different variables as proxies for Democratic control of state government and consequent climate policy adoption. I create a continuous variable whose count increases by one for every year since 2001 that Democrats controlled the state's House, one for every year that Democrats controlled the state's Senate, and one for every year that Democrats controlled the Governorship; this variable is

a good proxy for climate policy adoption *if* the likelihood of climate policy adoption increases each time Democrats control either House or the Governorship. I also create a variable whose count increases by one for each year since 2001 that Democrats have had a “government trifecta” in the state: control of the state’s House, Senate, and Governorship, all at once. This variable is a good proxy for climate policy adoption if Democrats need a government trifecta to pass climate policies.

I do not know which variable is a more accurate proxy for climate policy adoption, so I run my models twice – once using the first variable, and once using the second variable. Ideally, the regression results for the variables of interest will be robust to whichever proxy I use for climate policy adoption.

Finally, states in which transportation, shipping, and warehousing businesses make up a large portion of the economy may have more vehicle travel, all else being equal. To control for the prevalence of the transportation and shipping industries in a state, I include a variable measuring the amount of GDP (in 2012 dollars) in these industries in the state-year.

### Main models

My main models (Table 1, Models 1-4) include variables to control, to the best of my ability, for all possible causes of emissions other than the four independent variables of interest.

I take the natural log of all variables.  $\ln(y) = b \cdot \ln(x)$  can fit many different relationships between an independent and a dependent variable, depending on the value of  $b$ . Thus, performing a natural log transformation on both my independent variables and my dependent variable allows the computer find to a best fit line which closely approximates the relationship between the variables in my data. For independent variables that never take a value of zero in my data, I use the transformation  $\ln(y) = b \ln(x)$ . For my independent variables that take a value of zero for any unit of observation, I instead use the transformation  $\ln(y) = b \ln(x+1)$  – since  $\ln(0)$  is undefined.

For the independent variables that receive the transformation  $\ln(y) = b \ln(x)$ , a 1% increase

in the independent variable is associated with a  $b\%$  increase in the dependent variable. For the variables that receive the transformation  $\ln(y) = b\ln(x+1)$ , a 1% increase in the independent variable is associated with a  $b * x/(x+1) \%$  increase in the dependent variable. Variables that receive this latter transformation mostly have values of 10 or more. Thus, for most units of observation,  $b * x/(x+1)$  will be close to  $b$ ; a 1% increase in the independent variable will be associated with approximately a  $b\%$  increase in the dependent variable.

Table 1 Model 1, below, includes variables to control for as many other potential causes of emissions as possible, as well as the independent variables measuring average gasoline price and the percentage of workers who work from home. Table 1 Model 2 includes all four independent variables of interest.

Model 1 measures the effect of a 1% increase in average gasoline price and of a 1% increase in the percentage of workers working from home on emissions, holding everything else constant.

Model 2 also measures the effect of a 1% increase in vehicle fuel efficiency – and of a 1% increase in the percentage of workers commuting on public transit – on vehicle emissions. However, Model 2 may not capture the full effect of gasoline prices on vehicle emissions. Higher gasoline prices may cause people to buy more fuel-efficient cars (so driving will cost less) or to use public transit more often. Because Model 2 includes variables for vehicle fuel efficiency and for the amount of public transit use, this model's gas price variable only captures the effect of gasoline prices on vehicle emissions, through other means than inducing people to buy more fuel efficient cars or use public transit.

Table 1 Models 3 and 4 are the same as Models 1 and 2, respectively, except that Models 3 and 4 operationalize cumulative Democratic control of state government differently. Models 1 and

2 operationalize cumulative Democratic control of state government with a counting variable whose count increases by one every time Democrats control the state’s House, Senate, or Governorship for an additional year; Model 2 uses a variable whose count increases by one each time the Democrats have a “government trifecta” – control of the state House, Senate, and Governorship – for an additional year. I do not know which measure is a more accurate proxy for climate policy adoption. Thus, I run the main models twice – once using each variable for Democratic control of state government – to see whether the results for the variables of interest are robust to how I operationalize cumulative Democratic control of state government.

**Table 1 Model 1**

$$\begin{aligned}
 & \ln(\text{energy – related } CO_2 \text{ emissions in transportation}_{it}) \\
 & = \beta_1 \ln(\text{population}_{it}) + \beta_2 \ln(\text{age dependency ratio}_{it}) \\
 & + \beta_3 \ln(\text{urbanization}_{it}) + \beta_4 \ln(\text{mean household income}_{it}) \\
 & + \beta_5 \ln(\text{heating degree days}_{it} + 1) + \beta_6 \ln(\text{cooling degree days}_{it}) \\
 & + \beta_7 \ln(\text{Dem control of state}_{it} + 1) + \beta_8 \ln(\text{belief in climate change}_{it}) \\
 & + \beta_9 \ln(\text{state GDP in transportation}_{it}) \\
 & + \beta_{10} \ln(\text{average gasoline price}_{it}) + \beta_{11} \ln(\text{pct work from home}_{it}) \\
 & + u_i + w_t + e_{oit}
 \end{aligned}$$

**Table 1 Model 2**

$$\begin{aligned}
 & \ln(\text{energy – related } CO_2 \text{ emissions in transportation}_{it}) \\
 & = \beta_1 \ln(\text{population}_{it}) + \beta_2 \ln(\text{age dependency ratio}_{it}) \\
 & + \beta_3 \ln(\text{urbanization}_{it}) + \beta_4 \ln(\text{mean household income}_{it}) \\
 & + \beta_5 \ln(\text{heating degree days}_{it} + 1) + \beta_6 \ln(\text{cooling degree days}_{it}) \\
 & + \beta_7 \ln(\text{Dem control of state}_{it} + 1) + \beta_8 \ln(\text{belief in climate change}_{it}) \\
 & + \beta_9 \ln(\text{state GDP in transportation}_{it}) \\
 & + \beta_{10} \ln(\text{average gasoline price}_{it}) + \beta_{11} \ln(\text{pct work from home}_{it}) \\
 & + \beta_{12} \ln(\text{average mpg on highways}_{it}) \\
 & + \beta_{13} \ln(\text{pct public transit to work}_{it}) \\
 & + u_i + w_t + e_{oit}
 \end{aligned}$$

**Table 1 Model 3**

$$\begin{aligned}
& \ln(\text{energy} - \text{related } CO_2 \text{ emissions in transportation}_{it}) \\
& = \beta_1 \ln(\text{population}_{it}) + \beta_2 \ln(\text{age dependency ratio}_{it}) \\
& + \beta_3 \ln(\text{urbanization}_{it}) + \beta_4 \ln(\text{mean household income}_{it}) \\
& + \beta_5 \ln(\text{heating degree days}_{it} + 1) + \beta_6 \ln(\text{cooling degree days}_{it}) \\
& + \beta_7 \ln(\text{years of Dem trifecta}_{it} + 1) + \beta_8 \ln(\text{belief in climate change}_{it}) \\
& + \beta_9 \ln(\text{state GDP in transportation}_{it}) \\
& + \beta_{10} \ln(\text{average gasoline price}_{it}) + \beta_{11} \ln(\text{pct work from home}_{it}) \\
& + u_i + w_t + e_{0it}
\end{aligned}$$

**Table 1 Model 4**

$$\begin{aligned}
& \ln(\text{energy} - \text{related } CO_2 \text{ emissions in transportation}_{it}) \\
& = \beta_1 \ln(\text{population}_{it}) + \beta_2 \ln(\text{age dependency ratio}_{it}) \\
& + \beta_3 \ln(\text{urbanization}_{it}) + \beta_4 \ln(\text{mean household income}_{it}) \\
& + \beta_5 \ln(\text{heating degree days}_{it} + 1) + \beta_6 \ln(\text{cooling degree days}_{it}) \\
& + \beta_7 \ln(\text{years of Dem trifecta}_{it} + 1) + \beta_8 \ln(\text{belief in climate change}_{it}) \\
& + \beta_9 \ln(\text{state GDP in transportation}_{it}) \\
& + \beta_{10} \ln(\text{average gasoline price}_{it}) + \beta_{11} \ln(\text{pct work from home}_{it}) \\
& + \beta_{12} \ln(\text{average mpg on highways}_{it}) \\
& + \beta_{13} \ln(\text{pct public transit to work}_{it}) \\
& + u_i + w_t + e_{0it}
\end{aligned}$$

In the equations above, i represents the state, t represents the year,  $u_i$  represents the constant effect of being in a certain state, across years, and  $w_t$  represents the constant effect of being in a certain year, across states.

#### Statistical significance indicators

Some statistical studies sample a larger population and use statistical analysis to find correlations in the sample. These studies often use p-values to assess the likelihood that correlations in the sample hold for the larger population.

This study uses population data. Thus, the correlations in my data *are* the correlations in the larger population. Calculating “p-values” is unnecessary to determine the correlations between variables in the population.

Thus, while I report my regression results' associated "p-values" by convention, I do not use the calculated "p-values" when interpreting my results. Instead, I interpret the correlations between variables based on the sign and magnitude of the regression coefficients.

### Robustness checks

Regression models are large math problems. The researcher feeds the computer a dataset, specifies which variables relate to each other, and specifies many aspects of the relationship between the variables: which variable is the dependent variable, whether the relationship between the dependent variable and particular independent variables is linear. Then, given the dataset, the choice of which variables relate to each other, and the researcher's determination of how the different variables relate to each other, the researcher asks the computer to calculate the sign and magnitude of the relationship between the dependent variable and each independent variable. The danger with a regression model is that, if the researcher feeds the computer inaccurate data, chooses the wrong variables to include in the model, and/or specifies the wrong relationship between variables in the model, the model can yield inaccurate results.

I have been thoughtful about the data I used, the variables I included in my regression models, and the relationships between the variables in those models. However, it is still possible that my choice to include or exclude particular variables skewed my regression results, such that my main model results are incorrect as to the effect of my independent variables of interest on vehicle emissions.

To begin testing this possibility, in Supplement 1 Tables S1 and S2, I run my vehicle regression models again, including only one independent variable of interest per model run. Ideally, these supplementary models will find a similar relationship between my dependent variable and each independent variable of interest, when only including that one independent variable of interest in the model, as my main models find when I include multiple independent

variables of interest in the same model. Such a finding would indicate that my results are at least somewhat robust to my decisions about which independent variables of interest to include in the model.

#### Data sources

I retrieved data on emissions from consumption of fossil fuels for energy within vehicles from the US Energy Information Administration (EIA 2024a). The population in each state, in each year, was estimated by the US Census Bureau; I retrieved these estimates from the Federal Reserve of St. Louis (FRED 2024). I retrieved data on the average motor gasoline price, heating degree days, and cooling degree days in different state-years from the Energy Information Administration's State Energy Data System (EIA 2024b, EIA 2024c). I retrieved the amount of state GDP in transportation and shipping from the US Bureau of Economic Analysis (US BEA 2023).

I retrieved data on the number of vehicle-miles traveled on highways, and on total use of gasoline and gasohol on highways, in each state-year, from the US Federal Highway Administration (FHWA 2024a, 2024b). For each state-year, I divided the number of vehicle-miles traveled on highways by the total highway use of gasoline and gasohol to calculate vehicles' average miles per gallon on highways in that state-year.

I retrieved the number of housing units in urban areas, and the total number of housing units, in the years 2010 and 2020, from the US Census Bureau (Census Bureau 2010, 2020). I divided the number of housing units in urban areas from the total number of housing units to approximate the percentage of the population living in urban areas, in each state, in those years. I then linearly interpolated the data from years 2010 and 2020 to create annual estimates of the percentage of the population in urban areas for every year from 2008 to 2019.

The Yale Climate Communications has created estimates of the percentage of people in

each state, in each year, who believe climate change is mostly caused by human activities; I retrieved the estimates for years 2010 to 2019 from the project’s website and received the 2008 data directly from the project via email (Howe et al 2015; Marlon et al 2022). I constructed the proxy for Democratic control of state government using data on the composition of state legislatures from the National Conference of State Legislatures (NCSL 2011, 2024) and data on governorships from the Inter-university Consortium for Political and Social Research (Kaplan 2021).

A number of my independent variables – my measures of the percentage of workers commuting on public transportation or working from home, of the age dependency ratio, and of mean household income – are estimates from the American Community Survey (ACS 2024a, ACS 2024b, ACS 2024c). The ACS is administered each year to a sample of people in each US state, and the Census Bureau uses survey results to estimate values for the whole population. The ACS calculates population estimates based on a single year of survey data and estimates based on five consecutive years of survey data. For my variables based on ACS data, for the years 2008 to 2017, I use the five-year estimate centered around the current year: I use the five-year estimate for 2006-2010 as my value for 2008, the 2007-2011 estimate as my value for 2009, and so on.

The covid pandemic resulted in large changes to some of the variables I am examining – for example, the prevalence of work-from-home arrangements – so survey data from during the pandemic should not be used to estimate population data from the pre-pandemic period. Thus, I cannot use the method described above to estimate population values for the years 2018 and 2019. Instead, for those two years, I use the population estimates based on just that year of survey data.

## Results

### **Table 1: Effect of characteristics on CO<sub>2</sub> emissions in vehicles**

	Model 1	Model 2	Model 3	Model 4
log(pop_people)	1.01 *** (0.15)	1.00 *** (0.15)	1.04 *** (0.15)	1.01 *** (0.14)
log(age_dep)	0.26 (0.19)	0.34 (0.18)	0.27 (0.19)	0.34 (0.18)
log(pct_urban)	-0.04 (0.31)	0.11 (0.30)	-0.00 (0.31)	0.12 (0.30)
log(house_inc_2012dollars)	0.24 (0.14)	0.12 (0.14)	0.23 (0.14)	0.12 (0.14)
log(hdd + 1)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)	0.01 (0.03)
log(cdd)	-0.02 (0.01)	-0.02 (0.01)	-0.02 (0.01)	-0.02 (0.01)
log(state_dem_c + 1)	-0.00 (0.02)	-0.00 (0.02)		
log(pct_clim_cause_hum)	-0.06 (0.06)	-0.05 (0.06)	-0.08 (0.06)	-0.06 (0.06)
log(gdp_tran_2012dollar)	0.14 *** (0.03)	0.13 *** (0.03)	0.15 *** (0.03)	0.13 *** (0.03)
log(gas_price_2012dollars)	-0.21 ** (0.08)	-0.13 (0.07)	-0.22 ** (0.08)	-0.13 (0.07)
log(pct_work_home)	-0.08 * (0.03)	-0.06 (0.03)	-0.08 * (0.03)	-0.06 (0.03)
log(hw_mpg)		-0.37 *** (0.05)		-0.37 *** (0.05)
log(pct_transit)		-0.01 (0.03)		-0.01 (0.03)
log(dem_trif_c + 1)			0.00 (0.00)	0.00 (0.00)
R <sup>2</sup>	0.24	0.31	0.25	0.31
Adj. R <sup>2</sup>	0.14	0.21	0.15	0.21
Num. obs.	600	600	600	600

Table 1 Models 1, 2, 3, and 4 all find that increases in gasoline prices are associated with decreased vehicle emissions – whether or not the model controls for level of vehicle fuel efficiency

and for amount of public transit use. Models 1 and 3 find that, holding constant the control variables and the percentage of workers who work from home, a 1% increase in real, average retail gasoline price is associated with a statistically significant 0.21-0.22% decrease in on-site vehicle emissions, on average. Models 2 and 4 find that, holding constant all of the above as well as the level of vehicle fuel efficiency and the percentage of workers commuting on public transit, a 1% increase in real average gas price is associated with a non-significant 0.13% decrease in emissions, on average.

The models also find that an increased percentage of workers who work from home is associated with decreased emissions, though the emissions reductions are smaller than those associated with gasoline prices. Models 1 and 3 find that, holding constant the controls and the average gasoline price, a 1% increase in the percentage of workers working from home is associated with a statistically significant 0.08% decrease in vehicle emissions, on average. Models 2 and 4 find that, controlling for the above variables, as well as the level of vehicle fuel efficiency and the percentage of workers who commute on public transit, a 1% increase in the percentage of workers working from home is associated with a non-significant 0.06% decrease in emissions, on average.

Models 2 and 4 also test the effects of vehicle fuel efficiency and public transit use on emissions, all else being equal. Models 2 and 4 find that, all else being equal, a 1% increase in average vehicle miles per gallon on highways is associated with a statistically significant 0.37% decrease in vehicle emissions, on average. The correlations between vehicle fuel efficiency and vehicle emissions in Models 2 and 4 are the highest correlations between any variable of interest and vehicle emissions in any of my four models.

On the other hand, Models 2 and 4 find a negligible correlation between the percentage of

people who take public transit to work and vehicle emissions. Models 2 and 4 find that, all else being equal, a 1% increase in the percentage of people who take public transit to work is associated with a non-significant 0.01% decrease in emissions, on average.

Moving to the controls, all four models (Table 1, Models 1-4) find that a 1% increase in population is associated with approximately a 1% increase in vehicle emissions, while a 1% increase in the quantity of real GDP in transportation industries is associated with a 0.13-0.15% increase in emissions, on average. These results are statistically significant in all four models. All four models also find that real mean household income and the age dependency ratio are positively, but non-significantly, correlated with emissions, on average.

On the other hand, the models find that a 1% increase in the percent of people who believe in man-made climate change is associated with a small (0.05-0.08%) decrease in vehicle emissions, on average. These results are not statistically significant.

The models find that other variables – heating degree days, cooling degree days, and either cumulative measure of Democratic control of state government – have little correlation with emissions. The models find that a 1% increase in any of these four variables is associated with a non-significant 0.00 - 0.02% change in emissions, on average.

In Supplement 1, I ran regression models which only include one independent variable of interest, each (Tables S1 and S2, Models 1-4), to see if these models had similar findings as to the effect of my variables of interest on emissions. The models which include real, average retail gasoline price but not the other independent variables of interest (Tables S1 and S2, Model 1) find that a 1% increase in real, average retail gasoline price is associated with a statistically significant 0.18-0.20% decrease in vehicle emissions, on average. This is similar to the association in the main models which included retail gasoline price and the percentage of workers who work from home

but not average vehicle miles per gallon on highways or the percentage of workers who take public transit to work (main models 1 and 3). The supplementary models and the main models had similar findings concerning the effect of increased vehicle miles per gallon on highways, the effect of an increased percentage of workers working from home, and the effect of an increased percentage of workers who take public transit to work. Collectively, these supplementary model results provide more robustness to my main model results concerning the effect of gasoline price on vehicle emissions (when I do not control for vehicle fuel efficiency), the effect of workers working from home, the effect of vehicle fuel efficiency, and the effect of workers commuting on public transit.

## Discussion

My models yield three major findings. The first finding is that increasing vehicle fuel efficiency is effective at decreasing on-site vehicle emissions. According to Table 1 Models 2 and 4, holding gas price and other determinants of vehicle use constant, a 1% increase in average miles per gallon (on highways) in vehicles is associated with a 0.37% decrease in vehicle emissions.

As previously noted, improved vehicle fuel efficiency makes driving cheaper, and analysts worry that people may respond by driving more – resulting in smaller energy savings than we would expect, based on the improved fuel efficiency (Herring 2006, York and McGee 2016). It is possible that this phenomenon is occurring. However, if so, the empirical evidence suggests that increased fuel efficiency has not spurred sufficient additional driving to offset energy savings from efficiency. Empirically, holding other determinants of vehicle emissions constant, increasing vehicle fuel efficiency does cause a large decrease in carbon dioxide emissions from energy use in vehicles.

The second finding is that increasing gasoline prices decreases on-site vehicle emissions,

both by inducing the use of fuel-efficient vehicles and/or public transit, and by other means. As mentioned above, it is possible that higher gasoline prices could induce people to drive more fuel-efficient vehicles or to use public transit more, which could in turn decrease vehicle emissions; therefore, if we want to assess the full effect of higher gasoline prices on vehicle emissions, we would not want to control for the level of vehicle fuel efficiency or the amount of public transit use.

In Table 1 Models 1 and 3, which do not include the fuel efficiency and public transit variables, the gasoline price variable measures the total effect of an increase in real gasoline price on vehicle emissions. These models found that a 1% increase in the average real price of gasoline was associated with a 0.21-0.22% decrease in vehicle emissions, on average.

In Table 1 Models 2 and 4, which do include the fuel efficiency and public transit variables, the gas price variable measures the effect of an increase in real gas price on emissions, *other than* by spurring changes in vehicle fuel efficiency or public transit use. These models found that a 1% increase in the average, real retail price of gasoline was associated with a smaller 0.13% decrease in vehicle emissions, on average.

Model 1 and Model 3's results indicate that increasing the real price of gasoline does decrease vehicle emissions, and fairly significantly at that – a 1% increase in gasoline price decreases vehicle emissions roughly 0.2%. The disparity between the effect of gas prices when controlling for vehicle fuel economy and transit use (Models 2 and 4), or not (Models 1 and 3), indicates that some of the effect of gas price on emissions occurs by inducing people to drive more fuel-efficient cars or use more public transit. Given that Models 2 and 4, which include the additional variables, find the share of workers commuting on public transit has little effect on emissions, it seems unlikely that gas price is inducing emission reductions by increasing public

transit use. Rather, as Models 2 and 4 found that vehicle fuel efficiency has a large effect on vehicle emissions, it is more likely that higher gas prices decrease vehicle emissions by inducing people to drive more fuel efficient vehicles.

