# The Economic Determinants of Heat Pump Adoption

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**Executive Summary**

One concern with subsidies for low-carbon technologies is that they tend to go predominantly to high-income households. Previous research has shown, for example, that the top income quintile receives 60% of subsidies for rooftop solar and 90% of subsidies for electric vehicles. This paper finds that heat pumps are an important exception. Using newly available US nationally representative data, the paper finds that there is remarkably little correlation between heat pump adoption and household income. Nationwide, 14% of US households have a heat pump as their primary heating equipment, and adoption levels are essentially identical for all income levels ranging from the bottom of the income distribution (<$30,000 annually) to the top ($150,000+). Instead, the paper shows that heat pump adoption is strongly correlated with geography, climate, and electricity prices.

**JEL Codes:** H23, L51, Q41, Q42, Q48, Q54

**Keywords:** low-carbon technologies, carbon emissions, distributional impacts, efficiency vs. equity

## I. Introduction

Increased deployment of heat pumps plays a central role in most envisioned pathways for US decarbonization (National Academies 2021; Princeton University 2021; Williams et al. 2021). US electricity generation has become much less carbon intensive (Holland et al. 2020), so moving away from natural gas or other fossil fuels for home heating and toward electric heat pumps offers the potential for large-scale reductions in carbon emissions.

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Policy makers are increasingly introducing subsidies for heat pumps in an effort to accelerate this substitution. For example, US households can now receive a federal income tax credit of up to $2,000 for purchasing and installing a heat pump. This marks a considerable increase compared with the $300 tax credit that was available previously. Many states, cities, and utility districts offer additional subsidies.

One concern that is often raised with regard to subsidies for low-carbon technologies is that they tend to go predominantly to higher-income households. Previous research on US federal clean energy tax credits, for example, finds that the top income quintile receives 60% of tax credits for solar panels and 90% of tax credits for electric vehicles (Borenstein and Davis 2016).

This paper finds that heat pumps are an important exception. Using newly available US nationally representative data, the paper shows that there is remarkably little correlation between heat pump adoption and household income. Nationwide, 14% of US households have a heat pump as their primary heating equipment, and heat pump adoption is essentially identical for all levels of household income, ranging from the bottom of the income distribution (<$30,000 annually) to the top ($150,000+).

This lack of correlation contrasts sharply with the pattern for other low-carbon technologies. Using these same data, the paper documents a sharp gradient with regard to income for electric vehicles, solar panels, LED light bulbs, and energy-efficient clothes washers. Households in the top income category ($150,000+) are, for example, 10 times more likely than households in the bottom income category (<$30,000 annually) to have an electric vehicle and five times more likely to have solar panels.

These findings have potentially large policy implications. Probably most importantly, the lack of correlation between heat pump adoption and income suggests that the distributional impacts of heat pump subsidies are likely to be quite different from the distributional impacts of subsidies for other low-carbon technologies, upending the standard "efficiency-versus-equity" trade-off that has tended to characterize adoption patterns in this context.

Instead, heat pump adoption is shown to be strongly correlated with geography, climate, and energy prices. The correlation between heat pump adoption and electricity prices, for example, is shown to be negative, statistically significant, and robust even in regressions that control for other variables. These patterns are of considerable independent interest and point to where heat pump adoption is likely to occur in the future.

Finally, the paper performs a series of back-of-the-envelope calculations aimed at better understanding the cost-effectiveness of heat pump and electric vehicle subsidies (the latter for comparison purposes). These calculations rely on many strong assumptions, but overall, it appears that these two subsidies yield a similar amount of carbon abatement per dollar. Thus, these two subsidies appear to be quite similar from an efficiency perspective despite having very different distributional implications.

This study contributes to a growing literature on the economics of decarbonization through electrification. Whereas most of the literature has focused on the electrification of transportation (Holland et al. 2016; Li et al. 2017; Li 2019; Burlig et al. 2021; Springel 2021; Xing, Leard, and Li 2021; Muehlegger and Rapson 2022), the electrification of buildings has received relatively less attention (Borenstein and Bushnell 2022b; Davis, forthcoming).

The study is also related to a literature on the distributional impacts of energy policies. Previous papers have examined, for example, gasoline taxes (Poterba 1991; Bento et al. 2009), carbon taxes (Cronin, Fullerton, and Sexton 2019), fuel economy standards (Davis and Knittel 2019), building codes (Bruegge, Deryugina, and Myers 2019), utility rates (Borenstein 2012; Borenstein, Fowlie, and Sallee 2021), and solar panel subsidies (Borenstein 2017; Feger, Pavanini, and Radulescu 2022).

Although the paper focuses on the United States, it has implications for heat pump adoption elsewhere. A recent report by the International Energy Agency argues that heat pumps will play a critical role in global decarbonization efforts. According to the report, 10% of space heating needs worldwide are currently being met with heat pumps, but this would need to increase to approximately 24% by 2030 to meet the carbon abatement goals outlined by the Paris Agreement (IEA 2022).

The paper proceeds as follows. Section II documents the lack of correlation between heat pump adoption and household income, and it contrasts this with correlations for electric vehicles and other low-carbon technologies. Section III provides additional background about heat pumps and a summary of relevant US federal subsidies. Section IV examines geography, climate, energy prices, and other determinants of heat pump adoption. Section V performs back-of-the-envelope calculations aimed at understanding cost-effectiveness, and Section VI concludes.

## II. Technology Adoption and Income

### *A. Heat Pumps*

Figure 1 plots US heat pump adoption rates by household income. Nationwide, 14% of US households have a heat pump as their primary

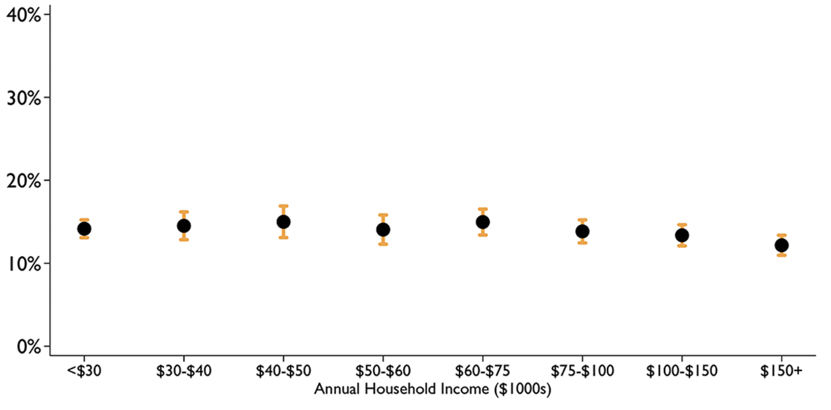


**Fig. 1.** Heat pump adoption by household income. Color version available as an online enhancement.

Notes: This figure shows how the percentage of US households with a heat pump varies with annual household income. These data come from RECS (2020). Households are weighted using RECS sampling weights. Brackets indicate 95% confidence intervals.

heating equipment. As the figure illustrates, the percentage of households with a heat pump is essentially the same for all levels of household income, ranging from the bottom of the income distribution (<$30,000 annually) to the top ($150,000+).

This figure was constructed using household-level microdata from the 2020 iteration of the *Residential Energy Consumption Survey* (RECS; U.S. Department of Energy, Energy Information Administration 2022). Conducted approximately every five years by the US Department of Energy, Energy Information Administration, RECS collects rich data about household energy–related durable goods and behaviors as well as information about household income and other characteristics. The underlying income variable in RECS has 16 categories, but some categories were combined when making this figure; for example, $30–$35 and $35–$40 were combined to make the single category $30–$40.