All of that said, the fact that increases in gas prices are associated with decreases in emissions in Models 2 and 4, even controlling for fuel economy and transit use, indicates that higher gas prices also reduce emissions through other mechanisms. For example, it may be that when gasoline is more expensive, people choose to drive less to save money.

The third finding is that a greater share of people commuting to work on public transit – and possibly even more public transit use in general – does not result in lower vehicle emissions, at least in the United States. Table 1 Models 2 and 4 find that a 1% increase in the percentage of workers commuting on public transit is associated with a negligible 0.01% decrease in emissions, on average. Interpreted narrowly, these results suggest that the percentage of workers commuting on public transit has little effect on vehicle emissions in the United States.

Interpreted broadly, this result may indicate that public transit use, in general, is not an effective means of decarbonization. Public transit use for commuting may be positively correlated with public transit use for other purposes. If this is the case, then the share of workers commuting on public transit can be used as a proxy for total public transit use – and the above finding suggests not just that increasing public transit use for commuting has little effect on vehicle emissions, but that public transit use *overall* has little effect on emissions.

This is a counter-intuitive finding, since transporting a large number of people on public transit requires much less energy than transporting the people an equivalent distance in personal vehicles, and since we generally assume that there is some set amount of demand for travel, to be met through one means or another. If this were true, and people used public transit to meet some of

their demand for travel, presumably people would use personal vehicles less, resulting in lower total vehicle energy use and lower vehicle emissions.

As previously explained, the potential issue with this logic is that the provision of cheap and accessible public transit may not induce people to drive less than they would have without public transit, but rather, to drive the same amount and use public transit on top of this driving. People might continue using cars for the same uses as before and might use public transit for additional trips which would otherwise be too inconvenient or expensive. Alternatively, people might switch to public transit for certain trips which would previously have required a car, saving money on gas, and they may use some of the money they save for additional vehicle trips. Model 2 and Model 4's findings concerning commutes on transit and emissions suggest that one or both of these phenomena may be occurring, causing at least public transit use for commutes – if not total transit use – to have little effect on aggregate driving and consequent emissions.

The control variables mostly yield the effects we would expect. Population is positively correlated with total vehicle emissions, all else being equal; this makes sense because we would expect the total amount of driving in a state to scale with the number of people. Average real household income is also positively correlated with emissions – possibly because households with more money can afford to take more short- and long-distance vehicle trips. The real amount of GDP in states' transportation and shipping industries is positively correlated with states' emissions, which is the result we would expect given that economic activity in these industries will presumably involve more vehicle use than economic activity in other industries. A greater share of people in the state believing in man-made climate change is associated with slightly lower vehicle emissions, all else being equal, which, again, we might expect: some people who believe in man-made climate change may make lifestyle decisions to drive less, in order to reduce their carbon

footprint. The reported effect of the percentage of households living in urban areas on carbon emissions is small, and switches signs depending on the model, suggesting that, all else being equal, the percentage of people in a state who live in urban areas has little effect on vehicle emissions.

The only surprising result, among the control variables, is that a greater degree of cumulative Democratic control over state government is not associated with reductions in carbon emissions from energy use in vehicles – no matter which way we operationalize cumulative Democratic control over state government – all else being equal. This may indicate that, beyond policies affecting real gas price, vehicle fuel economy, the prevalence of public transit use, the prevalence of working from home, or any of the demographic factors we have controlled for, other policies which vary between Democratic and Republican governments have had little effect on vehicle emissions.

Overall, the regression results suggest that increasing vehicles' average miles per gallon decreases total gasoline use in vehicles, leading to lower vehicle emissions. Increasing real gasoline prices decreases vehicle emissions, both by inducing people to drive cars with better fuel efficiency, and through other mechanisms. Public transit use for travel to and from work, and possibly public transit use overall, has little effect on vehicle emissions, at least in the United States.

## Conclusion

This study has three major findings. First, other characteristics of vehicle transportation being equal, substituting more fuel inefficient vehicles for more fuel efficient vehicles decreases vehicle emissions. Second, increasing the price of gasoline decreases vehicle emissions – both by incentivizing people to drive more fuel efficient vehicles, and through other means. Third,

increasing the share of people commuting to work on public transit – and possibly increasing the total amount of public transit use – has little effect on vehicle emissions.

Thus, the apparent takeaways for policymakers seeking to decrease vehicle emissions are: to decrease vehicle emissions, vehicle fuel efficiency and gasoline prices should be increased as much as possible. On the other hand, public transit – another frequently discussed approach (Aronoff et al 2019) – appears potentially ineffective at reducing vehicle emissions.

I see a number of directions for future research. First, given that many advocates see public transit use a way to significantly reduce vehicle emissions, more work needs to be done to test whether public transit generally has little effect on emissions – or whether my result was just a rare case in which increased transit does not decrease vehicle emissions.

Second, all else being equal, states in which a higher share of vehicles are electric will have lower on-site emissions from vehicle use – since most emissions associated with electricity use in electric vehicles are released where the electricity is generated, not in the vehicle where the electricity is consumed. Thus, ideally, I would like to include a variable controlling for the share of energy in vehicles provided by electricity – so the models do not mis-attribute to some other factor emission reductions actually caused by vehicle electrification. I could not include such a variable in my models, as I could not find any statistics on share of vehicle energy provided by electricity – or even, for the years 2008 to 2015, on the share of vehicles in each state which are electric. Omitting this control is unlikely to have a major effect on my results as so few vehicles on the road were electric during my study period: in 2019, the final year of my study, hybrids and electric vehicles only accounted for about 2.13% of light-duty vehicle registrations in the United States, and only about 5.22% even in California, a pioneering state on electric vehicles (Alternative Fuels Data Center n.d.). Nonetheless, a follow-up study would be made more rigorous if it could find a way to

control for electric vehicle use.

Third, this study did not assess another proposed approach to reducing vehicle emissions: building institutions that people frequent – schools, workplaces, residential homes, grocery stores, etc. – near each other. Theoretically, if cities were built out this way, more people might walk, bike, or use public transit to travel between the institutions they frequent in day-to-day life, and this might decrease aggregate vehicle miles traveled in personal vehicles. A future study could include a proxy for institutions being located near each other in a regression like mine to check whether locating institutions near each other actually decreases vehicle emissions.

Nonetheless, this study yields important findings: that increasing vehicle fuel efficiency and retail gasoline prices both decrease emissions in vehicles. Policymakers seeking to decrease carbon emissions from vehicles should push automakers to increase vehicle fuel efficiency, and should increase the retail price of gasoline, when possible.

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## Empirical Chapter 2: Assessing Economic Determinants of Residential Building Emissions

### Introduction

Another major source of emissions is fossil fuel use in residential buildings. Many people's residences have appliances which burn fossil fuels for power; as of 2022, CO<sub>2</sub> emissions from using these appliances contributes about 6.61% of total carbon dioxide emissions in the United States (US EPA n.d.). If policymakers wish to fully decarbonize the US economy, they must induce residents to vastly decrease use of fossil fuel appliances. One way to decrease use of fossil fuel-powered appliances is to replace these appliances in the home with electric equivalents, and some jurisdictions aiming to decarbonize their economies have taken this approach; for example, multiple cities in California have adopted building codes which require new houses have only electric appliances. However, policymakers are often interested in reducing building fossil fuel use in other ways, other than by electrifying appliances.

Policymakers have primarily proposed two other changes to residential buildings which might reduce emissions from on-site fossil fuel use: improving building energy efficiency and increasing the price of fossil fuel use in buildings. As with the proposed changes to vehicle transportation, there are theoretical arguments for why each proposed change might, or might not, much reduce emissions. Thus, empirical research is needed to determine the effect of each change on emissions.

In this chapter, I conduct such an empirical study. I leverage the fact that residential building energy efficiency and the residential retail price of natural gas – a fossil fuel often used to power building appliances – have varied in the US across states and years. I run panel regression models, using data from all fifty United States, from the years 2008-2019, to test the effects of increased energy efficiency and increased residential natural gas prices on emissions in residential

buildings, controlling for other potential causes of emissions. I find that both my proxy for increased energy efficiency and my measure of residential natural gas price are negatively correlated with emissions, controlling for other factors. This finding indicates that both increasing residential building energy efficiency, and increasing residential natural gas price, decreases on-site emissions from fossil fuel use in buildings.

### Approaches to reducing emissions

Policymakers and scholars have suggested multiple changes to residential buildings which, they contend, might reduce on-site emissions from burning fossil fuels for energy in buildings. Below, I discuss two potential changes to residential buildings which some policymakers and scholars believe might reduce on-location emissions from energy use: increasing energy efficiency, and increasing the cost of burning fossil fuels to power building appliances.

Another change to buildings which policymakers and scholars have proposed, as a way to decrease on-site carbon emissions, is to electrify heating, cooling, and all other building energy uses (e.g. U.S. White House 2016). However, in this chapter, I am not assessing the effect of building electrification on on-location residential building emissions. Electricity is mostly generated remotely from where it is consumed, and any emissions from generating electricity will be released where the electricity is generated, not where it is consumed. Therefore, if total energy use in residential buildings remains constant, switching out appliances which burn fossil fuels for energy with appliances which run on electricity will *necessarily* decrease on-site emissions – since this replaces appliances whose associated emissions occur on-location with appliances whose associated emissions occur elsewhere.

In the sections below, I examine, in turn, the two other changes to residential buildings

which have been proposed to reduce on-location carbon emissions: increasing building energy efficiency and making carbon fuel more expensive. I explain why proponents of each approach believe the approach would reduce on-location carbon emissions in residential buildings and why critics question each approach's efficacy.

Then, I use empirical evidence to weigh in on these debates myself. I use panel regression models to evaluate whether increased energy efficiency and/or higher carbon prices actually decrease on-location emissions from residential buildings.

### Energy efficiency

Some policymakers and other energy experts (e.g. Eldridge et al 2006, US White House 2016, Massachusetts 2022) believe that increasing the efficiency of energy use in residential buildings – achieving the same outcomes in buildings at lower energy expenditures – will decrease on-site carbon emissions from residential buildings. The logic is simple: a person uses energy to get certain comforts in his or her home. Changes could be made to appliances or to the home so the resident can get the same comforts while using less energy. The resident will continue to use energy to get the desired comfort but will now expend less energy doing so – decreasing his/her total energy use in the residential building (White House 2016). If the home uses appliances which run on fossil fuels, decreasing total energy use in the home will also decrease on-location carbon dioxide emissions.

For example, imagine that a resident wants the temperature in their home to be no cooler than 68 degrees Fahrenheit in the winter. However, the resident uses an old, inefficient natural gas-powered heater, and the resident's house is leaky, so the house loses warm air quickly. The heating system could be replaced with a more efficient gas-powered heater, so less energy is needed to produce an equivalent amount of heat, and the house could be insulated so it loses warm air more

slowly. If one or both of these changes were made, less energy would be needed to keep the home at 68 degrees or warmer. The resident might choose to keep their house at the same temperature as before, and would burn less gas to maintain this temperature, decreasing on-site greenhouse gas emissions from home heating.

Skeptics agree that the amount of energy needed to achieve any particular comfort in a residential home can be reduced. However, they question the extent to which doing so will actually decrease aggregate energy use and carbon emissions from buildings. Critics argue that people do not have some set outcome they use an appliance to achieve, regardless of the necessary energy expenditure. Rather, the amount that people use an energy-intensive appliance is determined by a number of factors, including the amount of money people have available to spend on energy and the cost of fueling an appliance to achieve some outcome. All else being equal, decreasing the amount of energy needed to achieve some outcome decreases the amount of fuel needed to achieve that outcome, meaning people can spend less on fuel and achieve the same outcome; using the appliance has become cheaper. Because using the appliance has become cheaper, people may respond by using the appliance more (York and McGee 2016; Gillingham et al 2014 summarize the argument, though they argue the most dire predictions are not supported by existing evidence). People may also take the money they saved on fuel for the efficient appliance and spend that money on other appliances powered by fossil fuels (Greening et al 2000; Herring 2006; Gillingham et al 2013; York and McGee 2016). Thus, decreasing the energy inputs needed to achieve some comfort may decrease emissions less than we would expect, based on changes in energy expenditure per use.

To illustrate this possibility, let us return to the resident who uses an inefficient gas heater, in a leaky home, to heat their home to 68 degrees in the winter. Let us say that the resident gets a

more efficient heater and insulates their home, and together, these changes decrease by 20% the amount of gas the resident must burn to keep their home at 68 degrees. The resident's heating bill for heating the house to 68 degrees has decreased. The resident may decide that, given that the cost of heating their house has decreased, they would actually rather heat the home to 70 degrees. The resident may also use their savings from spending less on space heating to take longer showers, powered by a natural gas water heater. Thus, although the resident needs 20% less natural gas to heat their house to 68 degrees, their actual natural gas use may decrease by less than 20%.

### Carbon pricing

Another approach to reducing emissions in buildings is to increase fossil fuel prices. Proponents argue that increasing the price of a good usually decreases consumption of that good. By this logic, increasing the price of fossil fuels may cause people to use fossil fuels less (Tietenberg 2013; Szasz 2023). In the case of building appliances, increasing the price of natural gas delivered to residential customers may cause customers to use their building appliances which run on natural gas less often, or to switch out gas-powered appliances for electric equivalents – decreasing total natural gas use in buildings.

On the other hand, it is also conceivable that increasing the price of natural gas delivered to residential customers may not much decrease use of gas-based building appliances. Even if the price of natural gas increases, a resident may not switch out a gas-powered appliance with an electric equivalent, for any of three reasons: electricity prices could be even higher, the upfront cost of replacing the appliance with an electric equivalent could be prohibitive, or the resident could be renting the house and could not have the option to switch appliances. If a resident does not switch out a gas-powered appliance with an electric equivalent, they may continue to use their gas-powered appliance at a similar rate, even if the price of natural gas increases, because they need the

benefit provided by the appliance. For example, if a resident lives in a cold climate and relies on a gas-powered heater to warm his or her home during the winter, there may be a limit to how much the resident can decrease use of the heater, even if the price of natural gas increases – because the resident needs to stay warm.

In this paper, I am only concerned with the effect of carbon pricing on changing carbon use in buildings, through means other than getting people to switch to electric appliances. I focus on the effect of carbon pricing other than through electrification for a methodological reason. As I explain below, my approach to assessing the effects of pricing allows me to reasonably estimate the effect of pricing on building emissions through means other than electrification, but not the total effect of pricing (including through inducing electrification).

## Data and Methods

As explained above, there are plausible arguments for why energy efficiency and carbon pricing each might or might not be effective at reducing on-site emissions from energy use in buildings. To determine whether increased efficiency and/or higher carbon prices decrease emissions from buildings, we must turn to empirical evidence.

I have done just that. I have gathered empirical data on the fifty United States' economic characteristics and building emissions and have run regressions to determine the effects of building energy efficiency and residential natural gas prices on emissions. In the following sections, I discuss the regression models I ran, the model findings, and the major takeaways.

I use the same approach to evaluate emissions as I outlined in the previous chapter. Below, I explain my approach to modeling again – but, because I have already explained my approach in the previous chapter, I will keep the explanation short.

I run panel regression models using data from all fifty United States, for the years 2008-

2019. My dependent variable is carbon dioxide emissions from the consumption of fossil fuels for energy on-location in residential buildings. The independent variables of interest are a measure of buildings' average energy efficiency in different states, in different years, as well as a variable measuring the average residential natural gas price in each state-year. I also include a variety of other independent variables to control for other features of a state's demography, economy, or building stock which may affect emissions from residential buildings.

The logic of the regression models is that many different factors may affect aggregate emissions from direct consumption of fossil fuels for energy in residential buildings – including the level of building energy efficiency and the price of burning fossil fuels, but also including demographic factors and characteristics of the housing stock that climate policy usually does not target, such as the average number of rooms in houses. We can control for the effect of demographic factors and various characteristics of the housing stock on residential building emissions. This leaves us with different state-years which have different levels of energy efficiency, different carbon prices, and differences in their emissions that cannot be explained by their demographics and by the other characteristics of their housing stocks. The computer solves this math problem to estimate the effect of energy efficiency and carbon prices on emissions in residential buildings.

In the following subsections, I explain the modeling in more detail.

#### Units of observation and dependent variable

My units of observation are state-years, for the fifty United States, for the years 2008-2019. My dependent variable is residential energy-related carbon dioxide emissions: an estimate of the total carbon dioxide emitted, in each state-year, from consumption of fossil fuels in residential buildings for energy.

### Independent variables of interest

My first independent variable of interest is a measure of building energy efficiency. The first independent variable of interest is an estimate, for each state-year, of the percentage of housing units built before the year 2000. Space heating and air conditioning in housing units has generally become more energy efficient over time (EIA 2013). Therefore, this variable can be used as a proxy for building energy efficiency – the higher the percentage of housing units built before the year 2000, the less energy efficient the housing stock is, on average.

My second independent variable of interest is the real average price of natural gas delivered to residential customers, in each state-year, in 2012 dollars per thousand cubic feet. Fossil fuel-powered appliances in residential buildings often run on natural gas. Therefore, a variable measuring retail residential natural gas prices is a reasonable proxy for the cost of burning fossil fuels in residential buildings, more generally. We can use this variable to evaluate the effect of increased retail fossil fuel prices on residential building emissions.

### Control variables

I also include independent variables to control for other aspects of states' demography, geography, and built environment which might affect fossil fuel use in residential buildings. I control for the size of the population, because aggregate emissions from residential buildings will likely scale with the number of people living in a state. I control for the age dependency ratio, as the age distribution of the population may affect building energy use. I control for average number of people per occupied housing unit because, according to Levinson (2013: 10), "energy use per capita shrinks with household sizes." I control for mean real household income (in 2012 dollars), as residents' energy consumption in buildings may scale with their income. I control for the share of a state's residents who live in urban areas; housing units in urban areas may be more

likely to have certain characteristics, such as being attached to other units (town houses), which could affect building energy use. I control for the number of heating degree days and cooling degree days in a state, in a given year, because the average temperature in a state-year may affect how often residents use space heaters – one of the major sources of fossil fuel use in buildings. I control for the percentage of people who believe climate change is mostly caused by human activities, as people who believe in man-made climate change may try to use fossil fuel-powered appliances less. All else being equal, people’s building energy use is likely to increase with the size of their residence, so I control for the median number of rooms in housing units in the state-year and the percentage of housing units with nine or more rooms as proxies for residence size.

I also control for cumulative Democratic control of the state legislature and governorship since 2001, as a proxy for the implementation of other policies intended to reduce emissions from energy use in buildings. Since 2001, the share of Democrats who believe in man-made climate change has increased, while the share of Republicans who believe in the same has decreased (Dunlap et al 2016). Therefore, the more control Democrats have had over a state government since 2001, the more climate policies the government has likely adopted.

When operationalizing cumulative Democratic control of state government over time, we are faced with a new question: to what degree must Democrats control state government to have an effect on the number of climate policies the state adopts? One could argue that Democratic control of a state’s House, Senate, or Governorship, even without the other two, will increase the likelihood that the state adopts climate policies – in which case, cumulative Democrat control of any of the three, over time, would be an accurate proxy for climate policy adoption. Alternatively, one could argue that Democrats likely must control a state House, Senate, and Governorship – what is sometimes termed a “government trifecta” (Ballotpedia, n.d.) – to pass climate policies; if

so, then a cumulative measure of the number of years Democrats have had a “government trifecta” would be a more accurate proxy for policy adoption.

I do not know which of these possibilities is accurate, so I run two different models – one with a variable whose count increases by one each year Democrats control the state’s House, Senate, or Governorship, and the other with a variable whose count increases by one each year Democrats control all three. Ideally, my model results will not be sensitive to the choice of proxy for Democratic control of state government.

I also control for electrification of energy use – more specifically, the share of residential energy provided by electricity in each state-year. The share of residential energy provided by electricity varies greatly in different state-years in my sample, from just 15.6% to 88.1%; the median state-year has about 40.8% of residential energy consumption coming from electricity. As I discussed above, switching out fossil fuel-powered appliances with electric appliances decreases on-site emissions in buildings, all else being equal, since emissions associated with producing electricity occur elsewhere from where the electricity is consumed. Thus, holding constant total energy use, the larger the share of household energy use which is electrified, the lower on-site emissions will be. Given the huge disparity in the percentage of household energy use which comes from electricity, my models must control for the percentage of energy use provided from electricity to correctly identify which differences in state-years’ emissions come from building electrification, and which from other factors.

A drawback of including percent electrification as a control is I cannot measure any effect that natural gas prices have on building emissions via inducing electrification. Theoretically, higher natural gas prices could induce residents to switch to electric appliances, which would decrease on-site building emissions. However, to not misattribute emission reductions from electricity use to

other causes, my models must include a control for the share of building energy provided by electricity. Therefore, the natural gas price variable measures the effect of gas price on building emissions, holding constant the level of building electrification – in other words, the effect gas prices have on emissions other than through building electrification.

Correspondingly, newer buildings might have lower on-site emissions than old buildings either because some appliances in new buildings are more energy efficient, or because more energy uses – space heating, water heating, etc. – are electrified in new buildings. Because my models include a variable holding constant the percentage of buildings’ energy uses which are electrified, the variable for the percentage of buildings constructed before 2000 only measures the effects of characteristics common in newer buildings, *other than* electrification, on emissions. The apparent other reason that newer buildings may have fewer on-site emissions from fossil fuel use is that some energy uses – for example, space heating – are generally more energy efficient in newer buildings (EIA 2013). Thus, in my models, the variable for the percentage of housing units built before the year 2000 measures the effect of building energy efficiency on on-site building emissions.

### Main Models

My main models (Table 2, Models 1 and 2) include the variable measuring the price of natural gas and the variable measuring the percentage of buildings constructed before the year 2000, as well as variables to control for other causes of building emissions. The models include both variables of interest, and variables to control for as many other potential causes of building emissions as possible, to avoid mis-attributing to one variable of interest some difference in emissions actually caused by the other variable of interest or by some other characteristic of the economy or the housing stock.

The difference between Models 1 and 2 is the variable I use to measure the effect of Democratic control of state government on emissions. I run both models to see if my findings about the effects of efficiency and fuel prices are robust to different proxies for Democratic control of state government and consequent adoption of more pro-climate policies. Table 2 Model 1 uses the counting variable which increases by one for each time Democrats control the state House, Senate, or Governorship for one year; Table 2 Model 2 uses the counting variable which increases by one for each time Democrats have a “governing trifecta” – control of the House, Senate, and Governorship – for a year.

**Table 2 Model 1**

$$\begin{aligned}
 & \ln(\text{energy} - \text{related } CO_2 \text{ emissions in residential buildings}_{it}) \\
 & = \beta_1 \ln(\text{population}_{it}) + \beta_2 \ln(\text{age dependency ratio}_{it}) \\
 & + \beta_3 \ln(\text{people per occupied house}_{it}) \\
 & + \beta_4 \ln(\text{urbanization}_{it}) + \beta_5 \ln(\text{mean household income}_{it}) \\
 & + \beta_6 \ln(\text{heating degree days}_{it} + 1) + \beta_7 \ln(\text{cooling degree days}_{it}) \\
 & + \beta_8 \ln(\text{Dem control of state}_{it} + 1) + \beta_9 \ln(\text{belief in climate change}_{it}) \\
 & + \beta_{10} \ln(\text{median rooms in houses}_{it}) + \beta_{11} \ln(\text{pct of houses with 9 + rooms}_{it}) \\
 & + \beta_{12} \ln(\text{electricity share of energy use}_{it}) \\
 & + \beta_{13} \ln(\text{pct of houses built before 2000}_{it}) \\
 & + \beta_{14} \ln(\text{average residential natural gas price}_{it}) \\
 & + u_i + w_t + e_{oit}
 \end{aligned}$$

**Table 2 Model 2**

$$\begin{aligned}
& \ln(\text{energy} - \text{related } CO_2 \text{ emissions in residential builindgs}_{it}) \\
& = \beta_1 \ln(\text{population}_{it}) + \beta_2 \ln(\text{age dependency ratio}_{it}) \\
& + \beta_3 \ln(\text{people per occupied house}_{it}) \\
& + \beta_4 \ln(\text{urbanization}_{it}) + \beta_5 \ln(\text{mean household income}_{it}) \\
& + \beta_6 \ln(\text{heating degree days}_{it} + 1) + \beta_7 \ln(\text{cooling degree days}_{it}) \\
& + \beta_8 \ln(\text{years of Dem trifecta}_{it} + 1) + \beta_9 \ln(\text{belief in climate change}_{it}) \\
& + \beta_{10} \ln(\text{median rooms in houses}_{it}) + \beta_{11} \ln(\text{pct of houses with 9 + rooms}_{it}) \\
& + \beta_{12} \ln(\text{electricity share of energy use}_{it}) \\
& + \beta_{13} \ln(\text{pct of houses built before 2000}_{it}) \\
& + \beta_{14} \ln(\text{average residential natural gas price}_{it}) \\
& + u_i + w_t + e_{oit}
\end{aligned}$$

In these equations,  $i$  is the state,  $t$  is the year,  $u_i$  is the constant effect of being in a certain state on emissions, across years, and  $w_t$  is the constant effect of being in a certain year, across states.

I take the natural log of all variables. The equation  $y = bx$  fits a linear relationship between  $x$  and  $y$ , while the equation  $\ln(y) = b\ln(x)$  can fit a variety of relationships between  $x$  and  $y$ , depending on the value of the coefficient  $b$ . Therefore, taking the natural log of all variables allows the computer to choose a best fit line which more closely matches the relationships between the variables in my data.

Taking the natural log of all variables creates a complication: some of my independent variables take zero values, and the log of zero is undefined. For the independent variables that take zero values, I instead use the transformation  $\ln(y) = b\ln(x+1)$ .

For the variables which receive the transformation  $\ln(y) = b\ln(x)$ , a 1% increase in the independent variable is associated with a  $b\%$  increase in the dependent variable. For the variables which receive the transformation  $\ln(y) = b\ln(x+1)$ , a 1% increase in the independent variable is associated with a  $b * x/(x+1)\%$  increase in the dependent variable. My variables which receive the transformation  $\ln(y) = b\ln(x+1)$  mostly have  $x$ -values of 10 or more, so  $b * x/(x+1)$  will generally

be close to  $b$ ; thus, for these variables too, a 1% increase in the independent variable is associated with approximately a  $b\%$  increase in the dependent variable.

### Statistical significance indicators

Often, social scientists looking to understand a population collect information from some sample of the population. The scientists use statistical analysis to determine the relationship between variables in their sample, then have the computer calculate a “p-value” for the statistical findings. The p-value is used to determine whether two variables, which are correlated in the sample, might also be correlated in the larger population: if the computer calculates that two variables are correlated in the sample, with a p-value of less than 0.05, then it is likely there is some correlation, of the same sign, between the two variables in the larger population.

My data is population data, not sample data, for the fifty United States. Because my data is population data, the correlations between the variables in my data *are* the correlations in the population. In this context, it is not clear what “p-values” mean. Accordingly, while I report “p-values” for the coefficients in my regression models, by convention, when interpreting my regression results, I focus on the sign and magnitude of the calculated coefficients, not the calculated “p-value.”

### Robustness checks

As I explained in the previous chapter, there is a concern with any regression model that the results may be incorrect. The researcher feeds the computer a dataset, tells the computer which variable will be the dependent variable and which variables will be the independent variables, and tells the computer whether each independent variable has a linear or non-linear relationship with the dependent variable. Given these inputs, the computer then calculates the sign and magnitude of the relationship between each independent variable and the dependent

variable. If the researcher feeds the computer the wrong inputs, the regression results will be incorrect.

One way a researcher can assess if their regression results may be correct is to check whether their results vary, if they change some details of the regressions models. If the researcher changes some details of their regression models, and the models still yield similar findings, this may indicate that the regressions have found the true relationship between the independent variables of interest and the dependent variable.

In Supplement 2, I conduct a first check of whether my regression models have similar findings, if I change some details of the models. More specifically, I run models which include only one independent variable of interest per model. I check whether my models which include both independent variables of interest in the same model, and my models which only include one independent variable of interest, have similar findings as to the effect of each independent variable of interest.

#### Data sources

I retrieved my data from a variety of sources. I retrieved data on residential energy-related carbon dioxide emissions, heating and cooling degree days, and average nominal natural gas prices from the Energy Information Administration (EIA 2024a, 2024b, 2025). I also retrieved data on the total amount of electricity sold to the residential end-use sector, and on the sum of this amount and the total primary energy consumed in the residential end-use sector, from the Energy Information Administration (EIA 2024c); I divided the former by the latter to calculate electricity's share of total energy consumed in residential buildings. I used United States Census Bureau estimates of the population in each state, in each year; I retrieved this data from the Federal Reserve of St. Louis's website (FRED 2024). I used the Yale Project on

Climate Change Communication’s estimates for the percentage of people who believe climate change is mostly caused by human activities. I retrieved the estimates for the years 2010-2019 from the Project’s website, and I received the estimates for the year 2008 from the Project researchers via email (Howe et al 2015; Marlon et al 2022). I constructed my other political variable, the measure of how much cumulative control Democrats have had over a state’s government since 2001, using National Conference of State Legislatures data on the partisan makeup of state legislatures (NCSL 2011, 2024) and Inter-university Consortium for Political and Social Research data on governor party affiliations (Kaplan 2021).

I retrieved the Census Bureau’s counts of the number of urban and rural housing units, for the years 2010 and 2020, from the Bureau’s own website (Census Bureau 2010, 2020), and I divided the number of urban housing units by the total number of urban and rural housing units to calculate the approximate percentage of people living in urban areas, in all fifty states, in 2010 and 2020. I then linearly interpolated between these lines to create estimates of the percentage of people living in urban areas, in each state, in each year from 2008 to 2019.

My other independent variables – the age dependency ratio, mean household income, the median number of rooms in housing units, the percentage of housing units which have nine or more rooms, and the percentage of housing units which were built before the year 2000 – are all estimates calculated using American Community Survey data (ACS 2024a, 2024b, 2024c). I also retrieved from the American Community Survey estimates for the number of occupied housing units in each state-year (ACS 2024c) – which I used to estimate the number of people per occupied housing unit in each state-year. The American Community Survey is an annual survey conducted by the Census Bureau; the Bureau then estimates population values based on the survey results. The Bureau releases two sets of population estimates each year: population estimates based on just

that year’s American Community Survey, and population estimates calculated using the last five years of ACS data. For the years 2008 to 2017, I use the five-year ACS estimate centered around a certain year as my estimate for that year; for example, I use the 2006-2010 five year estimates as the values for 2008, or the 2007-2011 five year estimates as the values for 2009.

I cannot use this approach for the years 2018 and 2019, since the five year estimates centered around these years – the five-year estimates for 2016-2020 and 2017-2021, respectively – include data collected during the covid pandemic. Covid likely had a major impact on many of the characteristics of states I am estimating with ACS data, such as average household income or the number of occupied houses. Therefore, I should not use survey data collected during the pandemic to estimate states’ characteristics pre-pandemic. Instead, for the years 2018 and 2019, I use the ACS population estimates based on just that year’s survey data.

## Results

**Table 2: Effect of characteristics on CO<sub>2</sub> emissions in residential buildings**

	Model 1	Model 2
log(pop_people)	0.84 *** (0.18)	0.83 *** (0.18)
log(age_dep)	-0.61 *** (0.18)	-0.66 *** (0.18)
log(pop_house)	-0.31 (0.33)	-0.27 (0.33)
log(house_inc_2012dollars)	-0.26 * (0.12)	-0.28 * (0.12)
log(pct_urban)	0.64 * (0.28)	0.61 * (0.28)
log(hdd + 1)	0.37 *** (0.03)	0.37 *** (0.03)
log(cdd)	0.01 (0.01)	0.01 (0.01)

	Model 1	Model 2
log(state_dem_c + 1)	-0.02 (0.02)	
log(pct_clim_cause_hum)	-0.09 (0.06)	-0.09 (0.06)
log(med_rooms_house)	0.05 (0.30)	0.10 (0.29)
log(pct_house_9rooms)	0.04 (0.09)	0.04 (0.09)
log(pct_elec_res)	-0.78 *** (0.05)	-0.79 *** (0.05)
log(pct_house_20century)	0.40 (0.22)	0.34 (0.21)
log(res_ng_price_2012dollars)	-0.12 *** (0.03)	-0.12 *** (0.03)
log(dem_trif_c + 1)		-0.01 (0.00)
R <sup>2</sup>	0.66	0.66
Adj. R <sup>2</sup>	0.61	0.61
Num. obs.	600	600

Table 2 Models 1 and 2 both find that, controlling for the percentage of building energy use which is electrified, a higher percentage of the housing stock having been built before the year 2000 is associated with higher on-site building emissions from fossil fuel use. Model 1 finds that, holding constant residential natural gas prices, the share of residential building energy provided by electricity, and all other control variables, a 1% increase in the share of housing units built before the year 2000 is associated with a 0.40% increase in on-site building emissions, on average, all else being equal. Model 2 finds that, again holding constant the same, a 1% increase in the share of housing units built before the year 2000 is associated with a 0.34% increase in emissions, on average. This result is not statistically significant in either model.

Table 2 Models 1 and 2 also find that, controlling for the percentage of building energy use which is electrified, higher real retail natural gas prices in buildings are associated with lower on-site building emissions. Models 1 and 2 both find that, holding constant the share of housing units built before the year 2000, the share of residential building energy provided by electricity, and all other control variables, a 1% increase in the real average retail price of natural gas delivered to residential customers is associated with a 0.12% decrease in residential building emissions. This result is statistically significant in both models.

As for the control variables, Table 2 Models 1 and 2 find that, all else being equal, a 1% increase in a state-year's population is associated with a statistically significant 0.83-0.84% increase in residential building emissions, and a 1% increase in the number of heating degree days is associated with a statistically significant 0.37% increase in emissions, on average. Model 1 finds that, all else being equal, a 1% increase in the share of households which are in urban areas is associated with a statistically significant 0.64% increase in residential building emissions, on average, while model 2 finds that a 1% increase in the share of households which are in urban areas is associated with a statistically significant 0.61% increase in residential emissions.

On the other hand, Table 2 Models 1 and 2 find that real average household income, the age dependency ratio, the number of people per occupied household, and the share of people who believe in man-made climate change are negatively correlated with aggregate building emissions in a state-year. Models 1 and 2 find, respectively, that a 1% increase in the age dependency ratio is associated with a statistically significant 0.61% or 0.66% decrease in building emissions, on average. The two models find that a 1% increase in mean real household income is associated with a statistically significant 0.26-0.28% decrease in emissions, while a 1% increase in the average number of people per occupied housing unit is associated with a non-significant 0.27-0.31%

decrease in emissions, on average. The models find that a 1% increase in the share of residents who believe in man-made climate change is associated with a non-significant 0.09% decrease in building emissions, on average, all else being equal.

Both models find that, holding other variables constant, my variables measuring average house size are slightly positively correlated with emissions. Table 2 Models 1 and 2 find, respectively, that a 1% increase in the median number of rooms in housing units is associated with a 0.05% or 0.10% increase in residential building emissions, on average, all else being equal. Both models find that a 1% increase in the percentage of housing units with nine or more rooms is associated with a 0.04% increase in residential emissions, on average, all else being equal. These results are not statistically significant in either model.

The models find that, holding other variables constant, a 1% increase in electricity's share of building energy is associated with a significant 0.78-0.79% decrease in on-site building emissions, on average.

Finally, Table 2 Models 1 and 2 find little correlation between either proxy for cumulative Democratic control of state government and residential building emissions. Model 1 finds that a 1% increase in the first proxy is associated with a non-significant 0.02% decrease in emissions, on average, all else being equal; Model 2 finds that a 1% increase in the second proxy is associated with a non-significant 0.01% decrease in emissions.

In Supplement 2, Tables S3 and S4, I rerun my regression models, including only one of my independent variables of interest in each model – rather than including both independent variables of interest in the same model. These models find similar results concerning the effect of each independent variable of interest on emissions.

More specifically, the regression models which include only one independent variable of

interest find that, controlling for other variables, a 1% increase in the percentage of housing units built before the year 2000 is associated with a statistically significant 0.43-0.48% increase in residential building emissions, on average. The regression models which include only one independent variable of interest find that, controlling for other variables, a 1% increase in the real average price of natural gas delivered to residential customers is associated with a statistically significant 0.12% decrease in residential building emissions, on average.

## Discussion

My main finding is that both increasing energy efficiency and increasing the price of fossil fuel use decrease on-site emissions in residential buildings. Below, I discuss these findings.

Table 2 Models 1 and 2 include a variable measuring the percentage of houses constructed before 2000, alongside a variable measuring the share of residential building energy provided by electricity. The former variable measures the effect of having an older building stock on emissions, other than through electrification.

As I have discussed, above, scholars have suggested two reasons that newer buildings may have fewer emissions from on-site consumption of fossil fuels. First, newer buildings generally use energy more “efficiently” – that is, they achieve the same outcomes with less energy use. Second, generally, a larger share of building appliances are electrified in newer buildings. Fossil fuel-based appliances burn fossil fuels on-location to provide energy, while any emissions associated with electricity are released where the electricity is generated, not where it is consumed. This means that, if the total quantity of energy use in buildings remains the same, but fossil fuel-powered devices are replaced with electric appliances, on-site emissions in buildings will decrease.

The electrification variable controls for the effect of electrification on building emissions. If I find that newer buildings have lower emissions, even controlling for electrification, this would

suggest that newer buildings' greater efficiency also results in lower emissions.

This is exactly what my models find. Table 2 Models 1 and 2 find that, even holding constant the share of residential building energy which is provided by electricity, the percentage of a state's houses which are constructed before the year 2000 is positively correlated with the state's emissions from residential buildings. In other words, holding constant the share of a state's residential building energy which is provided by electricity, as well as other causes of residential building emissions, states with a higher share of new, generally more energy efficient residential buildings have lower residential building emissions. This finding indicates that, all else being equal, improving energy efficiency in buildings decreases on-site fossil fuel use for energy – and consequent emissions.

Table 2 Models 1 and 2 also include a variable measuring the real, average price of natural gas delivered to residential customers; this variable is included to assess the effect of increased residential gas prices on emissions. As I explained above, scholars have theorized that increasing the price of fossil fuels may decrease fossil fuel use through two mechanisms. Higher fossil fuel prices may cause people and companies to switch from using fossil fuel-powered appliances to using electric equivalents. Alternatively, people and companies may respond to higher fossil fuel prices by continuing to use fossil fuel-powered appliances, but using these appliances less than before.

Because Table 2 Models 1 and 2 include a variable measuring the share of building energy provided by electricity, the coefficient for the gas variable measures the effect of increased natural gas prices on building emissions, holding constant the level of electrification of building appliances. In other words, the coefficient measures any effect on emissions from prices changing how often people use their gas-powered appliances – rather than from prices causing people to

switch to electric appliances altogether.

Table 2 Models 1 and 2 find that, holding constant the share of residential building energy provided by electricity, a 1% increase in the real, average retail price of natural gas delivered to residential customers is associated with a 0.12% decrease in building emissions. This finding indicates that, beyond potentially incentivizing people to switch to electric appliances, higher residential natural gas prices also cause people to use their natural gas-based appliances less – decreasing total emissions from residential buildings.

Turning to the control variables, Table 2 Models 1 and 2 found that, all else being equal, the size of a state’s population, the amount of time in a state-year in which the average temperature was below 65 degrees (“heating degree days”), the median number of rooms per housing unit, and the percentage of housing units with nine or more rooms are all positively correlated with on-location building emissions. These results are expected: as I stated above, all else being, we would expect total fossil fuel use for energy in residential buildings to scale with the number of people living in a state. We would also expect fossil fuel use to scale with the amount of time a state’s average temperature was below 65 degrees, as many homes’ space and/or water heaters run on fossil fuels. As previously mentioned, the median number of rooms per housing unit and the percentage of housing units with nine or more rooms are both proxies for house size. Holding the share of residential energy use provided by fossil fuels, and other characteristics of the housing stock, constant, we would expect that larger houses burn more fossil fuels for energy.

As expected, Table 2 Models 1 and 2 find that the share of a state’s residential building energy provided by electricity is negatively correlated with on-site residential building emissions. In accordance with existing literature (Levinson 2013), the models find that – holding total population constant – increased people *per occupied housing unit* is associated with lower building

emissions. The models also find a modest negative correlation between the share of residents who believe climate change is caused by humans and the total amount of residential building emissions. This finding indicates that some people who believe in man-made climate change may make lifestyle changes to reduce their use of fossil fuels in buildings.

Table 2 Models 1 and 2 also yield three unexpected findings for the control variables. First, the models find that the age dependency ratio – the ratio of people under 18 and over 65 to those who are working age – is negatively associated with building emissions; the higher the ratio of non-workers to workers, the lower the building emissions.

Second, the models find that mean real household income is negatively associated with emissions. This result is surprising, as we might expect people with more money to spend more on energy. One explanation is that people with more money can buy expensive appliances which are more energy efficient.

Third, the models find that, controlling for natural gas price, the proxy for energy efficiency, electrification, and my other controls, the cumulative amount of time that Democrats have controlled a state's government has little correlation with residential building emissions. This result indicates that climate policies passed at the state level have mainly affected on-site residential building emissions by changing residential natural gas price, residential building energy efficiency, building electrification, one of the other controls, or some feature of buildings closely correlated with one of these variables.

## Conclusion

Overall, I find that increasing residential building energy efficiency decreases residential building emissions. Increasing residential natural gas prices also decreases residential building emissions, even apart from any effect natural gas prices may have in pushing people to switch to

electric appliances. As we have discussed, all else being equal, electrification also decreases on-site emissions from residential buildings. The takeaway is clear: to decrease on-site emissions from residential buildings, policymakers should increase building energy efficiency, the residential retail price of natural gas, and the share of building appliances which are electrified as much as possible.

I see two fruitful directions for future research. First, as I discussed above, my modeling approach did not allow me to estimate the full effect of increased natural gas prices on building emissions – since higher gas prices may induce people to switch from gas-powered to electric appliances, and my models controlled for the share of building energy provided by electricity. A future study could look for a method to estimate the full effect of increased natural gas prices on (on-site) building emissions.

Second, to reduce emissions from residential building energy use to near-zero, policymakers must reduce on-site emissions from fossil fuel consumption for energy, but they must *also* reduce the emissions associated with generating electricity for use in residential buildings. This study addressed the former category of emissions but not the latter. Thus, follow-up studies are needed which examine how to reduce emissions associated with electricity use. I conduct such a study in the next empirical chapter.