RECS is a nationally representative survey of the United States. The target population for RECS is all occupied housing units in the 50 states and District of Columbia. The RECS sample is selected using stratified sampling by state to ensure sufficient coverage even in states with relatively small populations. Accordingly, RECS sampling weights are used in all calculations throughout the analysis. An attractive feature of the 2020 RECS is its relatively large sample size. The total sample for the 2020 RECS is 18,496 households, including more than 2,600 households with heat pumps.

As with all surveys, a potential concern is nonresponse bias. The 2020 RECS had a 39% response rate, down sharply compared with the 51% response rate with the 2015 RECS and the 79% response rate with the 2009 RECS. Survey documentation attributes this lower response rate to the 2020 RECS being entirely self-administered.[1] The RECS sampling weights attempt to correct for nonresponse by balancing observable household characteristics, but it is impossible to rule out concerns about unobserved differences between responders and nonresponders.

### B. *Other Technologies*

Figure 2 plots US adoption rates by household income for electric vehicles, solar panels, LED light bulbs, and energy-efficient clothes washers. There is a sharp gradient with regard to income for all four low-carbon technologies. Relative to the lowest income category, households in the

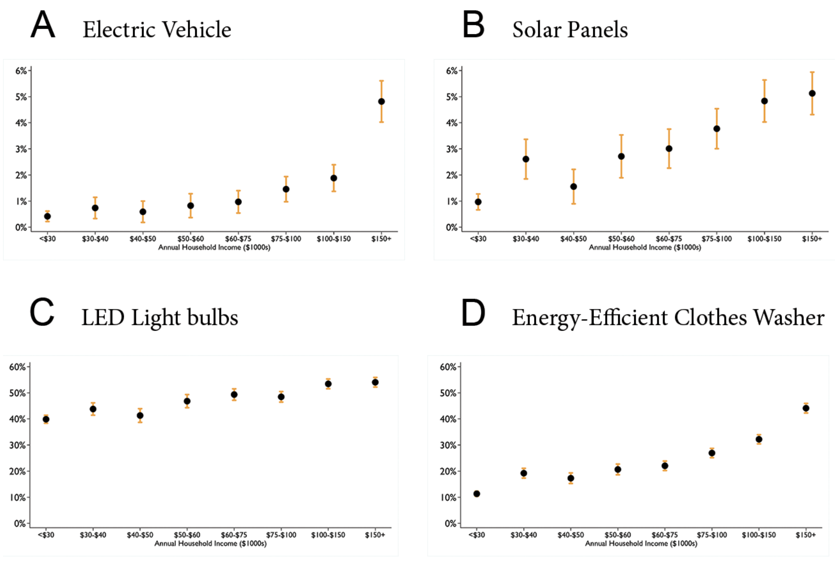


**Fig. 2.** Adoption of other low-carbon technologies by household income. (*A*) Electric vehicle. (*B*) Solar panels. (*C*) LED light bulbs. (*D*) Energy-efficient clothes washer. Color version available as an online enhancement.

Notes: This figure shows how the percentage of US households with low-carbon technologies varies with annual household income. These data come from RECS (2020). Brackets indicate 95% confidence intervals. The category "LED light bulbs" is defined as having "mostly" or "all" LEDs. Energy-efficient clothes washers are defined as being front-loading rather than top-loading.

highest income category are, for example, 10 times more likely to have an electric vehicle and five times more likely to have solar panels.

Baseline adoption levels vary widely across technologies. Electric vehicles and solar panels are relatively rare, with adoption rates in the single digits. LEDs and efficient washers are much more common, with adoption rates ranging from 40% to 55% for LEDs and from 10% to nearly 50% for efficient washers. LEDs, in particular, are much less expensive up front than these other technologies, which helps explain the higher adoption rates.

Previous economic analyses have posited that signaling to others may be an important driver of adoption decisions for low-carbon technologies.[2] If higher-income households derive more utility from this type of signaling, it could help explain the correlation between adoption and income. Interestingly, however, a sharp income gradient is observed both for technologies that are highly visible to other households, such as electric vehicles, and for less visible technologies like clothes washers.

Table 1 summarizes the information from figures 1 and 2. Adoption rates differ little for heat pumps, ranging from 12% to 15% across income categories. In contrast, there is a clear gradient for all other low-carbon technologies. For example, with solar panels, adoption levels range from 1% in the lowest income category to 5% in the highest.

**Table 1**
Technology Adoption by Income

| Income ($1,000s) | Heat Pump (%) | Electric Vehicle (%) | Solar Panels (%) | LED Lights (%) | Efficient Washer (%) |
|---|---|---|---|---|---|
| <$30 | 14 | 0 | 1 | 40 | 11 |
| $30–$40 | 15 | 1 | 3 | 44 | 19 |
| $40–$50 | 15 | 1 | 2 | 41 | 17 |
| $50–$60 | 14 | 1 | 3 | 47 | 21 |
| $60–$75 | 15 | 1 | 3 | 49 | 22 |
| $75–$100 | 14 | 1 | 4 | 48 | 27 |
| $100–$150 | 13 | 2 | 5 | 53 | 32 |
| $150+ | 12 | 5 | 5 | 54 | 44 |
| Test of equality ($p$ value) | .14 | .00 | .00 | .00 | .00 |

Note: This table describes US adoption levels by annual household income for five low-carbon technologies. These data come from RECS (2020). Households are weighted using RECS sampling weights. The last row reports $p$ values from a statistical test for which the null hypothesis is that all eight percentages are equal. Except for heat pumps, there is strong evidence against the null.

These differences across income levels are strongly statistically significant for electric vehicles, solar panels, LEDs, and washers. For each technology, a statistical test is performed for which the null hypothesis is that all eight percentages are equal.[3] The last row of the table reports $p$ values from these tests. With heat pumps, this null hypothesis cannot be rejected ($p$ value = .14). In the other four cases, however, the null hypothesis is firmly rejected ($p$ value = .00 for all four).

## III. Background

Before proceeding, it is helpful to provide some additional background about heat pumps. This content is not crucial for understanding figures 1 and 2, but it is valuable for motivating the exploration of other determinants of heat pumps in Section IV. Subsection III.A provides a basic introduction to heat pumps including what they are and how they work. Subsection III.B describes how much heat pumps cost to purchase and operate. Subsection III.C explains US federal subsidies for heat pumps.

### *A. What Is a Heat Pump?*

Put simply, a heat pump is an air conditioner that can be operated in reverse. Whereas an air conditioner provides cooling, a heat pump provides both heating and cooling. Moreover, because electric heat pumps operate using electricity, they can be substituted for natural gas furnaces and other forms of heating equipment and thus offer the potential to significantly reduce on-site consumption of natural gas, propane, and other fossil fuels used for heating. Heat pumps are widely deployed in both residential and nonresidential settings, though this paper focuses entirely on the former.

Electric heat pumps provide heating using a completely different approach from electric resistance heating. Whereas electric resistance heating converts electricity into heat, a heat pump uses electricity to move heat between the inside and outside of the home. Similar to refrigerators, freezers, air conditioners, and other compressor-based appliances, heat pumps move heat by compressing a refrigerant and then releasing it again. As the refrigerant evaporates (i.e., turns from a liquid into a gas), it absorbs heat, which then can be moved and released as the refrigerant turns back into a liquid.

The advantage of this approach is that heat pumps are considerably more energy efficient than electric resistance heating. Electric resistance heating, with 1 kilowatt-hour (kWh) of electricity, delivers approximately 1 kWh of heat. In contrast, a heat pump, with 1 kWh of electricity, can deliver 2, 3, or even 4 kWh of heat. Again, this is because with a heat pump, electricity is not converted into heat but is used to move heat. Heat pump energy efficiency for heating is typically measured using the coefficient of performance (COP), which is the ratio of the energy delivered to the energy consumed. Heat pump COP typically ranges from 2 to 4.