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## Empirical Chapter 3: Assessing Economic Determinants of Electricity Demand

### Introduction

Finally, I come to the question of decarbonizing electricity use in the United States. This is actually a three part task. To decarbonize electricity consumption, society must: generate a large amount of renewable energy; limit electricity demand to a level that can be met entirely with renewable energy; and use renewable electricity, rather than electricity from burning fossil fuels, to meet demand. This chapter focuses on the second of these three topics – limiting electricity demand to a level that can be met entirely with renewable energy.

Limiting electricity demand in the United States is deceptively difficult. York (2007) finds that energy use generally scales with population and GDP. Furthermore, in the last 200 years, when the global economy began using a new energy resource, total energy use increased – new sources were added to, not in place of, established energy sources (York and Bell 2019). Importantly, York (2012) finds that this pattern holds for adding non-carbon sources to electricity grids, globally, even controlling for economic growth. If the US is to continue growing its economy, increase renewable generation, and keep population constant or growing, existing literature predicts total electricity demand will increase. Yet, we must keep demand at levels that actually can be met by available renewable resources.

Thus, an important question for policymakers is: what economic or lifestyle factors, that policymakers could aim to alter, decrease electricity demand? In this chapter, I use a comparative case study of electricity consumption in Texas and California to look for such factors. Over the period 2001 to 2021, Texas and California share the traits identified above: population growth, economic growth, and increasing renewable generation. Yet, while Texas's electricity consumption has risen over the study period, California's electricity consumption peaked in the late-2000s and

then slowly decreased until 2021. In this chapter, I compare electricity consumption trends in the two states against demographic and economic trends in the states to examine what is causing electricity consumption in California to slowly decrease, in spite of its growing population and GDP and its new resources. I conclude due to California's milder climate, California residents used less air conditioning in individual residential and commercial buildings, on average; as the population of both states grew, these individual differences in electricity use for air conditioning compounded, contributing to the states' diverging consumption trends. Additionally, California's higher retail electricity prices likely lowering commercial and industrial electricity consumption, compared with consumption in Texas, while energy efficiency may be lowering residential electricity consumption. These findings suggest that policymakers seeking to limit electricity demand should encourage people to live in more temperate areas, increase retail electricity prices in the commercial and industrial sectors, and increase energy efficiency in residential buildings.

### Existing literature

In the section below, I first discuss the differences between California's and Texas's electricity consumption trends and explain the logic of comparing the two states. I then discuss different explanations presented in the literature as to why California and Texas have different electricity consumption trends. Then, in the later sections of this chapter, I examine empirical evidence to determine which factors actually seem to be affecting electricity consumption in the two states for residential, commercial, and industrial customers.

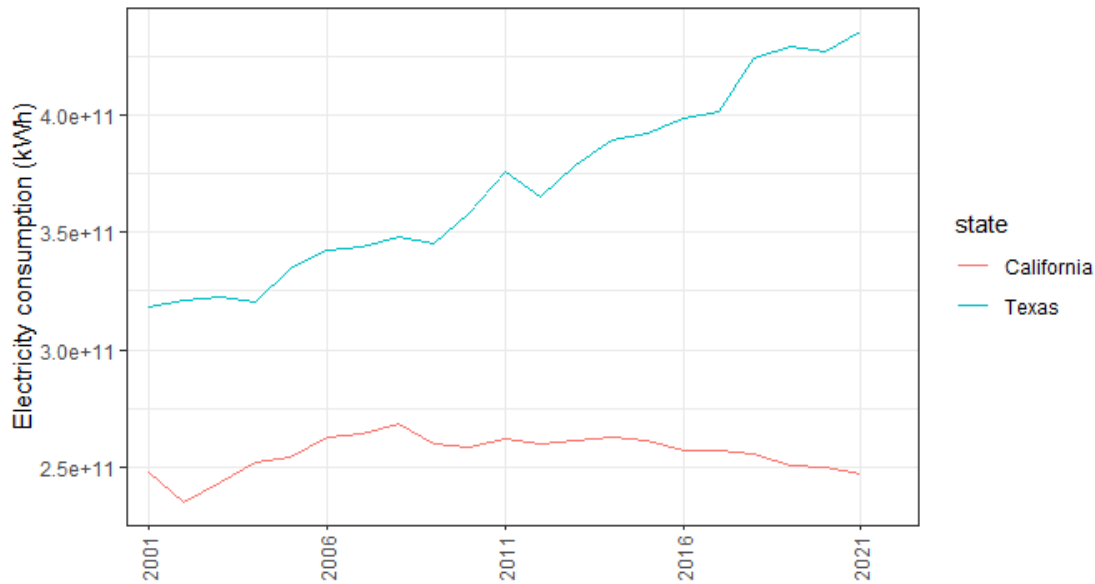
### The Texas-California comparison

Over the study period (2001-2021), both California and Texas had growing populations and growing economies – two factors that, as I have discussed, are generally correlated with increased energy use (York, 2007). Furthermore, both states have abundant potential for renewable electricity production (Lopez et al 2012), and both states saw large increases in total

wind and solar power generation between 2001 and 2021 (EIA 2023a, 2023d). As previously discussed, increased non-carbon electricity production has historically been positively correlated with total electricity production, even controlling for the effect of GDP on total electricity production (York 2012; York 2016).

Based on these facts, I would predict that both California and Texas would have increased electricity consumption over the study period. However, unexpectedly, California’s electricity consumption peaked in 2008 and then decreased between 2009 and 2021 (Figure 1).

Figure 1: Annual Electricity Consumption in Texas and California



If I can figure out which factors are driving the consumption trend in California, this may help us to determine what US policymakers can do to limit electricity demand as the economy, renewable generation, and (possibly) the population continues to grow. However, when considering a single case, it is difficult to determine which factors are driving an outcome – in this case, which aspects of California’s economy, demography, or other factors are causing decreasing electricity consumption.

This is where the comparison with Texas comes into play. Texas shares with California a

growing population and economy and increasing renewable resources. As predicted by the literature, and unlike the trend in California, Texas's electricity consumption has grown. Thus, Texas can be used as a reference case. By comparing Texas and California, I may be able to observe differences between the states that are causing Texas to consume more electricity, and California, to consume less. This comparison gives us empirical leverage to assess which characteristics of California *matter* in reducing its electricity use.

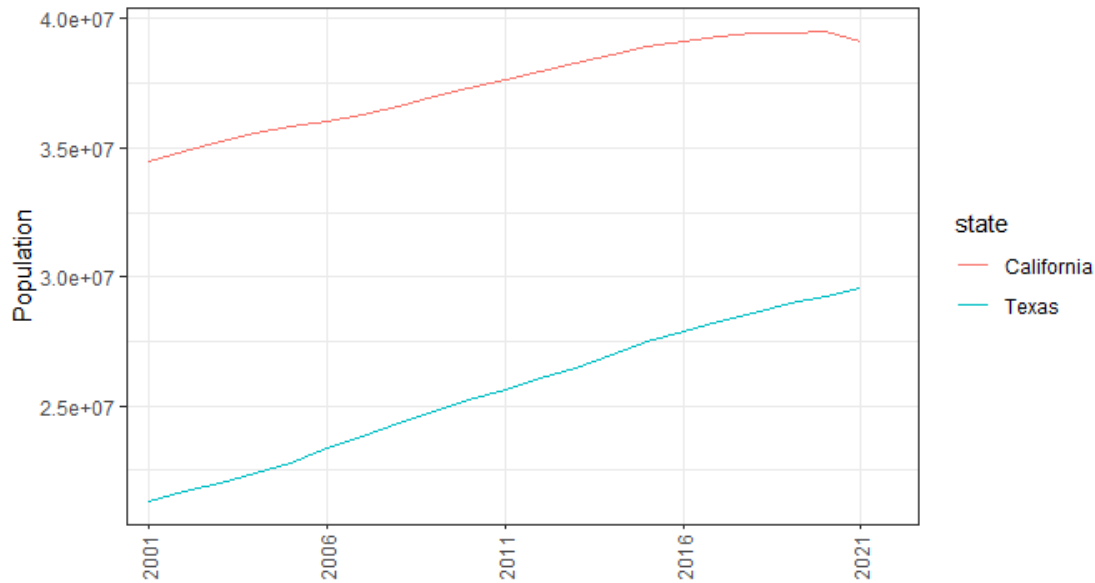
I am not the first person to compare these two states. There is a small cottage industry comparing Texas and California's policies, including energy policies. Relatedly, other authors have noted differences between the states and proposed that these differences may be the reason for the states' disparate energy outcomes.

More specifically, existing literature suggests several possible causes of the different consumption trends: population changes; climate; energy efficiency measures; differences in the two states' economies; and electricity prices. Below, I briefly discuss each of these potential causes. Then, in future sections, I examine empirical evidence to determine which appear to be responsible for the consumption trends.

### Population

York (2007, 2010) has demonstrated that, generally, population size is correlated with energy use. Texas's population is growing faster than California's population (Figure 2), and this may be a reason Texas's electricity consumption is growing while California's consumption is declining.

Figure 2: Population of California and Texas Over Time



## Climate

Texas's climate is far hotter than California's climate, and as a result, Texas buildings use far more air conditioning. According to the EIA, about 75% of California households have air conditioning (EIA 2023a), compared to "almost all homes" in Texas (EIA 2023d).

Furthermore, the EIA reports that "most of [California's] more densely populated areas are relatively mild for much of the year," (EIA 2023a) while "summer temperatures average above 90°F in the most densely populated parts of Texas." (EIA 2023d) Texas's summer climate leads residents to use substantial electricity for air conditioning (Ibid).

Population growth may further exacerbate the effect of air conditioning on electricity use. If each Texan uses more air conditioning than each Californian, on average, I would expect that as both states' population grows, the difference in net AC use would become greater and greater.

For all of these reasons, Texans' greater need for air conditioning may be a major reason that Texans consume more electricity.

### Beliefs about climate change

Over the study period, generally, a larger share of the electorate has voted Democrat in California, compared with Texas. Polling suggests that, over this same period, Democrats' and Republicans' views on climate change have diverged. For example, between 2001 and 2016, the percentage of Democrats who believed that climate change is primarily caused by humans steadily increased, while the percentage of Republicans who believed the same steadily decreased (Dunlap et al 2016). I can surmise that a higher share of California residents believe humans are causing climate change.

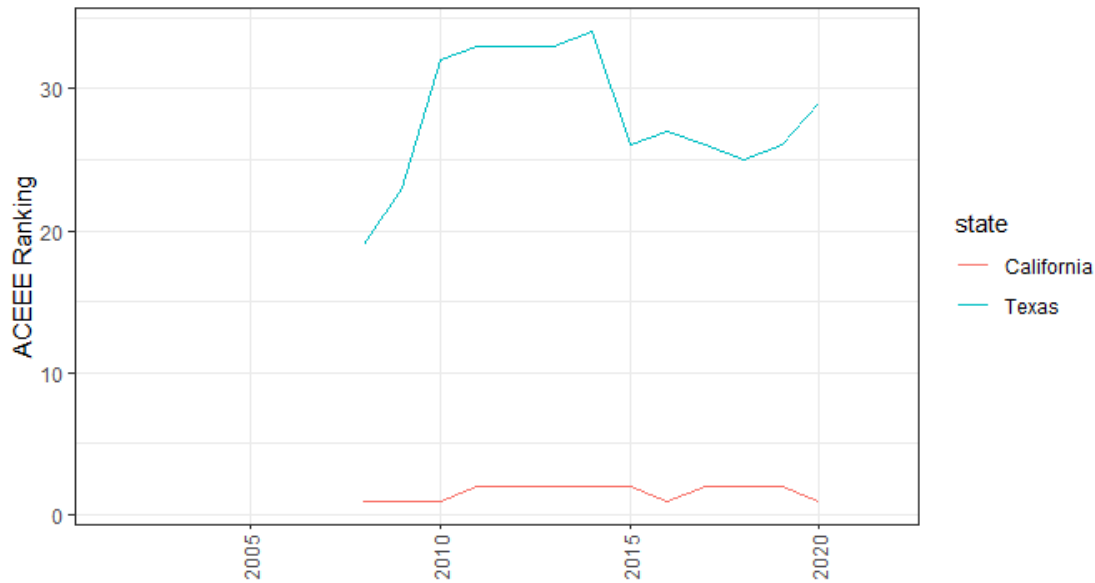
It may be that people who believe in man-made climate change are more likely to take actions to reduce their own footprint. If this is the case, then the fact that a larger share of California residents believe in climate change may be partially responsible for the states' different electricity consumption trends.

### Energy efficiency measures

California has been implementing energy efficiency measures, such as energy efficiency requirements for new buildings and appliances, for nearly fifty years. Between 1975 and 2016, California implemented multiple energy efficiency policies.

Available evidence suggests Texas saw fewer efficiency policies and energy efficiency gains over the same period. The American Council for an Energy-Efficient Economy released State Energy Scorecards, which rank all fifty states on their existing and new energy efficiency policies, for the years 2006 and 2008-2020. California ranked first or second out of fifty states every year. Texas ranked eleventh in 2006 and anywhere from nineteenth through thirty-fourth over the remaining years (Figure 3).

Figure 3: Annual ACEEE Energy Efficiency Ranking (out of 50 US states)



It is possible that California's energy efficiency policies, and consequent increases in energy efficiency, have pushed electricity consumption in the state onto a different trajectory, compared with electricity consumption in Texas.

#### Different economies

The size and trajectory of some economic sectors differs between California and Texas, and different sectors have different energy footprints. As a result, differences in Texas and California's economies may account for some of the differences in electricity consumption.

Figure 4 shows each state's real GDP, in 2012 dollars, broken down by economic sector. Spending in some of these sectors might scale with population, so I have also included a visualization of real GDP per capita in each sector (Figure 5) to show how the states' economies differ, controlling for population size.

Figure 4: GDP in CA and TX, broken down by sector

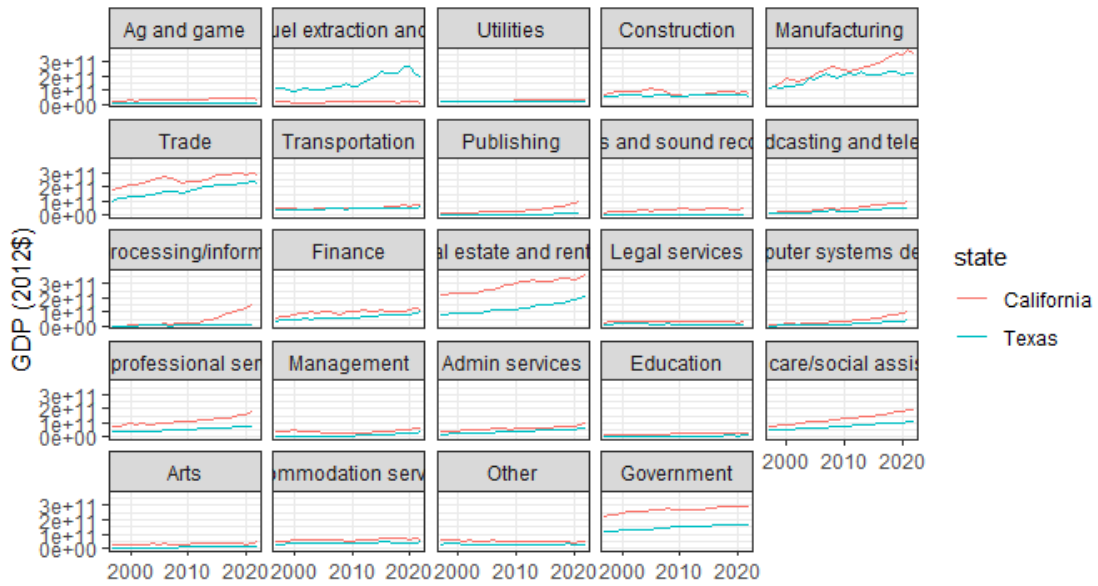
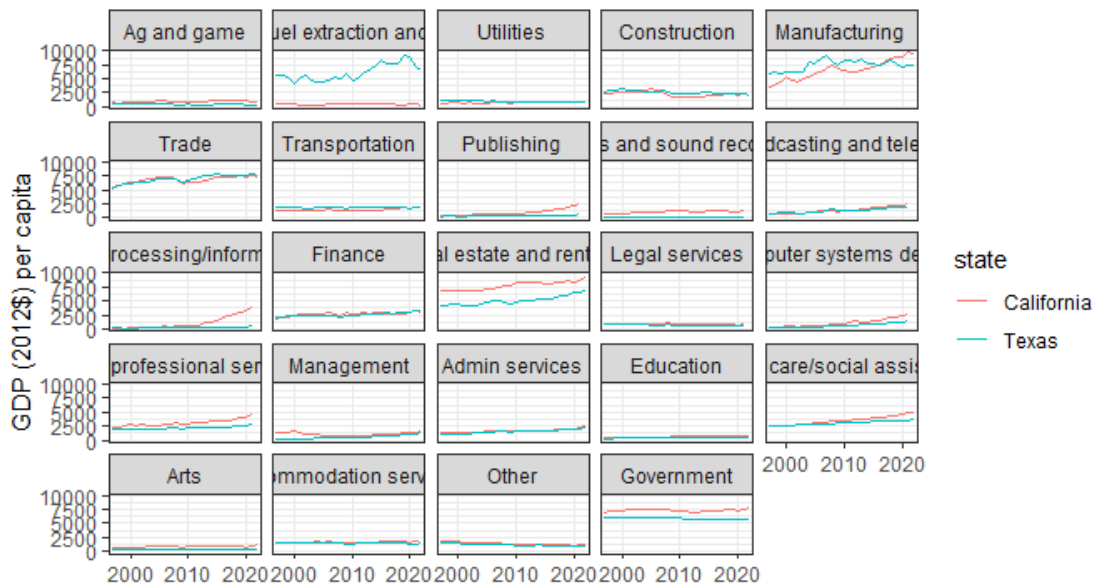


Figure 5: GDP per capita, broken down by sector



In the period from roughly 2005 onwards, when California and Texas’s electricity consumption diverged, three main trends are apparent. In California, GDP in manufacturing and in data processing/hosting/informatics greatly increased. In Texas, GDP from “extraction” – a category which includes mining, oil and gas extraction, and fossil fuel refining processes which take place at the extraction site – greatly increased.

The sector which saw the most growth in Texas – mining and fossil fuel extraction and processing – is very energy-intensive. The International Energy Agency (2023) estimates that in 2022, globally, the energy used for the extraction, processing, refining, and transportation of oil and natural gas accounted for about 2.3 Gigatonnes of CO<sub>2</sub> emissions – about 5.75% of total energy-related greenhouse gas emissions. (Not all activities the IEA tracked would fall under the mining/extraction sectoral numbers, since the sectoral numbers do not include any GDP from transport or off-site refining of fossil fuels. On the other hand, the IEA numbers do not include the energy footprint of mining other than oil and gas extraction.) It may be that the growth of mining, extraction, and on-site fossil fuel refining in Texas accounts for some of the difference in electricity consumption between Texas and California.

On the other hand, one of the major changes in California’s economy over the study period was a large increase in manufacturing – another energy-intensive sector. This evidence suggests that the relative size of different sectors might not cause the differences in aggregate electricity demand.

### Electricity prices

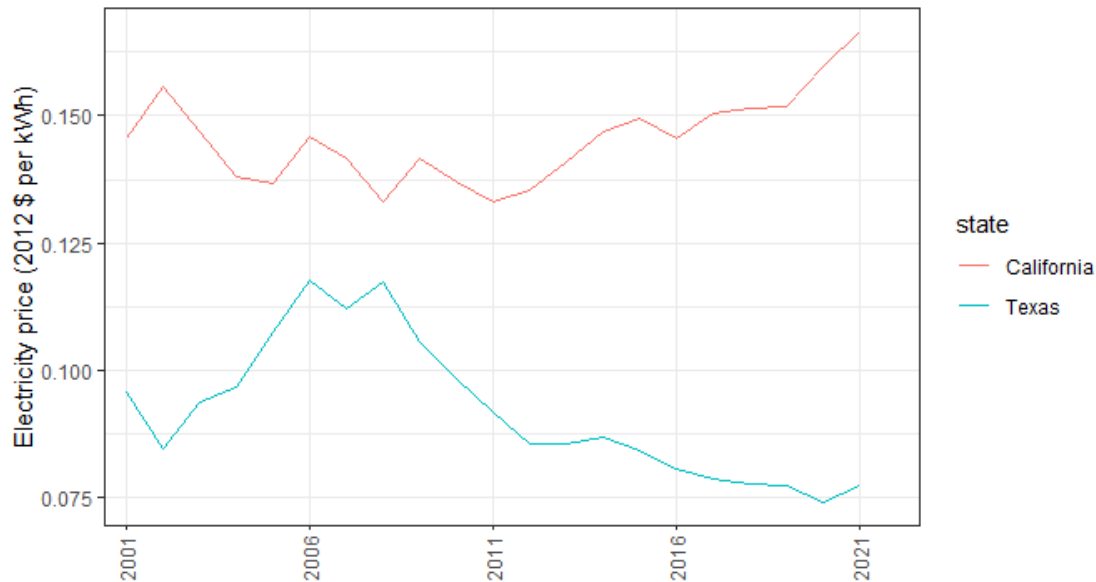
Over the period 2001 to 2021, real retail electricity prices in California and Texas diverged dramatically (Figure 6). This divergence is a result of the states’ different approaches to determining retail electricity prices.

Texas and California have similar systems for the generation, sale, and transmission of electricity. One set of companies generate electricity. Another set of institutions, either private companies or government institutions, buy electricity from generators and sell the electricity to customers. The electricity is delivered through transmission lines owned by private utility companies.

The states have also seen parallel decreases in wholesale prices over the study period.

Wolak (2018: 30) writes “the shale gas boom that started in the mid-2000s... led to a roughly 66 percent decline in the wholesale price of natural gas” in the United States, decreasing the wholesale price of electricity in California “one-half to two-thirds relative to their pre-shale gas boom levels.” He writes that Texas has seen comparable changes in wholesale electricity prices.

**Figure 6: Average Electricity Price in California and Texas**



However, the two states have very different systems for determining the retail price of electricity, and these different systems have caused the states’ electricity retail prices to diverge over time. Since the early 2000s, households on Texas’s isolated grid have been able to choose between different electricity plans offered by different Retail Electricity Providers (Pressler 2023). Providers offer lower prices to outcompete their rivals, allowing consumers to save money on electricity (Orlando 2022). Hartley et al (2019: 2) find that this price competition between providers has lowered the average retail price of electricity and decreased the “gap” between wholesale and retail electricity prices, for both residential and commercial electricity prices.

In California, by contrast, the largest electricity providers – large electric utilities – can only

change retail electricity prices subject to approval by the California Public Utilities Commission (CPUC), meaning the regulatory agency effectively decides the retail price of electricity (Guliasi 2018). The California Public Utilities Commission periodically allows the utilities to raise the retail price of electricity to make back money spent buying electricity, maintaining the transmission system, and administering state programs.

California's private utilities pay large costs to buy electricity from electricity producers. They also pay large costs related to their transmission and distribution system, including costs to maintain transmission lines and costs related to wildfires: "technology to detect line faults and shut off power before the line starts a fire... relocation of power lines, early replacement of lines and towers to reduce fire risk, and compensation for fire damage." (Borenstein et al 2021: 27)

California's state government has also required the large private utilities to administer several programs related to renewable energy and energy efficiency, including the Renewables Portfolio Standard, Net Energy Metering, and other "public purpose programs... including energy efficiency programs, energy research and development programs, and subsidies for customer-sited batteries, among others." (Ibid) Borenstein et al estimate that the public utilities have incurred relatively small costs implementing the Renewables Portfolio Standard, which requires that a certain percentage of procured electricity come from renewable sources, and the public purpose programs. On the other hand, they estimate that administering Net Energy Metering – which allows houses with solar panels to sell solar energy back to the utility at roughly the retail rate, rather than the much lower wholesale rate – is quite expensive for the private utilities (Ibid).

Borenstein and colleagues argue that the CPUC has allowed the utility companies to charge high retail prices to make back the above operating costs. As a result, California's utilities currently charge customers far more for each additional kWh of electricity than the marginal cost to generate

and transmit that additional kWh (Ibid).

The two states' electricity prices may be responsible for their diverging electricity consumption. According to standard economic theory, as the price of a good rises, demand for the good will usually fall, and vice versa. There is some evidence that this trend holds for energy use – for example, multiple empirical studies find that higher fossil fuel prices decrease fossil fuel consumption (Sterner 2007; Tietenberg 2013; Szasz 2023). It could be that rising retail electricity prices are causing a decline in electricity consumption in California, while falling retail prices are causing an increase in electricity consumption in Texas.

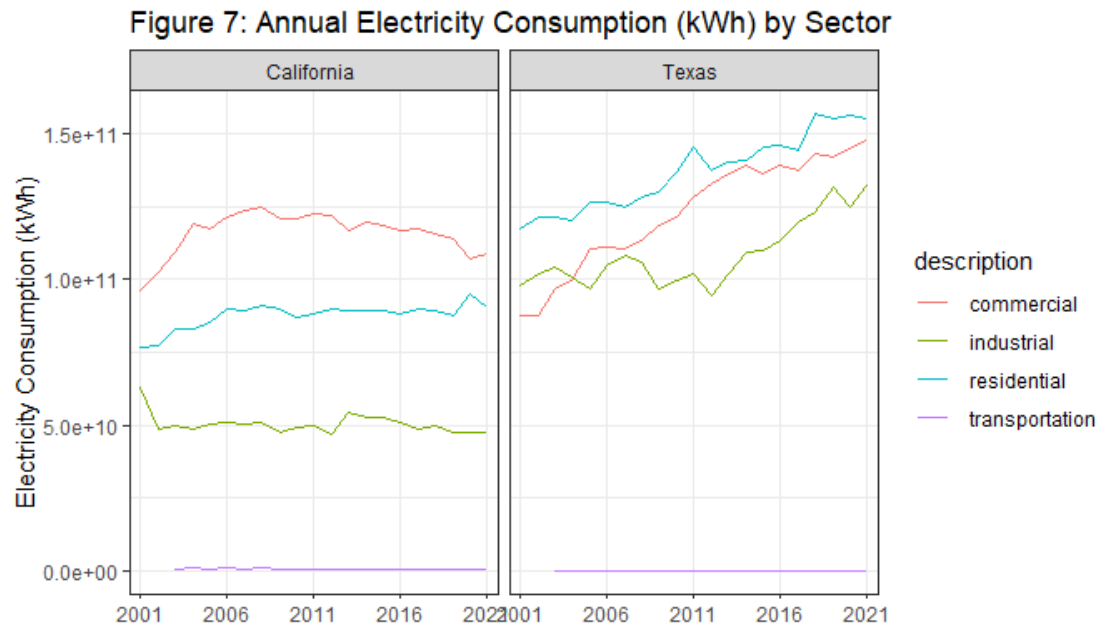
## Data and Methods

Now that I have presented different explanations for the divergent consumption trends, I can compare against available evidence to see which theories best fit the evidence.

As a first step, I divide electricity consumption into four categories: electricity used to power appliances in residential buildings, electricity used to power appliances in commercial buildings, electricity used in industrial processes, and electricity used to transport people and goods. As illustrated in Figure 7, residential, commercial, and industrial uses each account for a large portion of electricity consumption in both states, while transportation accounts for only a tiny fraction of electricity consumption. Furthermore, the trend that California's electricity use has stayed relatively constant or decreased, while Texas's electricity use has increased, holds for residential, commercial, and industrial electricity consumption.

Therefore, to explain why California's electricity use is remaining steady or decreasing, while Texas's electricity use is increasing, I must explain the states' different trajectories in residential, commercial, and industrial electricity consumption. Below, I discuss these different categories of electricity use one at a time and determine why we see this trend in each category of

electricity consumption.



For each category of electricity use, I consider the trajectory of electricity consumption in each state. I compare these trajectories against the various factors to which – as I discussed above – some have attributed the disparity in electricity consumption. By seeing which other factors appear to correlate with consumption, for each category of electricity use, I can at least make a first approximation of which factors may be driving the different consumption trends.

I retrieved the data for these comparisons from a variety of sources. I retrieved annual data for average retail electricity prices and total retail electricity sales, across different sectors, from the US Energy Information Administration (EIA 2023b, EIA 2023c). I retrieved estimates of the annual amount of GDP in different sectors, by state, from the US Bureau of Economic Bureau of Economic Analysis (BEA 2023). I retrieved US Census Bureau annual population estimates for each state from the Federal Reserve of St. Louis’s Federal Reserve Economic Data website (Census Bureau 2023). Data on electricity use in different economic sectors was retrieved from the US Census Bureau (Census Bureau 2024). The data breaking down electricity usage in residential

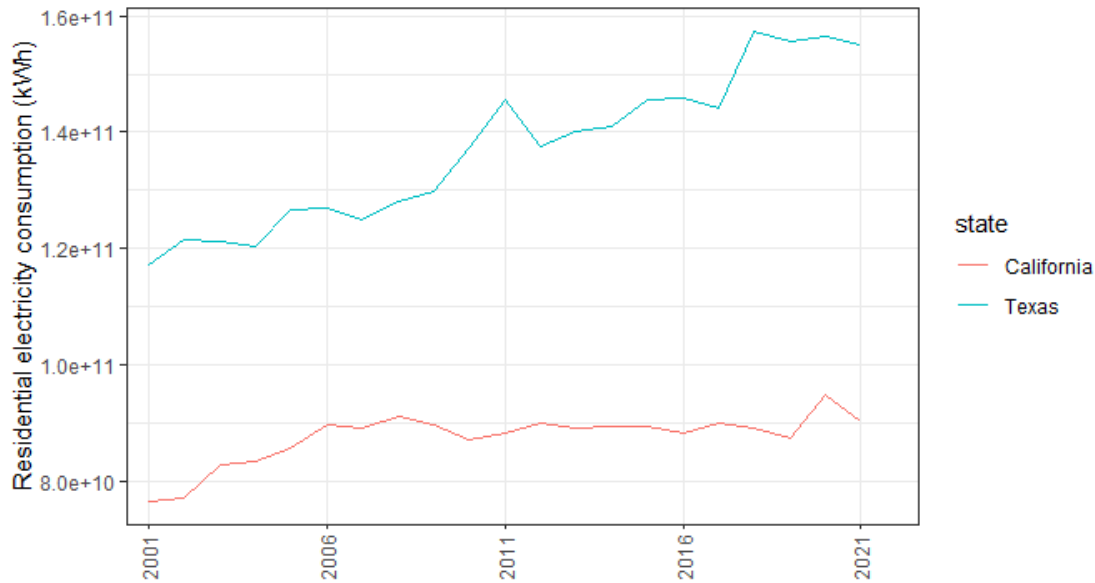
households was retrieved from the Energy Information Administration’s Residential Energy Consumption Survey (RECS) webpages (EIA 2024). Some of the data from the Yale Climate Communications project was retrieved from the project website; the rest of this data was sent to me directly by the lead author on a Yale Climate Communications publication, Jennifer Marlon (Howe et al 2015; Marlon et al 2022). I pulled the ACEEE’s annual, overall state rankings on energy efficiency (Figure 3) from the “ACEEE State Energy Efficiency Scorecard” documents (ACEEE 2022). Finally, I adjusted price values from nominal dollars to 2012 dollars using CPI data that I retrieved from the World Bank website (World Bank 2023).

## Results

### Residential Use

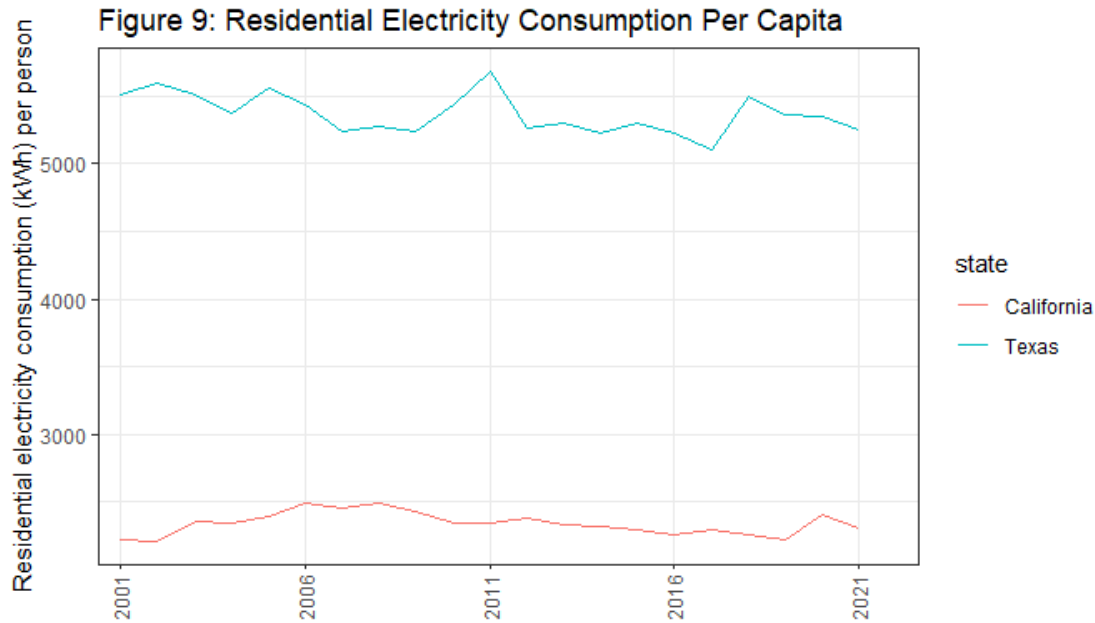
I start with electricity consumption in residential buildings. A cursory look at residential electricity consumption in Texas and California (Figure 8) shows that aggregate residential electricity consumption in the two states diverges over time: aggregate residential electricity consumption in Texas steadily rises over the study period, while aggregate residential electricity consumption in California rises until about 2008, then remains relatively constant through 2021.

Figure 8: Residential Electricity Consumption in California and Texas



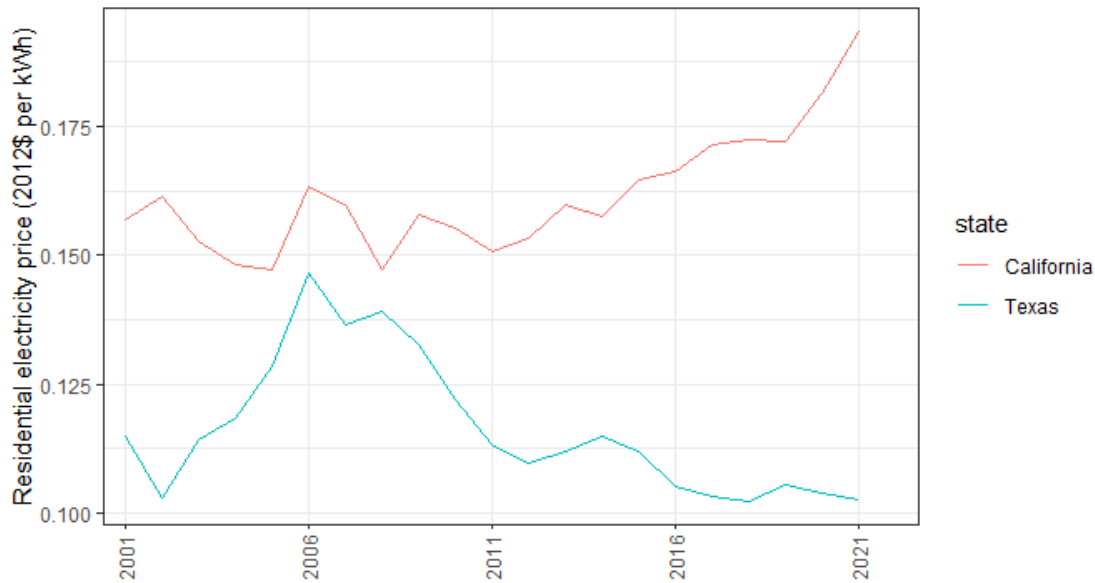
However, per capita residential consumption numbers – the average amount of residential electricity consumption, annually, per person – paint a different picture (Figure 9). Per capita residential electricity consumption has stayed relatively constant, if not slightly decreased, in both states since the mid-2000s – albeit that Texas’s per capita electricity consumption has consistently been much higher. Taking these two figures together, it appears that the two states’ diverging residential consumption trajectories result from Texas’s greater population growth, in the context of higher per capita residential electricity consumption in Texas.

The above analysis raises another question: why does Texas consistently have higher per capita residential electricity consumption?



The bulk of the difference between Texas and California in per capita residential electricity consumption is present from the beginning to the end of the study period (2001-2021). Therefore, events which occurred during the study period likely cannot explain the difference in per person electricity consumption – since most of the difference was there before the events occurred. For example, residential electricity prices diverged drastically in the two states (Figure 10) after around 2006, but most of the difference in per capita consumption in Texas and California pre-dates 2006 – so residential electricity prices cannot explain the difference in per capita consumption.

Figure 10: Average Residential Electricity Price in California and Texas

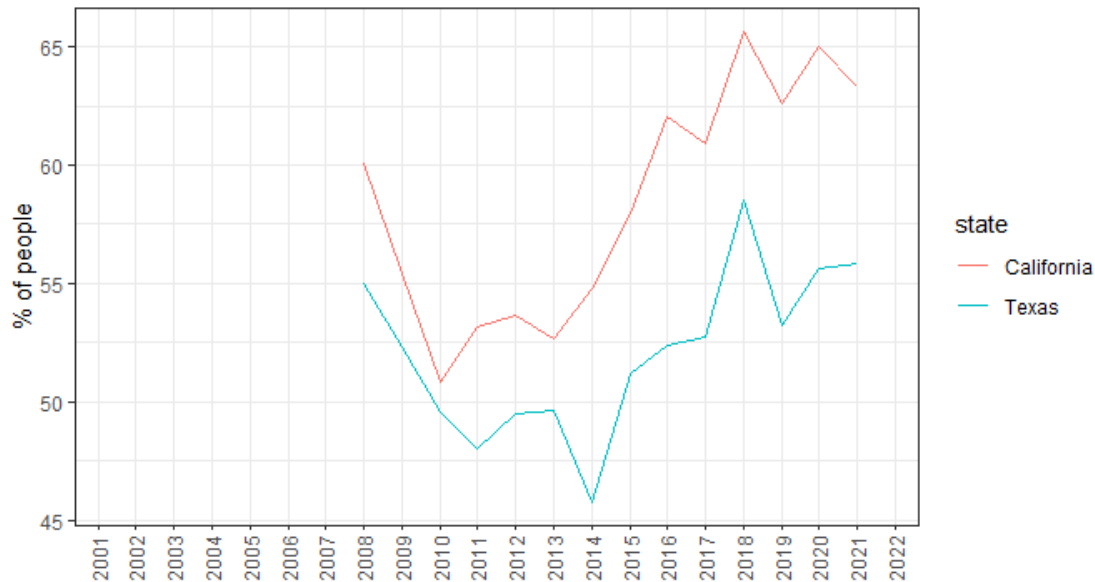


This majority of the difference in per capita consumption must be explained relative to differences between the states that were already present in 2001 and that were maintained over the course of the study period. Four potential causes of diverging consumption trends, discussed above, might plausibly fit these criteria: differences in beliefs about climate change, climatic differences, Texans’ use of electricity for space heating, and longstanding differences in building energy efficiency.

I will start with beliefs about climate change. It may be that belief in man-made climate change is correlated with a person’s residential electricity use – for example, that some people who believe in climate change try to reduce their own carbon footprint. Unfortunately, I have only one source of data on beliefs about climate change: estimates from the Yale Climate Communications project on the share of people in each state, for the years 2008 and 2010-2021, who have certain beliefs about climate change. Figure 11 shows the project’s estimate of the percentage of people in Texas and California, in each year, who think that climate change is caused mostly by human activities (Figure 11).

The project’s estimates corroborate the idea that a larger share of California residents than Texas residents have believed in man-made climate change, consistently, throughout the study period. If some percentage of people who believe in climate change try to reduce their electricity consumption, as proposed above, then a higher share of California residents believing in climate change might translate into lower average electricity consumption per person.

**Figure 11: Percent Who Think Climate Change Caused Mostly by Humans**



The problem with this theory is that the Climate Communications project’s data show substantial changes in the share of people who believe in climate change, in each state, over time. If the share of residents who believe in man-made climate change correlated with reduced per capita electricity consumption, then, as the share of each state’s population who believed in climate change declined in the late 2000s, I would expect per capita electricity consumption to rise. Similarly, as the share of people in each state who believed in climate change increased, in the 2010s, I would expect per capita electricity consumption to fall. Per capita residential electricity consumption has not behaved this way, in either state. Instead, per capita residential electricity consumption has slowly but steadily declined in each state from the late 2000s through 2021 –

regardless of increases or decreases in the proportion of people who believe in climate change. Overall, the data I have shows no correlation between the percentage of people who believe in man-made climate change and the level of per capita electricity consumption.

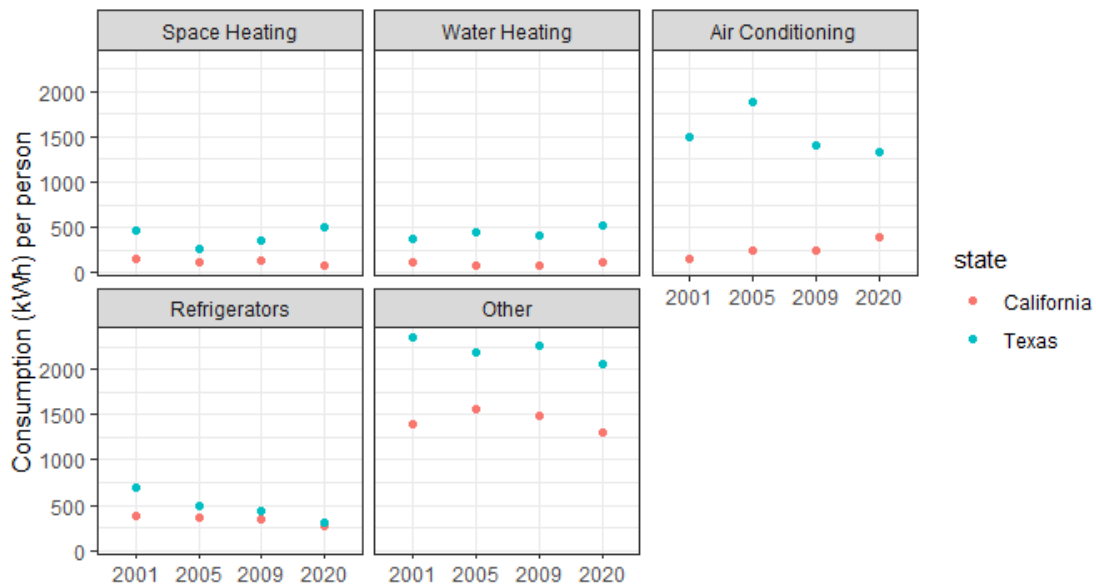
I cannot be sure, given the evidence at hand, that people's beliefs on climate change had no impact on their residential electricity consumption. At the same time, however, I cannot claim without evidence that a connection exists between people's beliefs and per capita electricity use. I therefore look to my other three candidates – climate, the use of electricity for space heating, and buildings' level of energy efficiency – to see if they can explain the consistent gap in per capita residential electricity consumption in the two states.