The energy efficiency of a heat pump depends on the outdoor temperature. Heat pumps are most efficient at relatively high outdoor temperatures (e.g., 60°F) because there is more warmth in the outside air to be moved. Energy efficiency decreases at lower outdoor temperatures because there is less heat outside to be moved, so a heat pump uses more electricity for each unit of heat that it delivers. For this reason, heat pumps are particularly well suited to locations with relatively mild winters.[4]

Heat pump capacity also decreases at lower temperatures. That is, the total amount of heat that can be supplied decreases when outdoor temperatures are low, sometimes making it impossible to sufficiently heat a home. Consequently, in colder locations, heat pumps are often combined with some other form of backup heating. In Kaufman et al. (2019), for example, heat pumps are assumed to be equipped with a backup electric resistance heater that provides additional heat when the building's heating demands exceed the compressor's capabilities.

### B. *Up-Front and Operating Costs*

Table 2 reports up-front costs for selected residential heating and cooling equipment. This information comes from the US Department of Energy and includes purchase and installation costs but not operating costs.

According to these estimates, an air-source heat pump has an up-front cost of $6,900–$8,600, which is $1,600–$2,600 more than a central air conditioner. This incremental cost is less than the up-front cost of a natural gas furnace and, in some cases, less than the up-front cost of electric resistance heating. Thus, heat pumps are particularly attractive for households that are already installing or replacing central air conditioning. This up-front cost for a heat pump does not include any backup heating system for very cold days.

Ground-source heat pumps are considerably more expensive. Whereas air-source heat pumps transfer heat to and from the air, ground-source heat pumps transfer heat to and from the ground, with refrigerant lines running through holes drilled underground. Air-source heat pumps represent 90%

**Table 2**
Up-Front Costs for Selected Residential Equipment

| | |
|---|---|
| Natural gas furnace | \$4,100–\$4,300 |
| Electric resistance furnace | \$1,500 |
| Electric resistance baseboard heaters | \$2,300 |
| Central air conditioner | \$5,300–\$6,000 |
| Air-source heat pump | \$6,900–\$8,600 |
| Ground-source heat pump | \$23,100–\$24,200 |

Note: This table presents up-front costs for selected residential heating and cooling equipment. These cost estimates come from US DOE (2023) and include purchase and installation costs. The table reports estimates for 2022 for equipment with a "typical" or "high" level of energy efficiency. In cases where equipment costs vary between "typical" and "high" or vary by region, this table reports the range. For electric resistance baseboard heaters, the assumed installation size is 6 units, and for ground-source heat pumps, the assumed installation size is 4 tons. Cost estimates have been rounded to the nearest \$100.

of US residential heat pumps in the RECS 2020 and 85% of heat pumps worldwide (IEA 2022). Ground-source heat pumps have certain advantages but tend to have considerably higher initial purchase and installation costs.

In addition to these up-front costs, all heating systems also have operating costs. In the United States, natural gas heating tends to have lower operating cost than electric resistance heating. Based on US average residential prices for electricity and natural gas in 2021, for example, the price per million British thermal units (MMBtu) of heating was \$13 for natural gas and \$40 for electric resistance heating.[5] Operating costs can be considerably lower for heat pumps, depending on the COP. For a COP of 3.0, for example, the price per MMBtu of heating would be \$13, equivalent to natural gas.[6]

These up-front and operating costs illustrate why there would be a regional pattern to heating choices. In warmer states like Florida, households tend to prefer electric heating because of its lower up-front costs. In colder states, however, the low operating costs associated with natural gas tend to make it attractive relative to electric heating. Moreover, where natural gas is not available, a heat pump will often be preferred relative to electric resistance heating based on its considerably lower operating costs.[7]

### C. *US Federal Subsidies for Heat Pumps*

The US Inflation Reduction Act provides income tax credits and direct point-of-sale rebates for heat pumps.[8] Both types of subsidies have various requirements, but there is no specific restriction preventing a household from receiving both a tax credit and direct rebate.

The tax credit is equal to 30% of the up-front cost of a heat pump, up to a maximum of $2,000. For example, if a household spends $6,000 purchasing and installing a heat pump, it can receive a tax credit of $1,800. Available since January 1, 2023, this tax credit was implemented by extending and amending the Energy Efficient Home Improvement Credit, formerly known as the Non-Business Energy Property Credit (Internal Revenue Code Section 25C), which was originally established by the Energy Policy Act of 2005 and subsidizes certain investments that reduce energy consumption in homes. Heat pumps have long been included under this tax credit, but at much lower subsidy levels. For example, as of 2022, a qualifying heat pump could qualify for a maximum tax credit of only $300.

The Inflation Reduction Act also created a grant program called the High-Efficiency Electric Home Rebate Program, which awards grants to states for point-of-sale rebates of up to $8,000 for heat pumps. These rebates are subject to income requirements: (1) households with annual income below 80% of median local income are eligible for a 100% rebate, up to $8,000, (2) households with annual income between 80% and 150% of median local income are eligible for a 50% rebate, up to $8,000, and (3) households with annual income above 150% of median local income are ineligible. In addition to heat pumps, these rebates are available for electric load service upgrades and other electrification investments, up to a total household maximum of $14,000.

As of May 2023, federal and state agencies are finalizing the procedures for distributing rebates. States have some discretion in how they implement these rebates, so there is likely to be variation across states with regard to when these rebates are first available and how income requirements are enforced. Rewiring America, an electrification nonprofit, is reporting that funding for these rebates will likely be distributed to state agencies in 2023, with rebates available to consumers by late 2023 or 2024.

Tax credits and point-of-sale rebates are likely to be used by different types of households. Probably most importantly, the maximum income requirements for the rebates mean that they are supposed to go only to low- and middle-income households. At the same time, there are also subtle factors affecting take-up of tax credits. As emphasized by Borenstein and Davis (2016), these are nonrefundable tax credits. Consequently, there are millions of mostly lower-income taxpayers who are ineligible because they have insufficient tax liability. Moreover, tax credits require households to wait many months before receiving the credit, which also tends to tilt take-up toward higher-income households that are less liquidity constrained.

## IV. Other Determinants of Heat Pump Adoption

This section explores other determinants of heat pump adoption. If not income, then what other factors are correlated with heat pump adoption? Guided by the background provided in the previous section, most of the factors considered in this section have implications for the operating costs and overall effectiveness of heat pumps.

Subsections IV.A, IV.B, and IV.C examine geography, climate, and energy prices, respectively. All three are shown to strongly predict heat pump adoption by US households. Subsection IV.D summarizes these findings and presents evidence on several additional factors that turn out not to be important. Subsection IV.E describes a regression analysis aimed at better disentangling the various factors.

These additional findings are interesting because they point to heat pump adoption having a very different pattern from electric vehicles, solar panels, and other low-carbon technologies. These patterns also have implications about where the tax credits and other subsidies for heat pumps are likely to go.

### *A. Geography*

Figure 3 maps heat pump adoption by state. As with the previous analyses related to household income, this information comes from the RECS 2020. This is the first wave of RECS for which such a state-level analysis is possible. Previous waves identified households in large states, such as Texas and California, but state of residence was not identified for most respondents, so a map like this would not have been possible with the 2015 or 2009 RECS.

As the figure reveals, there is a pronounced regional pattern to heat pump adoption. Heat pumps are most common in Alabama, North Carolina, and South Carolina. In those three states, about 40% of households have a heat pump as their primary heating equipment. Throughout the rest of the South, heat pump adoption rates range between 20% and 36%. In Texas and Florida, for example, 20% and 32% of households have heat pumps, respectively. See table A1 for the complete list of states.