To assess the effect of these factors on per capita residential electricity consumption, I can turn to another source of data: the results of the EIA's Residential Energy Consumption Survey (RECS). The RECS is a survey administered to a representative sample of households every few years; in our study period, the RECS was conducted in 2001, 2005, 2009, 2015, and 2020. EIA has RECS data for aggregate electricity consumption in Texas and California, to power different household appliances, for the years 2001, 2005, 2009, and 2020. I can use this data to approximate per capita electricity consumption for various household appliances in each state, in each year.

Although the breakdown of electricity consumption between different appliances (Figure 12) varies by year, I can identify some general trends. First, a large portion of the difference in per capita electricity consumption comes from air conditioning – Texans use much more electricity, per capita, in their households for air conditioning. By contrast, while Texans do use more electricity for space heating than do Californians, per capita, the difference is not large in most years. Together, this data points to climate as a major reason that Texans use more electricity per capita than Californians in residential buildings, and the use of electric space heaters, as a relatively

minor reason.

Figure 12: Annual electricity consumption, per capita, by residential end-use



Also notable from the RECS results is that Texans use much more electricity for other appliances - other than space heaters, water heaters, air conditioners, or refrigerators - compared with Californians. I can surmise this is likely not due to residential electricity prices, as residential electricity prices in the two states diverge over the study period, while electricity consumption in these other appliances does not much diverge in the two states over the same period. The data is consistent with the theory that some characteristic of Texas's residential buildings, such as less building energy efficiency, is driving systematically higher electricity consumption in Texas homes (as compared with electricity consumption in California homes).

Thus, in all, evidence suggests the divergence in electricity consumption in residential buildings, in California and Texas, can be attributed to two factors:

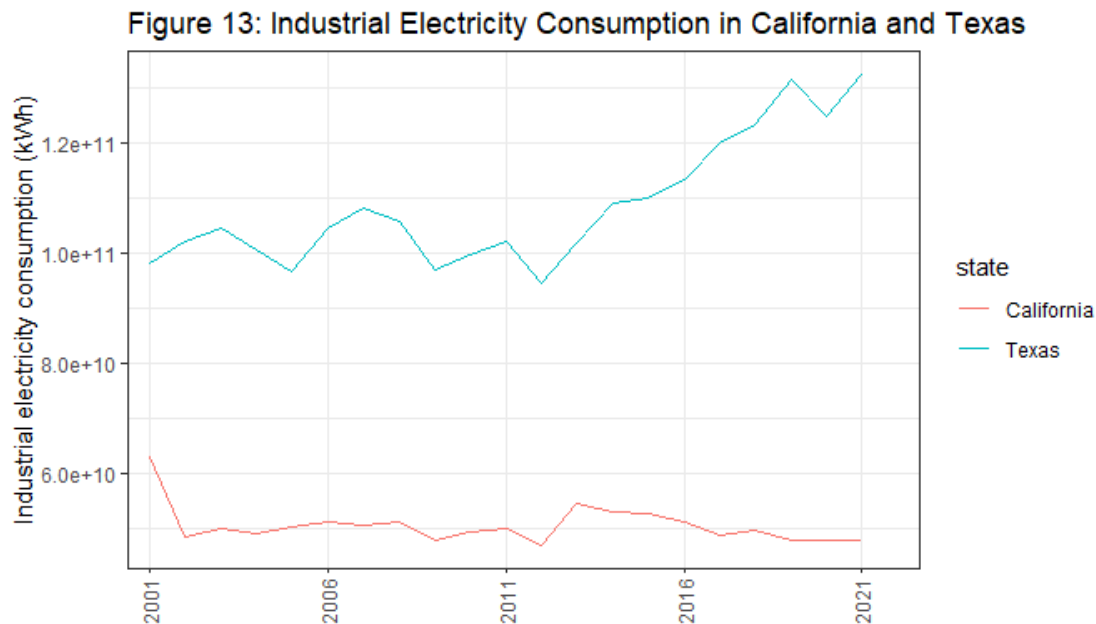
1. Consistent, much higher per capita electricity consumption in residential buildings, owing to the hotter climate and, possibly, to characteristics of the Texas building stock (such as less energy efficiency).

2. Faster population growth in Texas than in California over the study period (2001-2021).

### Industrial Use

I now turn to another category of electricity consumption: electricity consumption in industry (Figure 13). As defined by the US Energy Information Administration, the industrial sector “consists of all facilities and equipment used for producing, processing, or assembling goods. The industrial sector encompasses the following types of activity[:] manufacturing... agriculture, forestry, fishing and hunting... mining, including oil and gas extract... and construction.” (EIA 2025b)

Since the mid-2000s, industrial electricity consumption has been relatively constant in California, while industrial electricity consumption has steadily increased in Texas over this same time period.



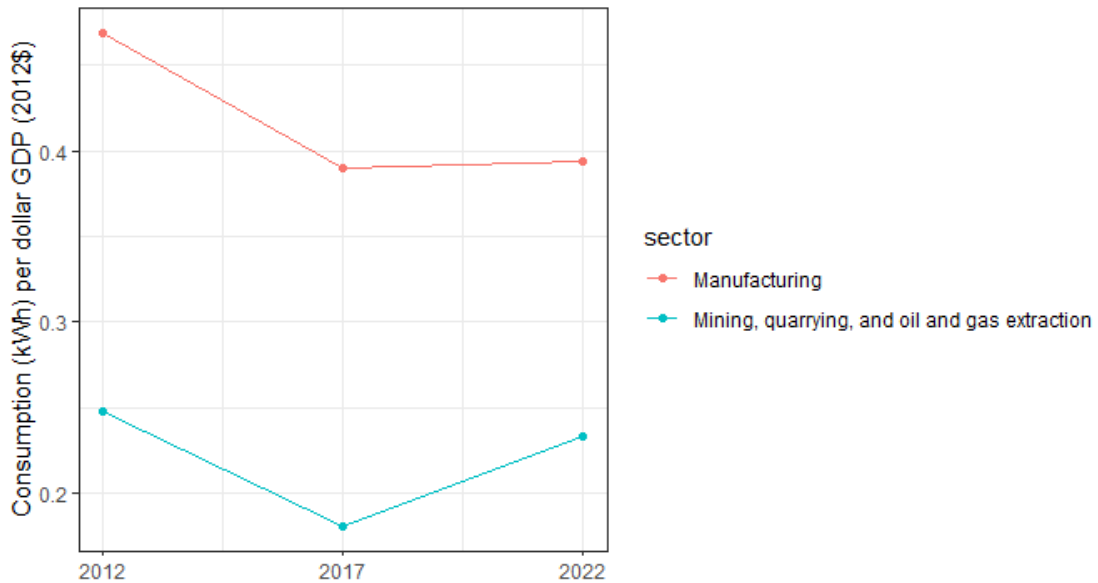
This disparity cannot be explained by the amount of aggregate growth of the relevant sectors: as we can see in Figure 4, above, the amount of GDP in agriculture or construction in California and Texas is relatively similar over the study period, while the GDP growth California

has seen in manufacturing roughly mirrors the GDP growth Texas has seen in mining and extraction.

Some commentators have suggested that Texas's higher electricity use can be explained by the makeup of Texas's economy – that Texas hosts more energy-intensive industries, compared with California. Again, however, the data does not support this assertion. As previously stated, California and Texas had very similar amounts of GDP from construction and agriculture over the period. Where the two economies' "industrial sectors", as defined by the EIA, differ is that California has seen more growth in manufacturing, while Texas has seen more growth in extraction/mining.

To test whether the fact that California has more manufacturing, while Texas has more mining, might explain the disparity in Texas and California's industrial electricity consumption, I calculated the average electricity consumption per real dollar GDP in the manufacturing sector, compared with the same in the mining/extraction sector, for the years 2012, 2017, and 2022 (Figure 14). As can be seen in Figure 14, nationally averaged, the manufacturing sector uses more electricity per dollar of real GDP, compared with the mining/extraction sector. Thus, I would not expect the parallel growth of manufacturing in California and mining/extraction in Texas to result in more electricity consumption in Texas, compared to in California.

Figure 14: Electricity consumption per dollar of real GDP, national average



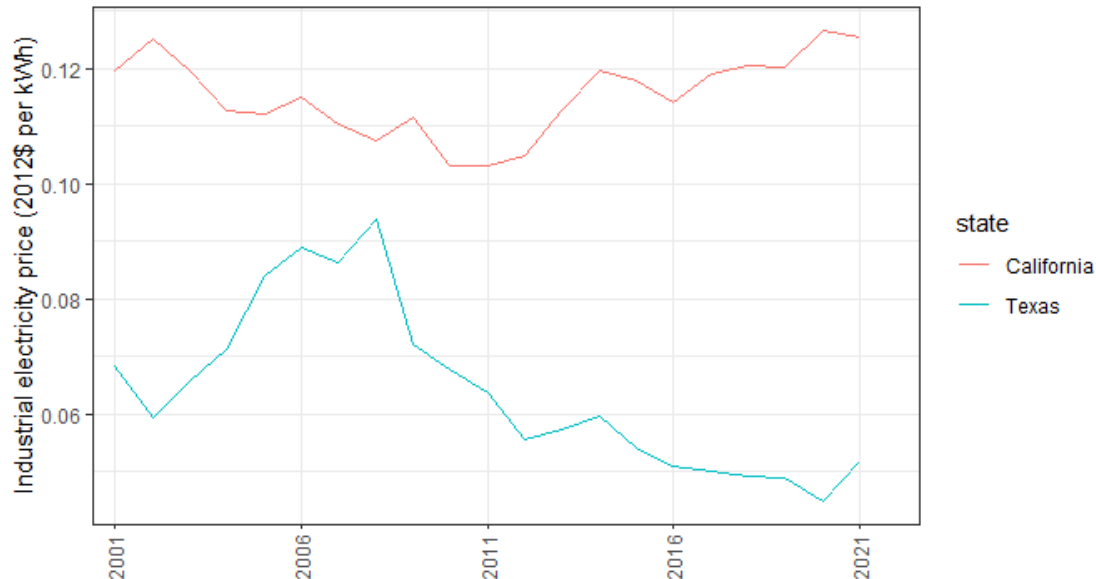
Alternatively, it could be the case that, while manufacturing is generally more electricity intensive than extraction, the particular subset of the manufacturing industry operating in California is less electricity intensive. However, available evidence suggests that this is likely not the case. Levinson (2013) tested whether low electricity use in California’s manufacturing sector is due to the particular manufacturing industries present in the state and found the opposite; California uses much less electricity than we would expect, given the specific manufacturing industries housed in California and the average electricity intensity of each industry. This is not a direct comparison against electricity use in the extraction sector, but it is more evidence that the makeup of the economy does not explain California’s low industrial electricity consumption. Overall, the evidence simply is not there to support the idea that California has low industrial electricity consumption because of the mix of industries in the state.

Another, more plausible cause of the differing industrial consumption trends are the differing retail prices for electricity in the industrial sector in each state. Figure 15 displays real retail electricity prices in the industrial sector, in Texas and California, over the study period. Since

the mid-2000s, industrial electricity retail prices and industrial electricity consumption are roughly inversely correlated in the two states: in Texas the retail price for electricity in the industrial sector has fallen over time, and industrial electricity use has grown, while in California the retail price has increased and industrial electricity use has remained flat.

The data is therefore consistent with the theory that the price of electricity is affecting electricity use - that industry is opting to use more electricity when it is cheaper and less when it is more expensive. This is also what basic economics would predict: if the cost of a production input increases, firms that produce goods will often look to use less of that input to keep costs down.

**Figure 15: Average Industrial Electricity Price in California and Texas**



It has also been suggested – see, for example, the discussion in Levinson (2013) – that energy efficiency may account for some of California’s low electricity use in industry. I have no way to measure overall energy efficiency in the industrial sector to test this proposition.

That said, the most plausible argument for energy efficiency would likely posit efficiency as one of multiple factors suppressing industrial electricity use in California. Let us imagine that energy efficiency, alone, caused California to have flat industrial electricity use over much of the

study period. This would mean that industry in California is so overwhelmingly more efficient, and efficiency is so effective at decreasing overall energy use, that the growth of extraction in Texas has caused a large increase in electricity use, while the growth of a similarly electricity-intensive industry in California has not increased electricity consumption *at all*. This is a very strong claim; more likely, if efficiency has reduced electricity consumption in industry in California, it has done so in tandem with other factors.

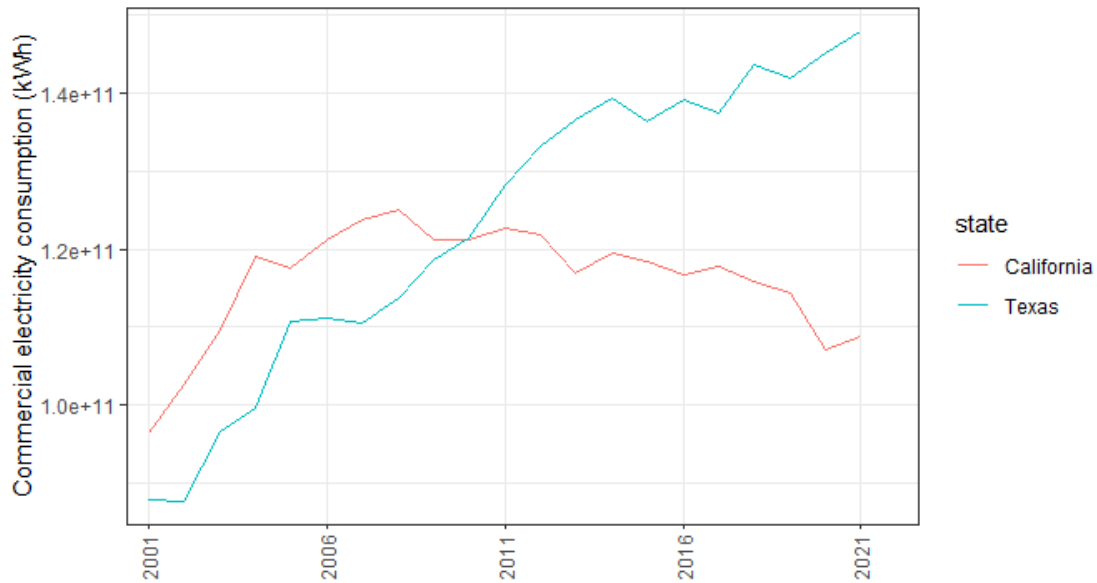
Overall, it appears likely that industrial electricity retail prices are at least partly responsible for the differing electricity consumption trends in Texas and California. Higher energy efficiency in California may also be a cause of the differing trends, but without good data on aggregate energy efficiency in industry, I cannot know for sure.

### Commercial Use

The third category of electricity consumption is consumption in the commercial sector. The commercial sector includes all energy uses needed to power businesses and business offices, including energy for “space heating, water heating, air conditioning, lighting, refrigeration, cooking, and running a wide variety of other equipment.” (EIA 2025a) I have collected relatively less data on commercial electricity consumption in the two states, compared with residential or industrial electricity consumption, so I cannot attribute commercial electricity consumption to particular causes with as much confidence, compared with attribution for residential or industrial electricity consumption. However, I can at least make a few educated guesses with the data I do have.

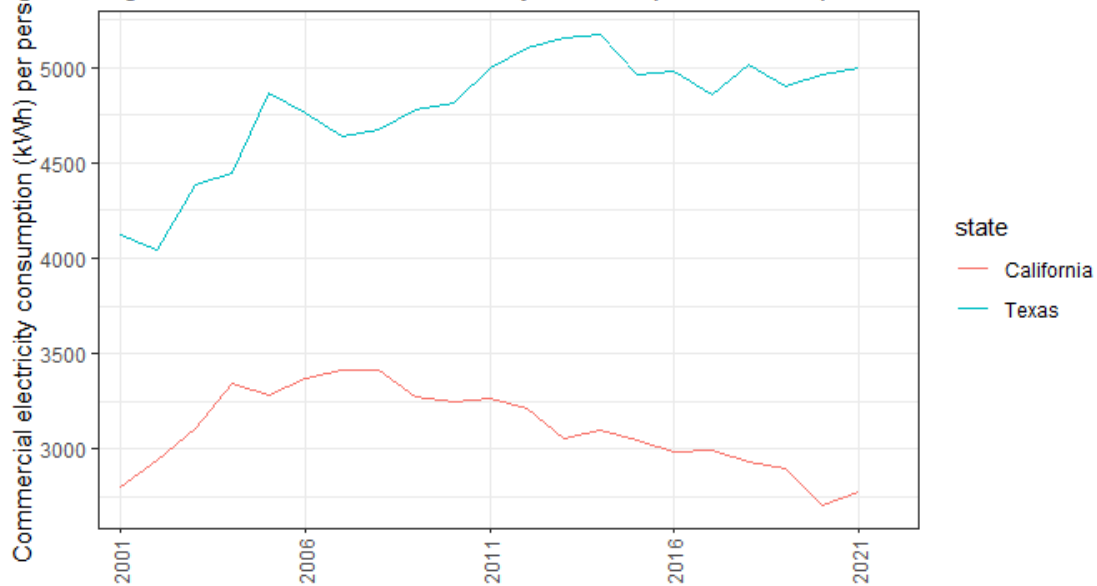
In this category of energy use, too, I see the same trend (Figure 16): from the mid-2000s through 2021, electricity consumption decreased in California but increased in Texas. Notably, these trends are even more pronounced in commercial electricity use than in residential or industrial electricity use.

Figure 16: Commercial Electricity Consumption in California and Texas



We would expect that the number of businesses and business offices would scale with the overall size of the population. Therefore, aggregate electricity consumption numbers may be function both of overall population size in each state and of individual businesses' average electricity use. I can examine individual businesses' average electricity consumption practices, in each state, by looking at per capita commercial electricity consumption (Figure 17).

Figure 17: Commercial Electricity Consumption Per Capita



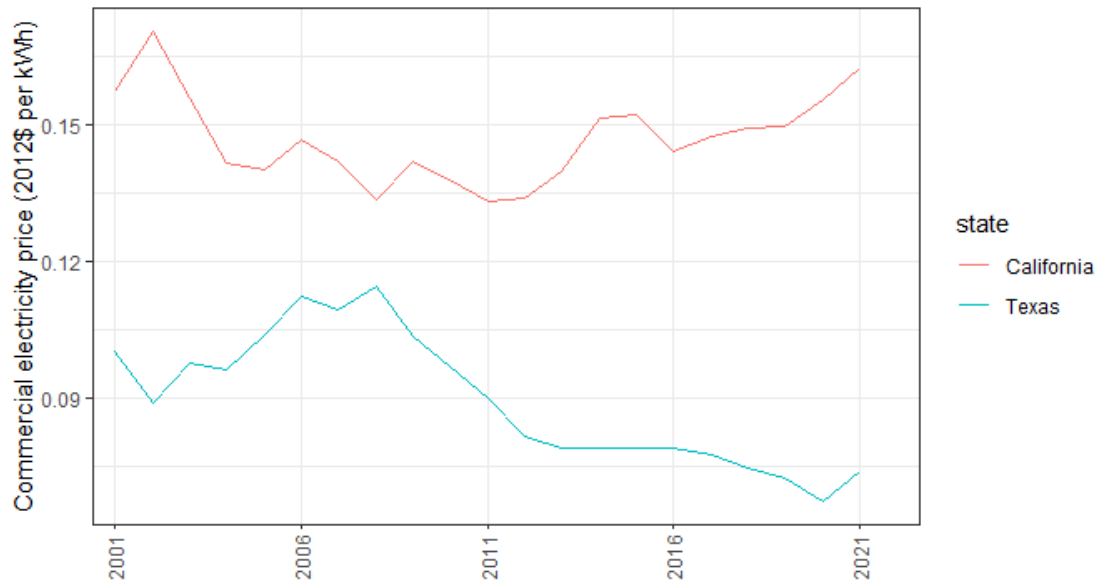
As with residential electricity use, there is a gap between per capita commercial electricity use in Texas and California which is maintained throughout the study period. Per capita commercial electricity use never rises above 3,500 kWh in California and never falls below 4,000 kWh in Texas.

Businesses located in Texas are subject to the same climatic conditions as are residential buildings in the state – most notably, very hot summers. It is very likely that businesses in Texas use more air conditioning than businesses in California, on average, and that this difference accounts for some of the time-invariant gap in per capita commercial electricity consumption between the two states. However, I do not have data which breaks down electricity use by appliance for commercial energy uses, as I have for residential energy uses, to check this theory.