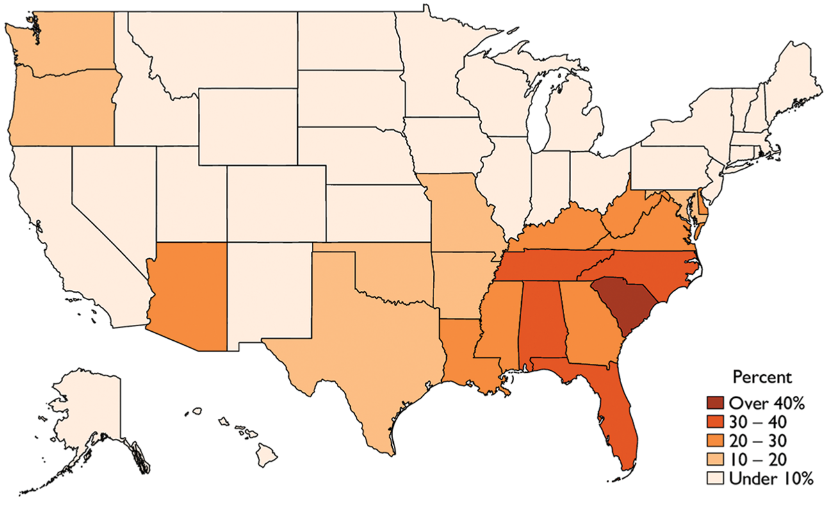


**Fig. 3.** Heat pump adoption by state. Color version available as an online enhancement. Notes: This map plots the percentage of households in each state that have a heat pump as their primary heating equipment. These data come from RECS (2020). Households are weighted using RECS sampling weights.

Another region with increased heat pump adoption is the Pacific Northwest. Heat pump adoption is 13% in Washington and 15% in Oregon. This higher rate of adoption is not a coincidence. As will be explored in more detail later, electricity prices are negatively correlated with heat pump adoption, and these two states have lower electricity prices than most other states due to the availability of low-cost hydroelectric power.

Heat pumps are rare throughout the rest of the country. This includes most of the West, the Midwest, and the Northeast, as well as Hawaii and Alaska. Perhaps surprisingly, California also has relatively low heat pump adoption. Again, this is not a coincidence. California has unusually high electricity prices, as has been highlighted by several recent economic analyses (Borenstein et al. 2021; Borenstein and Bushnell 2022a, 2022b).

### *B. Climate*

Figure 4 plots annual average heating degree days (HDDs) by state. HDDs are a widely used measure of heating demand that reflects the number of days with cold weather as well as the intensity of cold on those days. HDDs are calculated as the sum of daily mean temperatures

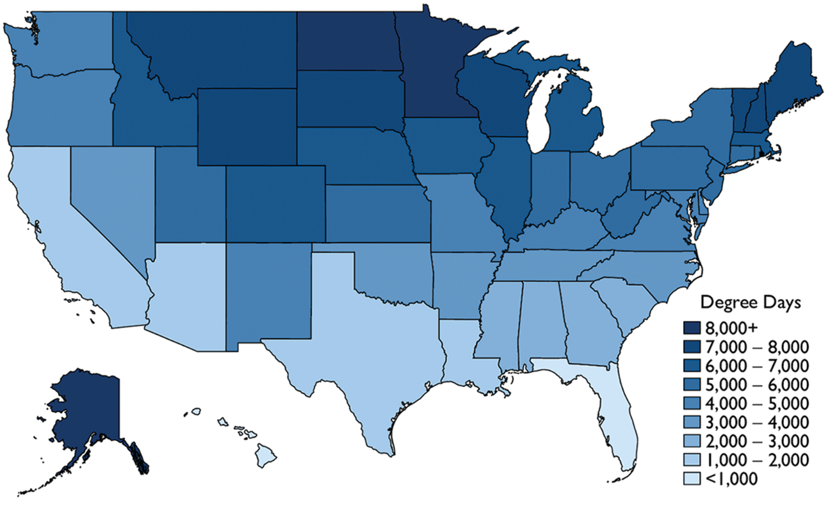


**Fig. 4.** Heating degree days by state. Color version available as an online enhancement.
Notes: This map plots heating degree days (HDDs) by state. HDDs are a widely used measure of heating demand that reflects the number of days with cold weather as well as the intensity of cold on those days. These data come from RECS (2020) and are 30-year annual averages from 1981 to 2010, relative to a base temperature of 65°F. Households are weighted using RECS sampling weights.

in Fahrenheit below 65°F. For example, a day with an average temperature of 55°F contributes 10 HDDs, whereas a day with an average temperature above 65°F contributes zero.

HDDs range widely across the United States. Warmer states like Hawaii, Florida, Arizona, Louisiana, and Texas experience fewer than 2,000 HDDs annually. Colder states like Maine, Vermont, Minnesota, North Dakota, and Alaska experience 7,000 or more HDDs annually.

This measure of HDDs is a 30-year annual average. Heat pumps tend to be used for many years before they are replaced. For example, the US Department of Energy's National Energy Modeling System assumes that heat pumps have a minimum lifetime of 9 years and a maximum lifetime of 22 years. Thus, it makes sense to think about heating-choice decisions as responding to a location's climate rather than to year-to-year weather variation.

Figure 5 presents a scatterplot of heat pump adoption versus HDDs. There is a pronounced negative correlation. For example, all 16 states with heat pump adoption above 20% have HDDs below or right at median HDDs. The correlation between the two variables is negative (–0.64) and strongly statistically significant.

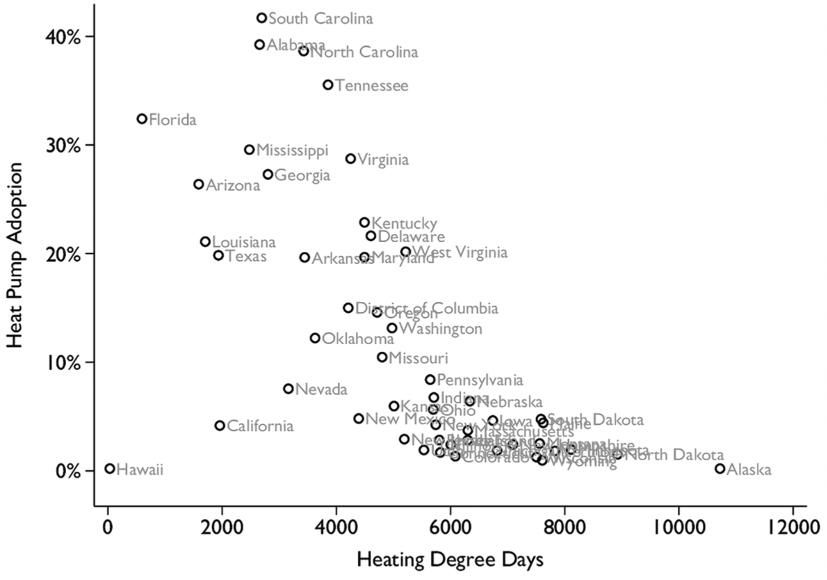


**Fig. 5.** Heat pump adoption versus heating degree days. Color version available as an online enhancement.

Notes: This scatterplot shows the percentage of households with heat pumps versus annual heating degree days. Both variables come from RECS (2020). Households are weighted using RECS sampling weights. The correlation between the two variables is negative (–0.64) and strongly statistically significant ($p$ value = .00).

Hawaii is a fascinating outlier. Households in Hawaii experience virtually no HDDs, yet heat pump adoption is near zero. There is so little need for heating in Hawaii that most households choose not to have any heating equipment whatsoever. At the same time, Hawaii also has surprisingly little air conditioning. Only 57% of households in Hawaii have air conditioning, compared with a national average above 90%. In part, this lack of air conditioning reflects that Hawaii has the highest residential electricity prices in the United States. The average residential electricity price in Hawaii in 2020 was 30 cents per kWh, compared with a national average of 14 cents per kWh. The lack of air conditioning in Hawaii is also likely related to the housing stock. Because it tends not to get very cold in Hawaii, homes are built with less insulation, making air conditioning less effective and more expensive.

Interestingly, for European countries there is a positive correlation between heat pump adoption and HDDs (Rosenow et al. 2022). This positive correlation is largely due to three countries—Finland, Norway, and

Sweden—that all experience high levels of HDDs and have heat pump adoption rates above 40%. Heat pump popularity in these Scandinavian countries reflects many factors, including low electricity prices, high taxes for fossil fuel alternatives, lack of natural gas infrastructure, and government subsidies for heat pumps (Gross and Hanna 2019).

Figures A1 and A2 present analogous evidence for cooling degree days (CDDs). Whereas HDDs measure demand for heating, CDDs measure demand for cooling. As discussed earlier, heat pumps are, essentially, air conditioners operating in reverse, so the incremental cost of a heat pump is smaller for a household that already has or is planning to install central air conditioning. Heat pump adoption is positively correlated with CDDs (0.55).

### C. *Energy Prices*

Figure 6 plots average residential electricity prices as of 2020. US electricity prices vary widely, from less than 10 cents per kWh in Louisiana, Washington State, and Idaho to more than 20 cents per kWh in California, Massachusetts, Rhode Island, Alaska, Connecticut, and Hawaii.

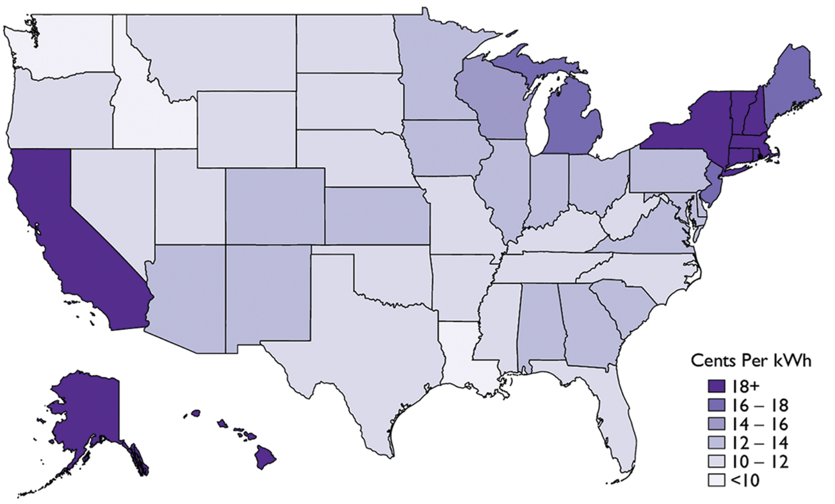


**Fig. 6.** Average residential electricity prices. Color version available as an online enhancement.

Notes: This map plots average residential electricity prices in 2020. These data come from the US Department of Energy, *Energy Information Administration*, *Electricity Data Browser* and include all relevant taxes and delivery charges.

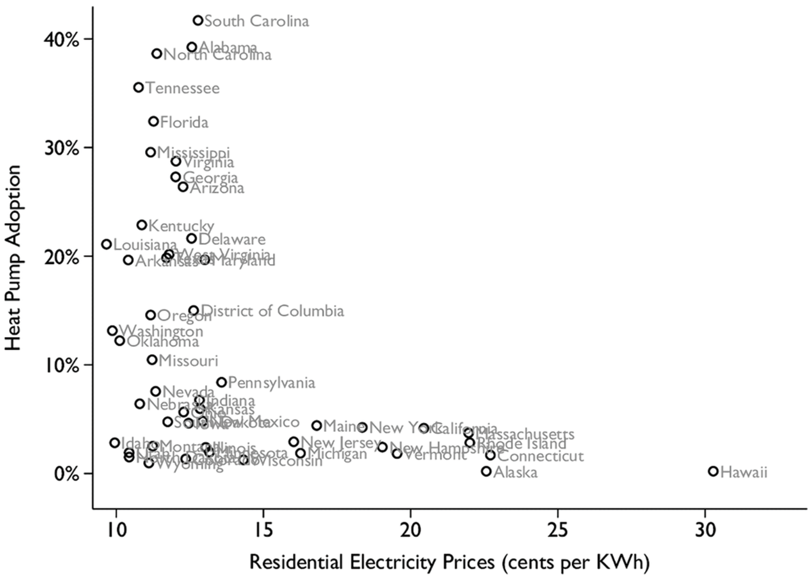


**Fig. 7.** Heat pump adoption versus electricity prices. Color version available as an online enhancement.

Notes: This scatterplot shows the percentage of households with heat pumps versus residential electricity prices. The percentage of households with heat pumps by state comes from RECS (2020) and was calculated using RECS sampling weights. Average residential electricity prices by state come from the US Department of Energy, *Energy Information Administration*, *Electricity Data Browser* and include all relevant taxes and delivery charges. The correlation between the two variables is negative (–0.41) and strongly statistically significant ($p$ value = .00).

Figure 7 plots heat pump adoption versus electricity prices. The correlation between the two variables is negative (–0.41) and strongly statistically significant. All of the states with adoption rates above 20% have electricity prices below 13 cents per kWh, and adoption rates are below 10% for all states with prices above 15 cents per kWh.

The states with high electricity prices are very different from the states with low electricity prices, so it is hard to make a strong causal statement about this relationship. Still, the negative relationship makes sense given that electricity prices determine operating costs for heat pumps, consistent with an existing literature documenting the responsiveness of electricity demand to prices. See, for example, Reiss and White (2005, 2008) and Ito (2014).

To the extent that lower electricity prices cause increased heat pump adoption, this underscores the importance of pricing electricity efficiently.

A key theme in recent economic analyses of US electricity markets is that electricity is not priced efficiently (Borenstein and Bushnell 2022a, 2022b). In particular, in many parts of the country, residential electricity prices are too high (i.e., higher than social marginal cost), which would imply inefficiently low levels of heat pump adoption.

Figures A3 and A4 present analogous evidence for natural gas prices. Natural gas furnaces are a substitute for heat pumps, so this "cross-price" effect would be expected to be positive with, everything else equal, heat pumps being more attractive in states with high natural gas prices. Indeed, the correlation between heat pump adoption and natural gas prices is positive. The correlation is smaller in magnitude than the correlation with electricity prices, and not statistically significant, but it has the expected sign.

### *D. Summary and Additional Evidence*

Table 3 describes heat pump adoption rates and the implied total number of households for different categories of U.S households. Nationwide, 14% of households have a heat pump as their primary heating equipment, implying 17.2 million total US households with heat pumps.

The breakdown by geography, electricity prices, and climate confirms the patterns shown in the previous subsections. Heat pump adoption in the South is three times higher than in the West and six times higher than in the Midwest and Northeast. Heat pump adoption in states with low electricity prices (i.e., below median) is three times higher than heat pump adoption in states with high electricity prices (i.e., above median). And heat pump adoption in warm states (i.e., below median HDDs) is more than three times higher than in cold states (i.e., above median HDDs).

The table also presents evidence on several additional potential determinants, which turn out not to be important determinants of heat pump adoption. Interestingly, heat pump adoption is similar for homeowners and renters. This is perhaps surprising given previous evidence on the "landlord-tenant" problem—that is, the idea that landlords have too little incentive to invest in energy efficiency when their tenants pay the energy bills (see, e.g., Gillingham, Harding, and Rapson 2012). But in many cases, heat pumps are actually less expensive up front than installing separate heating and cooling systems, so the analogy to the literature on energy efficiency is not so straightforward.