Another observation about per capita commercial electricity consumption is that – unlike with residential consumption – per capita commercial consumption varies over the study period in each state. The question is what might be causing the differing commercial consumption trends, between the two states, over time.

It may be that retail electricity prices are partly driving the changes in commercial electricity consumption, over time, in each state. The average retail price of electricity for commercial uses (Figure 18) and commercial electricity consumption are inversely correlated in California throughout the study period and in Texas from the mid-2000s onwards. The data is thus generally consistent with an explanation that businesses are responding to higher electricity prices by using less electricity, and to lower prices by using more. This is also what economic theory would predict: according to economic theory, businesses will try to maximize profits by keeping down costs, so if electricity becomes more expensive, I would expect some businesses to minimize costs by reducing electricity use where possible.

Figure 18: Average Commercial Electricity Price in California and Texas



It is also possible that the primary driver of California’s per capita commercial electricity consumption over the study period is energy efficiency in appliances or buildings themselves. The problem with this explanation is that California standards have consistently required buildings and appliances to be more energy efficient over the study period; if energy efficiency decreased energy use, and this was the primary driver of the level of electricity consumption, I would expect steadily less electricity consumption in California over the study period. Yet, as illustrated in Figure 16, per capita commercial electricity consumption actually increased between 2001 and 2007. Some other factor, such as retail electricity price, must at least be partially driving the commercial consumption trend in California.

Overall, then, the data and other information I have point to differing population growth, climate, and retail electricity prices as possible causes of the differing commercial electricity consumption trends in Texas and California.

## Discussion

Our investigation has identified several factors which led electricity consumption to diverge in California and Texas. The states' differing electricity consumption in residential buildings over the study period can largely be attributed to: Texas's faster population growth; Texas's hotter climate, which necessitates more air conditioning; and differing features of the states' building stocks – possibly including the fact that residential buildings are generally more efficient in California than in Texas. The states' differing industrial electricity consumption was likely caused, in part, by differing retail electricity prices in industry. Finally, the states' differing electricity consumption in commercial buildings can be attributed partly to Texas's faster population growth and, likely, to Texas's hotter climate and lower retail prices for electricity in commercial buildings.

I undertook this study to identify characteristics of California's economy – and of its larger society – which lead California to have lower demand for electricity than we might expect. Ideally, other jurisdictions' policymakers can learn from the California case and can change their own economies or societies to have these same characteristics. This may lower demand for electricity in the other jurisdictions, making it easier for them to decarbonize electricity use.

This study identified the following factors which lowered electricity demand in California: a mild climate, allowing for relatively little air conditioning use; high retail prices for electricity in industry and in commercial buildings; and (possibly) energy efficiency in residential buildings. Thus, the study results suggest that other jurisdictions which are seeking reduce electricity demand should increase the retail price for electricity used in industry and commercial buildings (more on this below) and should make residential buildings more energy efficient. Furthermore, while policies cannot affect a jurisdiction's climate, except by reducing carbon footprint, policies can push people to live in more temperate parts of a jurisdiction and not live in hotter areas.

Policymakers aiming to reduce electricity demand should adopt such policies.

These results are timely, as there is currently a debate in California policy circles about electricity prices. Severin Borenstein and his colleagues, in particular, have argued that residential electricity prices should be lower (Borenstein et al 2021), contending, among other points, that the current system of residential electricity pricing is regressive and that current residential electricity pricing is slowing down the electrification of other energy uses. This study did not find that residential electricity pricing has a large effect on residential electricity consumption in California – a result that casts serious doubt on Borenstein and colleagues’ second contention.

Beyond this point, however, this study also speaks to the potential benefits of higher electricity prices for decarbonization – potential benefits that Borenstein and colleagues do not acknowledge in the above study. As a society, we are trying to figure out how to generate all necessary electricity from renewable sources. This is a difficult task – and the higher electricity demand, the more difficult the task. I found in this study that higher retail electricity prices for industry and for commercial buildings can constrain total electricity demand. If they can do so without slowing down electrification of various goods – admittedly a big “if” – then, far from inhibiting decarbonization, high retail electricity prices for industry and commercial buildings may help to decarbonize the economy.

The finding that California’s milder climate has resulted in less air conditioning use in residential and (likely) commercial buildings – and, therefore, lower electricity demand – is also relevant. In the early 2020s, many of the United States’s fastest-growing metropolitan areas were located in the South; four (Dallas, Houston, Austin, and San Antonio) were located in Texas (Wilder and Mackun 2024). The fact that many of the fastest-growing metropolitan areas have hot summers may mean more air conditioning use, more demand for electricity, and, ultimately, more

difficulty in decarbonizing electricity use.

## Conclusion

This study examined which factors caused California's annual electricity consumption to decrease from the late 2000s through 2021, in spite of continued population growth, economic growth, and the scaling up of renewable resources. The analysis aimed to identify economic or lifestyle characteristics of a society, which jurisdictions could induce via policy, which would also decrease those jurisdictions' demand for electricity. Lowering demand for electricity would make it easier, in turn, for those jurisdictions to meet electricity demand entirely with renewable sources.

The results suggest that California has decreased electricity consumption through the following mechanisms: relatively slow population growth; a mild climate, which allows residential and commercial buildings to not use much air conditioning; high retail electricity prices for industrial and commercial electricity use; and, possibly, energy efficiency in residential buildings. These results suggest that jurisdictions which aim to limit electricity demand should encourage people to move to temperate areas, increase the retail price of electricity for industry and for commercial buildings, and increase residential buildings' energy efficiency.

Future research could build on this work in several ways. First, and most notably, future research could find a way to measure the level of energy efficiency in residential, commercial, and industrial energy uses and could compare electricity use in Texas and California against these efficiency numbers. As I explained, above, commentators have suggested that Texas and California's differing electricity trends may be partially attributable to California's buildings and appliances being more energy efficient. However, I could not find a good proxy for overall energy efficiency of commercial energy uses, or energy efficiency of industrial energy uses, to test the

theory for these categories of energy consumption. Even for residential energy use, I could only find a very imperfect proxy for energy efficiency: comparing trends in electricity consumption per capita in residential buildings, other than for space heating, air conditioning, and refrigerator use, in the two states. If a researcher could find good proxies for the overall efficiency of residential, commercial, and industrial energy use, in Texas and California, over time, the researcher could determine whether differing levels of energy efficiency are partly responsible for the observed electricity consumption trends.

Second, future research could collect more data on commercial electricity uses, and research could use this data to learn more about the causes of commercial electricity trends in Texas and California. I collected less data on commercial electricity consumption than on residential or industrial electricity consumption, so I could not explain as much of the observed difference in commercial electricity consumption, as compared with the observed differences in residential or industrial electricity consumption. Even when I could identify potential causes of the differing commercial consumption trends, I had less confidence in my causal attribution for commercial consumption than for residential or industrial consumption – owing, again, to my more limited data on commercial consumption. Future research could usefully build on my study by collecting more evidence about electricity use in commercial buildings in both states. This data would allow future research to identify the causes of the states’ differing commercial electricity trends with more certainty.

Third, future research should examine the other two prerequisites to decarbonize electricity supply: generating large amounts of renewable energy and making sure that demand is met through renewable resources, not fossil fuel resources. Electricity can only be decarbonized if the total demand for electricity is limited to an amount that can be met with renewable resources, and this

study has identified several changes to an economy or the surrounding society which can limit electricity demand: people moving to milder climates; the retail price of electricity for commercial or industrial use increasing; and (possibly) residential buildings becoming more energy efficient. However, even if electricity demand is limited to an amount which *could* be met entirely with renewable resources, this does not mean demand *will* be met with renewable resources. Thus, future research should identify policies which ensure all electricity supply, to meet that demand, comes from non-carbon sources.

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## Conclusion

To avoid the worst possible scenarios of future climate change, global society must stop burning fossil fuels for power. Policymakers and scholars have given various accounts of the reasons it is difficult for society to stop burning fossil fuels for energy and, relatedly, of the sorts of policies which might decrease fossil fuel use. However, more research is needed testing these theories and seeing which policies actually decrease fossil fuel use, in practice.

This dissertation helps to fill this gap. To decarbonize the economy, society must (among other tasks) decrease fossil fuel use in vehicles, decrease fossil fuel use in residential buildings, and limit electricity demand to a level which could be met entirely with renewable energy. This dissertation examined empirical evidence from the United States to determine which characteristics of an economy actually produce these outcomes. My hope is that policymakers, armed with my results, can pass policies which inculcate these characteristics in their own economies – thereby decreasing emissions.

My research yielded several findings about which structural characteristics of economies result in lower carbon emissions. My research found that both greater energy efficiency, and higher retail fossil fuel prices, cause people to use less fossil fuels in vehicles and residential buildings. Additionally, my research found that higher retail electricity prices for industrial and commercial energy uses, more temperate climates, and, possibly, more efficient residential buildings cause people to use less electricity.

These findings suggest that, when possible, policymakers looking to decrease direct fossil fuel use in vehicles and in residential buildings should increase the retail price of fossil fuels in vehicles and residential buildings and should increase vehicles' and homes' energy efficiency. Likewise, policymakers looking to limit electricity demand should increase commercial and

industrial retail electricity prices, induce people to settle in more temperate regions, and increase homes' energy efficiency.

Below, I summarize the results from each empirical chapter, and I analyze the empirical takeaways that become apparent when we look at all the results together. I then discuss some policy and academic considerations arising from my dissertation results. I discuss policies jurisdictions could adopt to change their economies in the ways I identified. I question whether the structural characteristics of economies which I identified, which individually decrease fossil fuel use or limit electricity demand, can all be implemented in the same economy. I also respond to the critique that increasing fossil fuel prices hurts poorer people's economic situation. I then return to the three theoretical literatures concerning emission reduction policy which I discussed in the Introduction, and I check whether claims made by each literature are consistent with my empirical results.

## Empirical Results

Empirical chapter one uses fixed effect panel models to assess the effect of various characteristics of a vehicle transportation system on emissions from fossil fuel use in vehicles. The units of observation are state-years, for all fifty United States, for all years from 2008 to 2019. The models control for a variety of factors which may be associated with higher or lower aggregate vehicle use in a state-year, such as the amount of GDP in the transportation and shipping industries and the size of the population. The models also control for the time-invariant effect of a being in a particular state, or the location-invariant effect of being in a particular year, on vehicle emissions. After controlling for these other factors, the models include variables measuring: average miles per gallon of highway travel in the state-year; average retail gasoline prices in the state-year; the percentage of workers who commute on public transit; and the

percentage of workers who work from home. These variables are intended to measure the effect of vehicle fuel efficiency, retail gasoline prices, public transit use, and work from home on vehicle emissions, controlling for other factors.

The models find that, controlling for other factors, vehicle fuel efficiency has the largest effect on emissions of any of my variables of interest: a one percent increase in average vehicle fuel efficiency is associated with approximately a 0.37% decrease in vehicle emissions, on average. Increasing retail gasoline prices also appears to decrease vehicle emissions, partly by pushing people to drive more fuel efficient vehicles, and partly by other means. A 1% increase in the share of workers who work from home is associated with a small decrease in vehicle emissions, on average. The models find that a greater share of people commuting on public transit – and, possibly, greater public transit use, in general – has little effect on emissions.

Empirical chapter two uses the same approach to study the effects of residential natural gas retail prices and building energy efficiency on emissions from fossil fuel use in residential buildings. The units are again state-years, for the fifty United States, for the years 2008-2019. The models control for a variety of potential determinants of total fossil fuel use – including the size of the population, the local climate, the mean household income, and the percentage of building energy uses in a state-year which are electrified. The independent variables of interest are the percentage of residential buildings in the state-year which were constructed before the year 2000, as a proxy for building energy efficiency, and the real, average retail price of natural gas delivered to residential customers. The goal of these models is to measure the effects of increased residential building energy efficiency and increased residential natural gas retail prices on emissions (controlling for other factors).

The models find that, controlling for other factors, increasing residential building energy efficiency, and increasing retail natural gas prices in residential buildings, both decrease residential building emissions. The models find that, controlling for the level of building electrification and many other factors which may affect the amount of fossil fuel use in residential buildings, a 1% increase in the percentage of houses which were built before the year 2000 is associated with a 0.34 to 0.40% increase in emissions, on average. In other words, after controlling for other factors, older (and thus leakier) housing stocks had higher emissions from fossil fuel use, on average.

The models find that retail natural gas prices also have an effect on emissions in residential buildings – albeit a smaller effect than building energy efficiency has. The models find that a 1% increase in the average residential retail price of natural gas is associated with a 0.12% decrease in residential building emissions.

Empirical chapter three investigates the factors which caused electricity consumption trends to diverge in Texas and California between 2001 and 2021. The purpose of this comparison is to determine characteristics of California’s economy or surrounding society which caused electricity consumption in the state to decrease between the mid-2000s and 2021. Policymakers in other jurisdictions could try to inculcate the same features in their own economies to limit electricity demand and, therefore, make it easier to meet all electricity demand with renewable energy.

I find that the following factors caused California to have lower electricity consumption over the study period. California had slower population growth. The state had a colder climate, and its residents consequently used less air conditioning in residential and (probably) commercial buildings. California had higher retail electricity prices for industrial and commercial energy

uses, which decreased electricity consumption for both categories of energy use. Finally, California's more energy efficient residential buildings may also have decreased electricity consumption. These findings suggest that policymakers seeking to decrease electricity demand in their jurisdictions should encourage people to move to milder climates, should increase retail electricity prices for industrial and commercial energy uses, and, possibly, should increase energy efficiency in residential buildings.

### Takeaways: Energy Prices and Energy Efficiency

If we compare the results from our different empirical chapters, the clear takeaways are that higher retail energy prices and greater energy efficiency can decrease energy use. Both regression models found that increasing the retail price of fossil fuels decreases fossil fuel use; the Texas-California comparison likewise found that increased retail electricity prices in California decreased electricity consumption in industry and in commercial buildings. Both regression models found that increasing fossil fuel-powered appliances' average energy efficiency decreases aggregate emissions from those appliances, while the third empirical chapter found that increasing residential building energy efficiency may also decrease electricity use in residential buildings. Clearly, then, higher retail energy prices and greater energy efficiency *can* be effective at reducing emissions.

On the other hand, these interventions will not necessarily have the same effect across all categories of energy use. For example, raising retail energy prices may decrease energy consumption for one type of energy use but have no effect on another type of energy use. Thus, another way to arrive at takeaways from my dissertation is to consider which characteristics of an economy test as effective for reducing specific types of energy use, then to sketch out what an economy would look like if it had all of these characteristics, together.

An economy which combined the characteristics I found to be effective in reducing fossil fuel use in vehicles, reducing fossil fuel use in buildings, and limiting electricity demand would have: energy efficient vehicles and residential buildings; high retail fossil fuel prices for fuels used in vehicles and buildings; and high retail electricity prices for commercial and industrial energy uses. The economy's residents would live in more temperate areas, to reduce air conditioning use in residential and commercial buildings. Finally, my results are agnostic as to whether such an economy should have widespread public transit. My results indicate that such an economy would have relatively low direct fossil fuel use in residential buildings and in vehicle transportation and would have limited electricity demand, making it easier to decarbonize the electricity supply.

I will briefly discuss the policy and academic implications of my findings in the sections that follow. First, in sections focused on policy considerations, I will discuss the policies which can induce the characteristics identified above in an economy, consider the feasibility of implementing all of the above characteristics in the same economy, and address equity concerns associated with increased fossil fuel prices. Second, in a section discussing the academic implications of the dissertation, I will consider whether my findings support the major claims of each of the three literatures on emission reduction policy outlined in the Introduction.

## Policies

Above, I identified structural characteristics of an economy, and the surrounding society, which reduce emissions from on-site fossil fuel consumption in vehicles and residential buildings, or which limit electricity demand: high retail prices for gasoline and residential natural gas; energy efficient vehicles and residential buildings; high retail electricity prices for commercial and industrial electricity use; and more temperate climates. Therefore, I argued,

policymakers looking to decrease on-site fossil fuel use in vehicles and residential buildings, or looking to limit total electricity demand, should pass policies to change their own economies to have these structural characteristics. However, I did not identify which policies can effect these changes – except in empirical chapter three, when I identified policies California has implemented which, likely, have increased the retail price of electricity for many customers.

Fortunately, though, policymakers have already identified policies which increase energy efficiency in vehicles and electric buildings and policies which increase the retail price of various goods. Jurisdictions can require that new cars of a certain size sold in their jurisdictions meet certain requirements, on average, for grams of carbon dioxide equivalent produced per mile (Taylor 2018). Similarly, jurisdictions can adopt residential building energy efficiency codes which require that newly constructed and/or renovated residential buildings meet certain energy efficiency requirements (Szasz 2023).

Governments have also identified several policy tools which reliably increase retail energy prices. A government can use its role as regulator to cause private electric utilities to raise retail prices. For example, California has used its regulatory power over the state’s private utilities to require the private utilities to implement costly programs and has then allowed the private utilities to increase their retail electricity prices to cover the cost of the programs – thus increasing the retail price of electricity (Borenstein et al 2021). As for fossil fuels, governments can levy taxes on fossil fuel producers which are then passed on to consumers, increasing retail fossil fuel prices. The federal gas tax works this way (FHWA 2005; He et al 2022). Governments can also impose emissions trading schemes (“cap and trade”) which limit economic sectors’ carbon emissions and, therefore, their fossil fuel use; neoclassical economic theory suggests that

limiting fossil fuel supply relative to demand in this way will also increase retail fossil fuel prices (Szasz 2023).

I am not well-versed in immigration policy, as this area of policy rarely comes up in discussions about energy use and emission reduction. Therefore, I do not know if governments have identified effective, humane policies which induce people to settle in milder rather than hotter climates. If such policies have not been identified, this would be a good topic for future research.

Migration policy aside, though, governments have already identified policies which, if implemented, increase energy efficiency in vehicles and in residential buildings and increase retail prices for electricity and fossil fuels. These are, respectively, efficiency requirements for new cars, residential building energy efficiency codes, use of government regulatory authority to force utilities to raise retail electricity prices, and carbon taxes and/or cap and trade schemes. Governments seeking to reduce their emissions from fossil fuel use, and to source electricity from non-carbon sources, should seriously consider adopting all of these policies.

### Low-Carbon Attributes Together

This brings up another consideration: to this point, no state economy in the United States matches the theoretical low-emissions economy sketched out above. In 2019, according to my data, no state scored in the top five, among the fifty United States, in more than two of the following: average gasoline price, average residential natural gas retail price, average vehicle fuel efficiency, and average home energy efficiency. It is possible that this is not coincidental: that some phenomenon, not identified in this dissertation, makes it difficult to have an economy with high retail gasoline and residential natural gas prices, high vehicle and home efficiency, and high retail electricity prices for commercial and industrial uses, all at once.

On the other hand, it is also possible that there is no such phenomenon making it difficult for economies to achieve all these characteristics at the same time. If so, then the fact that no state in the United States has implemented policies to optimize on all of these characteristics, simultaneously, presents a path to decrease emissions in the United States. Going forward, each of the fifty United States could change their economy to match the description above – high retail gasoline and residential building natural gas prices, high retail electricity prices for commercial and industrial electricity uses, and energy efficient homes and vehicles. Based on my findings, changing vehicles, residential buildings, and energy prices in this way should decrease CO<sub>2</sub> emissions in the United States.

### High Fossil Fuel Prices and Lower Income People

Beyond the possibility that some unidentified phenomenon makes it difficult to have an economy with all of these characteristics, at the same time, there is another potential issue with instituting a high fossil fuel-price, high efficiency economy: the effects of high fossil fuel prices on poor people. Previous authors have argued that raising fossil fuel prices will hurt lower income people who rely on fossil fuels for daily necessities. If low-income people have some energy need and can only meet it by burning fossil fuels, then raising the price of fossil fuels will put the low-income people in a difficult situation. They could spend the same amount on fossil fuels as before, use less fossil fuels overall, and potentially fail to meet their energy needs. Alternatively, they could keep buying the same amount of fossil fuels to meet their energy needs but – given the higher fossil fuel prices – hurt their financial situation in the process. Either way, the critique alleges, raising fossil fuel prices will negatively impact low-income people.

I have a few responses to this critique. First, when we are considering the effects of fossil fuel use on lower-income people, we cannot only consider the short-term effects of having

access to cheap fuel; we must also consider the long-term effects on people of climate change, caused by fossil fuel use. Climate change is expected to increase the frequency and severity of natural disasters, and a large literature finds that natural disaster events generally hurt lower-income people more than their higher-income counterparts (e.g., Tierney 2007, Klinenberg 2015). In higher emission scenarios, climate change may also cause the failure of major breadbaskets, mass conflict, and mass migration (King et al 2015; Xu et al 2020) – all of which will also hurt lower-income people. So, even if raising fossil fuel prices does hurt lower-income people in the short term, if raising these prices decreases fossil fuel use as planned, raising prices may actually benefit lower-income people in the long term.

Second, if the economy decarbonizes as intended, then increasing fossil fuel prices will only cause shortfalls in people’s ability to meet energy needs in the short term. In the longer term, energy for these needs will come from electricity or some other lower-carbon fuel (e.g., biomass). As long as these other energy sources remain affordable for lower-income people, high fossil fuel prices should hopefully not stop people from meeting their energy needs in a decarbonized future.