Heat pump adoption is also similar for single-family and multiunit homes, and for homes with different numbers of bedrooms. The lack

**Table 3**
Heat Pump Adoption in the United States

| | Percent of Households with Heat Pumps (%) | Total Households (in Millions) |
|---|---|---|
| Entire United States | 14 | 17.2 |
| By geography: | | |
| South | 28 | 12.9 |
| West | 8 | 2.1 |
| Northeast | 5 | 1.0 |
| Midwest | 4 | 1.2 |
| By electricity prices: | | |
| Below median | 21 | 12.9 |
| Above median | 7 | 4.3 |
| By climate: | | |
| Below median HDDs | 21 | 13.3 |
| Above median HDDs | 6 | 3.9 |
| Homeowner versus renter: | | |
| Homeowner | 14 | 11.8 |
| Renter | 13 | 5.4 |
| By type of home: | | |
| Single-family | 14 | 13.0 |
| Multiunit | 13 | 4.2 |
| By size of home: | | |
| One or two bedrooms | 13 | 6.1 |
| Three bedrooms | 16 | 7.7 |
| Four or more bedrooms | 12 | 3.4 |

Note: This table describes heat pump adoption for different categories of US households, as well as the implied total number of households in each category. These data come from RECS (2020). Households are weighted using RECS sampling weights. The four regions are as defined by the US census. Single-family homes include single-family detached homes as well as single-family attached homes (duplexes and townhouses).

of correlation with these housing characteristics is notable because one might have expected economies of scale to provide clear advantages or disadvantages for heat pumps relative to alternative technologies. Were this only a comparison between heat pumps and electric resistance heating, then one might indeed expect to see single-family homes and larger homes disproportionately choosing heat pumps. But households are also considering natural gas heating which tends to be attractive in larger homes because of the relatively low operating costs.

Regardless of the exact explanations, the lack of correlation with these other factors helps explain the lack of correlation between heat pumps and household income, and why heat pumps are so different from solar panels and other technologies. For example, one of the reasons solar panels tend to be more frequently adopted by higher-income households is that such households are more likely to live in single-family homes, where it is typically easier to install solar panels. Similarly, households in single-family homes are also more likely to have a convenient parking spot with a garage or driveway, which makes charging an electric vehicle easier.

### *E. Regression Analysis*

Table 4 reports estimates from a regression model aimed at better disentangling the various determinants of heat pump adoption. Coefficient estimates and standard errors are reported from eight separate least-squares regressions. In all eight regressions, the dependent variable is an indicator variable for homes for which an electric heat pump is the primary form of space heating.

Across all eight columns, there is a striking lack of association between household income and heat pump adoption. In column 1, without any additional variables, the coefficient on income is –0.01. Thus a $100,000 increase in annual household income is associated with a 1.0 percentage point decrease in heat pump adoption, a relatively small effect. With additional variables, the coefficient on income becomes positive but remains small in magnitude in all specifications. Thus, whether one controls or does not control for these other variables, there is a pronounced lack of association with household income.

Instead, heat pump adoption is strongly associated with geography, energy prices, and climate. These patterns are largely consistent with the results presented earlier, but it is interesting to see that these relationships tend to persist even in regressions with other variables.

- Heat pump adoption is more common in the South and less common in the Midwest and Northeast. These regional effects attenuate somewhat but remain mostly statistically significant after controlling for additional variables. The magnitude of these effects is large. For example, in column 5, a household in the South is 14 percentage points more likely to have a heat pump, which is a doubling relative to the national mean of 14%.
- Heat pump adoption decreases with electricity prices. The point estimates are large. For example, the estimate in column 5 implies that a 10% increase in electricity prices decreases heat pump adoption by 2.0 percentage points. In 2020, residential electricity prices in the continental

**Table 4**
Heat Pump Adoption, Regression Estimates

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| Household income, 100,000s | −.01** | .00 | .00 | .00 | .00 | .01 | .01 | .01 |
| | (.00) | (.01) | (.01) | (.01) | (.01) | (.01) | (.01) | (.01) |
| South | | .20** | .13** | .14** | .14** | | | |
| | | (.04) | (.04) | (.05) | (.05) | | | |
| Northeast | | −.03 | −.01 | .00 | .00 | | | |
| | | (.03) | (.01) | (.02) | (.02) | | | |
| Midwest | | −.03 | −.01 | .00 | .00 | | | |
| | | (.03) | (.02) | (.03) | (.03) | | | |
| Electricity price, in logs | | | −.18** | −.19** | −.20** | | | |
| | | | (.04) | (.03) | (.03) | | | |
| Natural gas price, in logs | | | .15** | .14** | .14** | | | |
| | | | (.05) | (.05) | (.05) | | | |
| Heating degree days, 1,000s | | | | −.01 | −.01 | | −.02 | −.02 |
| | | | | (.01) | (.01) | | (.01) | (.01) |
| Cooling degree days, 1,000s | | | | −.01 | −.01 | | −.01 | −.01 |
| | | | | (.03) | (.03) | | (.03) | (.03) |
| Homeowner | | | | | .02* | | | .02* |
| | | | | | (.01) | | | (.01) |
| Single-family home | | | | | −.01 | | | −.02 |
| | | | | | (.02) | | | (.02) |
| Number of bedrooms | | | | | .00 | | | .00 |
| | | | | | (.00) | | | (.00) |
| State fixed effects | No | No | No | No | No | Yes | Yes | Yes |
| Observations | 18,496 | 18,496 | 18,496 | 18,496 | 18,496 | 18,496 | 18,496 | 18,496 |
| $R^2$ | .00 | .10 | .11 | .11 | .11 | .13 | .13 | .13 |

Note: This table reports coefficient estimates and standard errors from eight separate least-squares regressions. In all regressions, the dependent variable is an indicator variable for homes for which an electric heat pump is the primary form of space heating. The indicator variables South, Northeast, and Midwest refer to three of the four census regions, with West as the excluded variable. Electricity and natural gas prices are both state-level averages, so these variables are excluded in the regressions with state fixed effects in columns 6, 7, and 8. All regressions are estimated using RECS sampling weights. Standard errors are clustered by state.
*Significant at the 5% level.
**Significant at the 1% level.

United States ranged from 9.7 cents in Louisiana to 22.6 cents in Connecticut, a difference of 0.85 log points. The regression implies that, everything else equal, an increase in electricity prices of this magnitude would decrease heat pump adoption by 17 percentage points. One standard deviation in log electricity prices is .261, so an increase in electricity prices of 1 standard deviation decreases adoption by 5.2 percentage points, or 37%.

- Heat pump adoption increases with natural gas prices. In column 5, for example, a 10% increase in natural gas prices increases heat pump adoption by 1.4 percentage points. Thus, both the own-price and cross-price effects have the expected signs.

• Heat pump adoption decreases with HDDs and CDDs. These effects are not statistically significant, but the point estimates are large when viewed relative to the relevant range. HDDS, for example, range within the continental United States from 600 in Florida to 8,400 in Minnesota, so the −.015 estimate in column 8 implies that an increase in HDDs of this magnitude would decrease heat pump adoption by 12 percentage points. One standard deviation in HDDs is 2,300, so an increase in HDDs by 1 standard deviation decreases adoption by 3.5 percentage points, or 25%.

• Homeowners are modestly more likely than renters to have a heat pump, but there is little association between heat pump adoption and the type of home (i.e., single-family versus multiunit) or the number of bedrooms. This is not unexpected given the lack of correlation with these factors in table 3, but it is interesting to see that this lack of correlation persists even in a regression with other variables.

The main takeaways from the regression analysis are as follows: (1) there is very little association between heat pump adoption and household income; (2) instead, heat pump adoption is strongly associated with geography, climate, and energy prices; and (3) these patterns are similar whether one examines simple correlations or estimates from a regression framework. The following section switches gears and considers the question of cost-effectiveness of subsidies, but the conclusion returns to this evidence and offers additional broader lessons with regard to potential policy implications.

## V. Cost-Effectiveness of Subsidies

This section performs back-of-the-envelope calculations aimed at better understanding the cost-effectiveness of heat pump subsidies. As discussed previously, there is growing enthusiasm about heat pumps as a means to reduce carbon emissions from residential heating. In the United States, 56 million households (46%) heat their homes with natural gas, 5 million households (4%) heat their homes with propane, and 5 million households (4%) heat their homes with heating oil.[9]

The goal of this section is to calculate how much carbon abatement occurs per dollar spent on heat pump subsidies in the United States. Then, as a point of comparison, a similar calculation is performed for electric vehicles. These calculations require many strong assumptions. Where possible, existing data and previous estimates in the literature are used as points of comparison. Nonetheless, these should be viewed as preliminary rough calculations and interpreted with considerable caution.

The focus is on carbon abatement. In future research, it would be interesting to expand the analysis to incorporate other externalities. For example, on the one hand, burning fossil fuels releases nitrogen oxides (NOx) and other local pollutants that are dangerous to human health. In addition, there are negative externalities from fossil fuel production, including methane leaks, water use, and water contamination. On the other hand, heat pumps use refrigerants, which are a potent greenhouse gas. Quantifying these additional externalities is challenging but also important, as they have the potential to significantly affect the trade-offs associated with heat pumps.

### A. *Baseline Assumptions*

This section describes the baseline assumptions used to quantify the carbon abatement from heat pump subsidies. The basic thought experiment is to focus on the US federal tax credit of $2,000 for heat pumps. As discussed previously, under the US Inflation Reduction Act, low- and moderate-income households will also be able to receive point-of-sale rebates of up to $8,000, but the exact implementation of these rebates is still being finalized.

#### Percentage Additional

For the baseline calculation, it is assumed that 50% of subsidy recipients are induced to purchase a heat pump because of the subsidy, whereas 50% of subsidy recipients would have purchased a heat pump even without the subsidy. That is, half of recipients are "additional," and the other half are "nonadditional." This is an important assumption and, unfortunately, one about which there is no existing empirical evidence. Thus, in addition to 50%, results are also reported for 25% and 75%.

#### Counterfactual Heating Source

The baseline calculation assumes that households induced to use a heat pump otherwise would have heated their homes using natural gas. This is another important assumption and, again, one for which there is little existing empirical evidence. Natural gas is the most common form of residential heating in the United States, but heat pump subsidies will also lead to substitution away from other heating fuels. Accordingly, results are also reported for propane, heating oil, and electric resistance heating.

Level of Heating Demand

Households are assumed to consume 35 MMBtu of heating annually, regardless of energy source.[10] As already discussed, the United States has a wide range of climates. Thus, in addition to reporting results for 35 MMBtu, the paper also reports results for 20 MMBtu and 50 MMBtu.

Operating Efficiency

Heat pumps are assumed to deliver 3.0 MMBtu of heating for each MMBtu of electricity (i.e., 300% efficient), compared with 1-to-1 (100% efficient) for electric resistance heating and 0.9-to-1 (90% efficient) for natural gas, propane, and heating oil.[11] Based on these assumptions, 35 MMBtu of heating can be met using 3,419 kWh of electricity (via a heat pump), 10,257 kWh of electricity (via electric resistance heating), 37.4 thousand cubic feet of natural gas, 425 gallons of propane, or 281 gallons of heating oil.[12]

Emissions Factors

Standard emissions factors are used to convert electricity and fuel consumption into carbon emissions. Electricity is assumed to emit 310 pounds of carbon dioxide per MMBtu of electricity consumed.[13] Natural gas, propane, and heating oil are assumed to emit 116.65, 138.63, and 163.45 pounds of carbon dioxide per MMBtu, respectively.[14] It is perhaps surprising that electricity produces more carbon dioxide per MMBtu than fossil fuels, but this reflects that a considerable amount of energy is lost when fossil fuels are converted into electricity. On average, US natural gas power plants convert only 45% of the energy content of natural gas into electricity, whereas US coal power plants convert only 32% of the energy content of coal into electricity.[15] Although these are rough averages, even the most efficient fossil fuel power plants typically have an efficiency below 60%.

System Lifetime

Heating systems are assumed to have a 20-year lifetime, with no changes in operating efficiency or emissions factors over that period. This is a bit longer than typical assumptions in the literature. For example, the US Department of Energy's National Energy Modeling System assumes that heat pumps have a minimum lifetime of 9 years and a maximum lifetime of 22 years. But the somewhat longer lifetime is intended to reflect the inertia in heating system choices and that a heat pump subsidy could affect heating system choices even beyond the lifetime of the initial equipment.

### Discount Rate

Finally, these calculations assume a 5% annual discount rate. Discounting future carbon abatement takes into account that although the costs of these subsidies are borne up front, the carbon abatement occurs over many years. Discounting has little effect on the comparison between heat pumps and electric vehicles, but it lowers the overall level of abatement from both types of subsidies. Results are also reported for discount rates of 3% and 7%.

## *B. Cost-Effectiveness: Results*

Table 5 presents the cost-effectiveness calculations. Under the baseline assumptions, a $2,000 heat pump subsidy reduces lifetime carbon dioxide emissions by 4 tons. Carbon abatement scales as expected in response to

**Table 5**
Carbon Abatement for a $2,000 Heat Pump Subsidy

| | |
|---|---|
| Baseline assumptions | 4 tons |
| Higher proportion of recipients additional (75% rather than 50%) | 5 tons |
| Lower proportion of recipients additional (25% rather than 50%) | 2 tons |
| Household otherwise would have used propane | 6 tons |
| Household otherwise would have used heating oil | 10 tons |
| Household otherwise would have used electric resistance heating | 22 tons |
| Households assumed to use less heating (20 MMBtu rather than 35) | 2 tons |
| Households assumed to use more heating (50 MMBtu rather than 35) | 5 tons |
| Lower discount rate (3% rather than 5%) | 4 tons |
| Higher discount rate (7% rather than 5%) | 3 tons |

Note: This table reports calculated lifetime carbon abatement in tons for a $2,000 heat pump subsidy. Under the baseline assumptions, 50% of subsidy recipients are additional, the household otherwise would have used natural gas, households use 35 MMBtu of heating per annually, heat pumps have a 20-year lifetime, and there is a 5% annual discount rate. Abatement is rounded to the nearest ton.

alternative assumptions about the proportion of additional recipients, level of heating demand, and discount rates. For example, carbon abatement is lower when one assumes that only 25% of recipients are additional. This makes sense. After all, from a carbon abatement perspective, the worst-case scenario would be that all recipients are "free riders," that is, getting paid for doing what they would have done otherwise.

The results for other heating fuels are interesting and merit additional discussion. Carbon abatement is higher if one assumes that household otherwise would have used propane or heating oil. This reflects that these fuels are more carbon intensive than natural gas. Interestingly, carbon abatement is much higher if the household otherwise would have used electric resistance heating. This is a bit surprising because typically heat pump subsidies are described as inducing households to substitute away from natural gas and other on-site direct consumption of fossil fuels. These calculations illustrate, however, that there are significant reductions in carbon dioxide emissions from encouraging households to switch to a much more energy-efficient form of electric heating.

It is tempting to compare the calculations in table 5 to estimates in the literature for the social cost of carbon. For example, the US government currently uses a social cost of carbon of $51 per ton (US Interagency Working Group 2021), and one recent study finds a preferred social cost of carbon of $185 per ton (Rennert et al. 2022). However, this is not an apples-to-apples comparison. Subsidies are transfers, not economic costs, and many households value subsidies at close to $1-for-$1. Non-additional recipients, for example, value each $1 subsidy at exactly $1, so for them the subsidy should be viewed as a pure transfer from taxpayers to households. These transfers are not costless because they must be financed through distortionary taxes (i.e., the marginal cost of public funds), but this is typically thought of as imposing economic costs much lower than $1 per $1 raised.