Third, policymakers might be able to enact other policies which help low-income people’s economic situation, at the same time that policymakers raise fossil fuel prices – so people’s overall economic situation does not worsen. Aronoff et al (2019: 80) argue that increasing access to higher education, instituting government-run healthcare, and funding childcare could improve people’s lives, without causing large amounts of fossil fuel use: they write that “care and education are inherently low-carbon.” Whether the authors are correct that care and education work, in particular, are low-carbon, this argument gets at an important point. There may be policies which can improve low-income people’s lives but which do not require

much fossil fuel use. It might be possible to pair such policies with higher fossil fuel prices to decrease aggregate fossil fuel consumption, without worsening low-income people's economic situation.

### Literatures on Emission Reduction

Now that I have discussed the policy implications of my findings, I turn now to potential academic takeaways. In the Introduction, I noted that several literatures have made theoretical claims about which policies can reduce carbon emissions, but that more empirical work is needed to test these different claims. I thus argued that the most pressing task for research on emission reduction policies, in our current moment, “is to bring the full weight of empirical evidence to assess which, if any, of these arguments are *correct*.” In the empirical chapters, I discussed theoretical debates about how to reduce fossil fuel use in vehicles and in residential buildings and about why California has lower electricity demand than Texas, and I weighed in on these debates using empirical evidence. However, beyond specific debates about this or that sector, the literature on policies to reduce emissions can generally be sorted into three distinct groups, each with their own perspectives on which policies can decarbonize the economy – as I explained in the Introduction. My dissertation findings can also be used as an empirical check for these three groups' claims about which sorts of policies successfully decarbonize an economy.

As I explained in the Introduction, the theoretical literature on climate policies to reduce emissions can be demarcated into several groups, each with its own view of which policies will reduce emissions. First, there is a policy literature which looks at decarbonization as a four-part process: electrify as many energy uses as possible, find low-carbon fuel sources for energy uses which cannot be electrified, source electricity exclusively from low-carbon sources, and increase energy efficiency wherever possible. The policy literature notes technological or fiscal “barriers”

getting in the way of electrifying or increasing energy efficiency in particular energy use cases and identifies “solutions” which could be implemented to overcome these “barriers.” Second, there is an academic literature from Economics which views climate change as an “externality,” in which those selling and buying fossil fuels do not pay the full cost of fossil fuel use, and which advocates for price adjustments to fossil fuels to “internalize” the “externality.” Third, there is a left-wing academic literature which argues that the capitalist economic system, and possibly other social systems which interlock with this economic system, are responsible for climate change. Some left-wing academics believe society must abolish the capitalist economic system, and possibly other interlocking social systems, to stop burning carbon or otherwise hurting the environment; other left-wing academics believe that, short of abolishing these social systems, environmental harm can be reduced with policies which target the mechanisms within existing social systems causing this harm. For example, York and Bell (2019) argue that a large share of fossil fuel use, historically, has been caused by the conjunction of the capitalist system, which incentivizes companies to maximize short-term profits, and the availability and short-term profitability of fossil fuels as a resource. They have therefore argued that making fossil fuels scarcer or more expensive may reduce aggregate fossil fuel use.

My empirical results offer some supportive evidence and some contradictory evidence for each perspective. My finding that the effect of particular changes to the economy (e.g. higher energy prices, or greater energy efficiency) varies, depending on the category of energy use, fits well with the policy literature. The policy literature’s authors think about specific use cases in which people or organizations burn fossil fuels. They implicitly expect the challenges associated with reducing fossil fuel use to vary from use case to use case – and, consequently, they also expect the policy solutions which will effectively reduce fossil fuel use to vary case-to-case.

These authors, therefore, would probably not be surprised to hear my finding that the effects of higher energy prices or energy efficiency vary depending on the use case. The policy literature also regularly cites energy efficiency as an important tool to decrease fossil fuel use in various sectors (see, for example, Taylor 2018). This fits with my finding that vehicle and residential building energy efficiency decrease fossil fuel emissions, and with my finding that residential building efficiency may reduce electricity demand.

On the other hand, in my experience, it is fairly rare for local, regional, state, or federal United States governmental entities to discuss large increases in fossil fuel prices as a way to greatly decrease carbon emissions. Yet, my findings suggest that increasing fossil fuel prices does decrease fossil fuel consumption, at least for petroleum and residential natural gas. I also find that increasing retail electricity prices for commercial and industrial uses decreases electricity demand for those same uses – which might help to limit overall demand to levels which could be met with renewable resources. It may be that the policy literature does not consider large increases in carbon prices as a potential decarbonization strategy, in spite of this dissertation research and other research findings (Sterner 2007; Tietenberg 2013; Szasz 2023), because, at least in the United States, neither large corporations nor the general public support large price increases (Cullenward and Victor 2020; Stoll and Mehling 2021).

My empirical findings also offer both supporting and contradictory evidence for the economics and the left-wing social science literatures. Both the economics literature (Stern 2007; Nordhaus 2008) and the left-wing social science literature (York 2006) have argued that companies decide how much of a resource to use based on what will maximize profits; thus, both literatures agree that many companies will respond to a good's price increasing by using less of the good (Stern 2007; Nordhaus 2008; York and Bell 2019). This claim is consistent with my

finding that increasing retail electricity rates for commercial and industrial uses decreases electricity demand for the same. The economics literature also claims that raising the market price of fossil fuels will cause consumers to use less of these goods. This claim is consistent with my finding that higher petroleum and residential natural gas prices result in lower emissions.

That said, my findings do not fully support the economics literature and left-wing social science literature's positions on energy efficiency. The literatures argue that, by decreasing the amount of energy needed for a particular energy use – say, driving a certain distance, or heating one's house to a certain temperature – efficiency makes that energy use cheaper; people may respond by doing that energy use more often. Additionally, people may take some of the monetary savings from energy efficiency and spend them on other goods and services which also require energy. For these reasons, both economists and left-wing social scientists expect that aggregate energy savings from efficiency will be smaller than one would expect, based on the number of energy uses before the efficiency improvement and the amount of energy saved per use (Herring 2006; York 2006; York and McGee 2016).

My findings are consistent with this view, to an extent. In both empirical chapter one and empirical chapter two, one percent changes in my proxies for efficiency are associated with less than one percent changes in emissions, controlling for other factors. This may indicate that, as scholars predict, higher energy efficiency causes people to use energy more often, limiting the reductions in energy use from efficiency.

Yet, I still find that increasing energy efficiency in vehicles and residential buildings causes large decreases in fossil fuel emissions. The simple explanation for this finding is that energy efficiency *does* decrease aggregate energy use in cars and residential buildings in the United States, resulting in decreased fossil fuel use and carbon emissions. In fact, both of my

regression models found that efficiency was *more* effective than the other tested interventions at reducing energy use – a result that neither the economics literature nor the left-wing social science literature predict.

Overall, then, my findings are consistent with some of the claims made by each literature and inconsistent with other claims made by each literature. More empirical studies are needed to check my results. If, however, future research corroborates my findings, then researchers working within each literature should think about why their expectations – about which changes to an economy will or will not decrease emissions – are not entirely borne out by evidence.

## Conclusion

This dissertation has examined empirical evidence to identify structural characteristics, which policymakers could aim to induce in an economy, which would lower the economy's fossil fuel footprint. The dissertation finds that high retail gasoline and residential natural gas prices and vehicle and residential building energy efficiency decrease direct fossil fuel use in vehicles and residential buildings. The dissertation also finds that people living in more temperate climates, high retail electricity prices for industrial and commercial uses, and, possibly, residential building energy efficiency decrease an economy's electricity demand. (Limiting electricity demand may be necessary to source all electricity from low-carbon sources.) Thus, my dissertation finds that, to lower carbon emissions, policymakers should seek to: increase vehicle and residential building energy efficiency; increase retail prices for gasoline and residential natural gas; increase retail electricity prices for commercial and industrial energy uses, and induce people to live in more temperate climates.

Future research could investigate other structural characteristics an economy can have, which result in relatively low emissions. Research could examine what economic characteristics

result in low fossil fuel use in commercial buildings or in low emissions from cement and steel production.

As noted in empirical chapter three, decarbonizing electricity is a three-part task: society must generate large amounts of electricity from low-carbon sources, limit electricity demand to levels that can be met entirely with low-carbon electricity, and ensure that electricity demand actually *is* met using low-carbon electricity. This dissertation examined structural characteristics of the economy which can help accomplish the second of these tasks. However, more research is needed examining policies and structural characteristics of the economy that accomplish the other two tasks.

Nonetheless, this dissertation's findings are significant. The findings identify specific characteristics of an economy, which policies can aim to induce, which will likely reduce the economy's emissions.

Thus, I end on a hopeful note. Our fate as a species is not yet decided. We can use social science research to identify, piece by piece, what a low-carbon economy would look like, and we can enact policies to change our economy to match. If we identify, through careful research, the characteristics of a low-carbon economy – and if we change our own economy to make it low-carbon – we can still decrease greenhouse gas emissions. Perhaps we can limit emissions enough to avoid the worst potential effects of climate change.

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## Supplement 1

### Background

As I explained in Empirical Chapter 1's Data and Methods section, I am seeking to learn if my vehicle emission regression models have similar findings, concerning the effect of each independent variable of interest, if I include different variables in my models. If my regression models have similar findings, even when I make some different decisions about which variables I include in the models, this would indicate that my findings are correct, not a function of the particular variables I include or exclude. In this supplement, as a first test of my vehicle regression findings' sensitivity to including or excluding different variables, I re-run my vehicle emission regression models including only one independent variable of interest in each regression model.

In Table S1 and S2, each, Models 1 through 4 include only one of the independent variables of interest, while Models 5 and 6 reproduce the main vehicle regression models (to make comparison with the models which only include one variable of interest easier).

The models in Table S1 use the count variable which increases by one for each year that Democrats controlled the state's House, each year they controlled the Senate, and each year they controlled the Governorship as my proxy for cumulative Democrat control of state government. The models in Table S2 use the count variable which increases by one for each additional year the Democrats have had a "government trifecta" as the proxy for cumulative Democrat control of state government.

### Results

**Table S1: Effect of characteristics on CO<sub>2</sub> emissions in vehicles (incl. one variable of interest per model, using first proxy for Dem control)**

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
log(pop_people)	0.96 *** (0.15)	0.90 *** (0.15)	0.91 *** (0.14)	0.86 *** (0.15)	1.01 *** (0.15)	1.00 *** (0.15)
log(age_dep)	0.36 (0.19)	0.21 (0.19)	0.38 * (0.18)	0.30 (0.19)	0.26 (0.19)	0.34 (0.18)
log(pct_urban)	0.04 (0.31)	0.07 (0.31)	0.22 (0.29)	0.13 (0.31)	-0.04 (0.31)	0.11 (0.30)
log(house_inc_2012dollars)	0.29 * (0.14)	0.22 (0.14)	0.12 (0.13)	0.27 (0.14)	0.24 (0.14)	0.12 (0.14)
log(hdd + 1)	0.02 (0.03)	0.01 (0.03)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)
log(cdd)	-0.02 (0.01)	-0.03 * (0.01)	-0.02 (0.01)	-0.02 * (0.01)	-0.02 (0.01)	-0.02 (0.01)
log(state_dem_c + 1)	-0.01 (0.02)	-0.01 (0.02)	-0.01 (0.01)	-0.01 (0.02)	-0.00 (0.02)	-0.00 (0.02)
log(pct_clim_cause_hum)	-0.08 (0.06)	-0.09 (0.06)	-0.08 (0.06)	-0.10 (0.06)	-0.06 (0.06)	-0.05 (0.06)
log(gdp_tran_2012dollar)	0.14 *** (0.03)	0.13 *** (0.03)	0.13 *** (0.03)	0.13 *** (0.03)	0.14 *** (0.03)	0.13 *** (0.03)
log(gas_price_2012dollars)	-0.18 * (0.08)				-0.21 ** (0.08)	-0.13 (0.07)
log(pct_work_home)		-0.06 (0.03)			-0.08 * (0.03)	-0.06 (0.03)
log(hw_mpg)			-0.39 *** (0.05)			-0.37 *** (0.05)
log(pct_transit)				-0.00 (0.03)		-0.01 (0.03)
R <sup>2</sup>	0.24	0.23	0.30	0.23	0.24	0.31
Adj. R <sup>2</sup>	0.14	0.13	0.21	0.13	0.14	0.21
Num. obs.	600	600	600	600	600	600

**Table S2: Effect of characteristics on CO<sub>2</sub> emissions in vehicles (incl. one variable of interest per model, using second proxy for Dem control)**

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
log(pop_people)	1.00 *** (0.15)	0.94 *** (0.14)	0.94 *** (0.14)	0.90 *** (0.14)	1.04 *** (0.15)	1.01 *** (0.14)
log(age_dep)	0.37 * (0.19)	0.20 (0.19)	0.37 * (0.18)	0.28 (0.18)	0.27 (0.19)	0.34 (0.18)
log(pct_urban)	0.08 (0.31)	0.11 (0.31)	0.23 (0.29)	0.18 (0.31)	-0.00 (0.31)	0.12 (0.30)
log(house_inc_2012dollars)	0.27 * (0.14)	0.20 (0.14)	0.11 (0.13)	0.25 (0.14)	0.23 (0.14)	0.12 (0.14)
log(hdd + 1)	0.02 (0.03)	0.01 (0.03)	0.01 (0.03)	0.02 (0.03)	0.02 (0.03)	0.01 (0.03)
log(cdd)	-0.02 (0.01)	-0.03 * (0.01)	-0.02 (0.01)	-0.02 * (0.01)	-0.02 (0.01)	-0.02 (0.01)
log(dem_trif_c + 1)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
log(pct_clim_cause_hum)	-0.10 (0.06)	-0.12 * (0.06)	-0.10 (0.06)	-0.13 * (0.06)	-0.08 (0.06)	-0.06 (0.06)
log(gdp_tran_2012dollar)	0.14 *** (0.03)	0.13 *** (0.03)	0.13 *** (0.03)	0.13 *** (0.03)	0.15 *** (0.03)	0.13 *** (0.03)
log(gas_price_2012dollars)	-0.20 ** (0.08)				-0.22 ** (0.08)	-0.13 (0.07)
log(pct_work_home)		-0.07 (0.03)			-0.08 * (0.03)	-0.06 (0.03)
log(hw_mpg)			-0.40 *** (0.05)			-0.37 *** (0.05)
log(pct_transit)				-0.01 (0.03)		-0.01 (0.03)
R <sup>2</sup>	0.24	0.23	0.30	0.23	0.25	0.31
Adj. R <sup>2</sup>	0.14	0.13	0.21	0.13	0.15	0.21
Num. obs.	600	600	600	600	600	600

In both Tables S1 and S2, my regressions which include only one variable of interest and

my regressions which include multiple variables of interest have very similar findings as to the effect on vehicle emissions of a higher percentage of workers working from home, a higher percentage of workers taking public transit to work, and higher average vehicle miles per gallon on highways. Thus, my results concerning the effects of these variables of interest on emissions are not sensitive to whether my regressions include all independent variables of interest in the same model, or only include one independent variable of interest at a time.

The regression models which include the average, real retail price of gasoline, but not the other independent variables of interest (Tables S1 and S2, Model 1), and the regression models which include retail gasoline price *and* the share of workers working from home (Tables S1 and S2, Model 5), have similar findings as to the effect of gasoline price on emissions. However, the models which only include the average, real retail price of gasoline have different findings, as to the effect of increased gasoline price, compared to the models which also include a variable for average vehicle miles per gallon on highways (Tables S1 and S2, Model 6). This is evidence that my results, concerning the effects of retail gasoline price on emissions, may be sensitive to the inclusion/exclusion of my variable measuring average vehicle miles per gallon on highways, but not sensitive to the inclusion/exclusion of my variable measuring the share of workers who work from home.

## Supplement 2

### Background

In this supplement, Tables S3 and S4, I test whether my residential building emission regression models have similar findings concerning the effects of my independent variables of interest, if I only include one independent variable of interest in each model, compared with if I include both independent variables of interest in the same model.

Tables S3 and S4 differ in the variable used as a proxy for cumulative Democrat control of state government over time. The models in Table S3 use a count variable which increases by one each year Democrats controlled the state's House, each year Democrats controlled the state's Senate, and each year Democrats controlled the state's Governorship. The models in Table S4 use a count variable which increases by one each additional year the Democrats have had a "government trifecta".

In each table, Model 1 and Model 2 each run a regression only including one independent variable of interest. Model 3 reproduces one of the main residential building regression models for comparison; Model 3 includes both independent variables of interest.

### Results

**Table S3: Effect of characteristics on CO<sub>2</sub> emissions in residential buildings (incl. one variable of interest per model, using first proxy for Dem control)**

	Model 1	Model 2	Model 3
log(pop_people)	0.96 *** (0.18)	0.65 *** (0.14)	0.84 *** (0.18)
log(age_dep)	-0.55 ** (0.18)	-0.71 *** (0.17)	-0.61 *** (0.18)
log(pop_house)	-0.86 ** (0.32)	-0.23 (0.33)	-0.31 (0.33)
log(house_inc_2012dollars)	-0.24 * (0.12)	-0.28 * (0.12)	-0.26 * (0.12)

	Model 1	Model 2	Model 3
	(0.12)	(0.12)	(0.12)
log(pct_urban)	0.49	0.61 *	0.64 *
	(0.28)	(0.28)	(0.28)
log(hdd + 1)	0.40 ***	0.36 ***	0.37 ***
	(0.03)	(0.03)	(0.03)
log(cdd)	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)
log(state_dem_c + 1)	-0.02	-0.01	-0.02
	(0.02)	(0.02)	(0.02)
log(pct_clim_cause_hum)	-0.08	-0.06	-0.09
	(0.06)	(0.06)	(0.06)
log(med_rooms_house)	0.05	0.06	0.05
	(0.30)	(0.30)	(0.30)
log(pct_house_9rooms)	0.05	0.05	0.04
	(0.09)	(0.09)	(0.09)
log(pct_elec_res)	-0.78 ***	-0.79 ***	-0.78 ***
	(0.05)	(0.05)	(0.05)
log(pct_house_20century)	0.48 *		0.40
	(0.22)		(0.22)
log(res_ng_price_2012dollars)		-0.12 ***	-0.12 ***
		(0.03)	(0.03)
R <sup>2</sup>	0.65	0.66	0.66
Adj. R <sup>2</sup>	0.60	0.61	0.61
Num. obs.	600	600	600

**Table S4: Effect of characteristics on CO<sub>2</sub> emissions in residential buildings (incl. one variable of interest per model, using second proxy for Dem control)**

	Model 1	Model 2	Model 3
log(pop_people)	0.94 ***	0.65 ***	0.83 ***
	(0.18)	(0.14)	(0.18)
log(age_dep)	-0.60 ***	-0.74 ***	-0.66 ***
	(0.18)	(0.17)	(0.18)
log(pop_house)	-0.79 *	-0.21	-0.27
	(0.31)	(0.33)	(0.33)
log(house_inc_2012dollars)	-0.26 *	-0.29 *	-0.28 *
	(0.12)	(0.12)	(0.12)

	Model 1	Model 2	Model 3
log(pct_urban)	0.45 (0.28)	0.57 * (0.28)	0.61 * (0.28)
log(hdd + 1)	0.40 *** (0.03)	0.37 *** (0.03)	0.37 *** (0.03)
log(cdd)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)
log(dem_trif_c + 1)	-0.01 (0.00)	-0.01 (0.00)	-0.01 (0.00)
log(pct_clim_cause_hum)	-0.08 (0.06)	-0.06 (0.06)	-0.09 (0.06)
log(med_rooms_house)	0.10 (0.29)	0.08 (0.29)	0.10 (0.29)
log(pct_house_9rooms)	0.03 (0.09)	0.03 (0.09)	0.04 (0.09)
log(pct_elec_res)	-0.78 *** (0.05)	-0.79 *** (0.05)	-0.79 *** (0.05)
log(pct_house_20century)	0.43 * (0.21)		0.34 (0.21)
log(res_ng_price_2012dollars)		-0.12 *** (0.03)	-0.12 *** (0.03)
R <sup>2</sup>	0.65	0.66	0.66
Adj. R <sup>2</sup>	0.60	0.61	0.61
Num. obs.	600	600	600

In Table S3 and Table S4, the models which include one independent variable of interest (Models 1 and 2) and the model which includes both independent variables of interest (Model 3) have similar findings concerning the effects of the variables of interest.

Table S3 Model 1 finds that, controlling for other variables except the price of natural gas delivered to residential customers, a 1% increase in the percentage of housing units built before the year 2000 is associated with a statistically significant 0.48% increase in residential building emissions, on average. By comparison, Table S3 Model 3 finds that, controlling for the same

variables and also the residential retail price of natural gas, a 1% increase in the percentage of housing units built before the year 2000 is associated with a slightly smaller, non-significant 0.40% increase in emissions.

Table S4 Model 1 finds that, controlling for other variables except residential natural gas price, a 1% increase in the share of housing units built before 2000 is associated with a statistically significant 0.43% increase in residential building emissions, on average. By comparison, Table S4 Model 3 finds that, controlling for the same variables *and* residential natural gas retail price, a 1% increase in the share of housing units built before 2000 is associated with a slightly smaller, non-significant 0.34% increase in building emissions.

My regression models which include only one independent variable of interest and my regression models which include both independent variables of interest all find that, controlling for all other variables, a 1% increase in real, average residential natural gas price is associated with a 0.12% decrease in residential building emissions, on average.