The following section presents analogous estimates for electric vehicles. This is more of an apples-to-apples comparison because in both cases the objective is to calculate the carbon abatement that would result from a $2,000 subsidy. These comparisons can be viewed in the spirit of Hendren and Sprung-Keyser (2020) and the "marginal value of public funds" (MVPF). Intended as a metric for evaluating the desirability of government policies, the MVPF is the ratio of a policy's benefits to a policy's cost to the government. The advantage of the MVPF is that it makes it possible to easily compare the societal returns to alternative uses of government expenditure.

### C. Cost-Effectiveness: Comparison to Electric Vehicles

The approach taken for the back-of-the-envelope calculations for electric vehicles is quite similar. For comparability, the basic thought experiment is to consider a $2,000 subsidy for electric vehicles. At this subsidy level, it is assumed under the baseline assumptions that 25% of subsidy recipients are additional. A lower percentage is used here than the 50% assumed for heat pumps because a $2,000 subsidy is a smaller percentage of total costs.[16]

These calculations implicitly assume that the incidence of the subsidy is at least partly on buyers. If supply were perfectly inelastic, then sellers would capture 100% of the subsidy, there would be no change in the number of electric vehicles sold, and 0% of subsidy recipients would be additional. Although this is an interesting extreme case, it makes more sense to think about suppliers having at least some ability to increase the quantity supplied, particularly over the medium and long run. Muehlegger and Rapson (2022), for example, find that buyers capture 73%–85% of electric vehicle subsidies in California.

Households are assumed to otherwise have used a gasoline-powered vehicle that gets 30 miles per gallon and is driven 10,000 miles per year, with a 15-year lifetime. These assumptions are informed by previous research and empirical data on driving behavior. Perhaps most relevantly, Xing et al. (2021) use US vehicle sales data from 2010 to 2014 and a discrete choice model to find that households with an electric vehicle otherwise would have driven a vehicle with an average fuel economy of 28.9 miles per gallon. Holland et al. (2016) assume vehicles are driven 15,000 miles per year, whereas other studies of electric vehicle driving behavior have tended to find lower levels of driving intensity (Davis 2019; Burlig et al. 2021). Finally, Bento, Roth, and Zuo (2018) find that the average lifetime for passenger vehicles in the United States is 15.6 years.

Table 6 presents the cost-effectiveness results for electric vehicles. Under the baseline assumptions, a $2,000 electric vehicle subsidy reduces lifetime carbon dioxide emissions by 5 tons. Carbon abatement scales as expected in response to alternative assumptions about the proportion of additional recipients, fuel efficiency, vehicle miles traveled, and discount rates.

These calculations suggest that heat pump and electric vehicle subsidies yield a similar amount of carbon abatement per subsidy dollar. This finding of roughly equivalent efficiency is notable given the very different

**Table 6**
Carbon Abatement for a $2,000 Electric Vehicle Subsidy

| | |
|---|---|
| Baseline assumptions | 5 tons |
| Higher proportion of recipients additional (35% rather than 25%) | 10 tons |
| Lower proportion of recipients additional (15% rather than 25%) | 3 tons |
| Vehicle otherwise less fuel efficient (20 mpg compared with 30) | 7 tons |
| Vehicle otherwise more fuel efficient (40 mpg compared with 30) | 3 tons |
| Vehicles driven less (7,500 annual miles traveled) | 4 tons |
| Vehicles driven more (12,500 annual miles traveled) | 7 tons |
| Lower discount rate (3% rather than 5%) | 6 tons |
| Higher discount rate (7% rather than 5%) | 5 tons |

Note: This table reports calculated lifetime carbon abatement in tons for a $2,000 electric vehicle subsidy. Under the baseline assumptions, 25% of subsidy recipients are additional, households otherwise would have used a gasoline-powered vehicle that gets 30 miles per gallon and is driven 10,000 miles per year, vehicles have a 15-year lifetime, and there is a 5% annual discount rate. Abatement is rounded to the nearest ton.

patterns for distributional impacts presented earlier. Economists have pointed out that many energy-related policies involve efficiency-versus-equity trade-offs, with, for example, policy makers sometimes eschewing more efficient policies due to concerns about equity (Deryugina, Fullerton, and Pizer 2019). These results suggest, however, that heat pump subsidies achieve a similar amount of carbon abatement as electric vehicle subsidies, but with more equitable distributional impacts.

Before proceeding, it is worth reiterating that tables 5 and 6 should be viewed as preliminary back-of-the-envelope calculations. This exercise requires many strong assumptions, and as more evidence becomes available, it will be interesting to update these calculations to reflect better information about additionality, substitution patterns, usage levels, and other factors. Perhaps most importantly, these calculations assume that emissions from the US electricity sector remain constant. The argument for heat pumps and electric vehicles as a climate solution hinges on the assumption that the US grid will continue to become less carbon intensive over time. Although this would not tend to affect much the comparison between heat pump and electric vehicles, it would significantly increase the overall carbon abatement from both types of technologies.

## VI. Conclusion

This paper started off by showing that heat pump adoption is remarkably similar across US households with different income levels. This surprising finding stands in sharp contrast to adoption patterns for electric vehicles, solar panels, and other low-carbon technologies, which are disproportionately adopted by high-income households. The paper showed, for example, that households with an annual income above $150,000 are twice as likely to have solar panels and six times more likely to have an electric vehicle than households with income between $50,000 and $60,000.

This lack of correlation between heat pump adoption and household income has important potential implications for the distributional impact of heat pump subsidies. Whereas subsidies for other low-carbon technologies have tended to go overwhelmingly to high-income households, heat pump subsidies are likely to be much more widely distributed across the income distribution.

Instead, geography, climate, and energy prices all were shown to strongly predict heat pump adoption. Regression evidence showed, for example, that a 1 standard deviation increase in HDDs decreases heat pump adoption by one-fourth, whereas a 1 standard deviation increase in electricity prices decreases heat pump adoption by one-third. Other factors like homeowner versus renter, single-family versus multiunit, and the size of the home were shown to be less important.

Finally, the paper presented back-of-the-envelope calculations aimed at quantifying the carbon abatement from heat pump and electric vehicle subsidies. These calculations suggest that the two types of subsidies yield a similar amount of carbon abatement per subsidy dollar. These calculations rely on strong assumptions and should be interpreted cautiously, but they suggest that these two subsidies are quite similar from an efficiency perspective, despite having very different distributional implications.

## Appendix

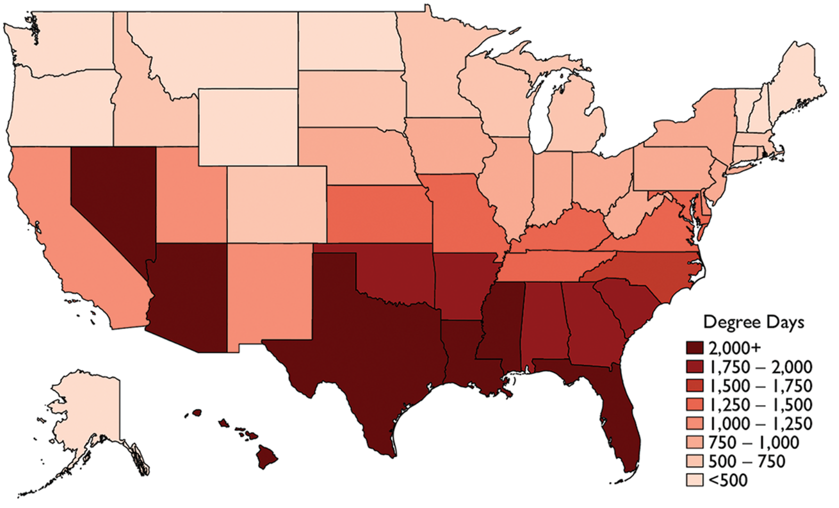


**Fig. A1.** Cooling degree days by state. Color version available as an online enhancement. Notes: This map plots cooling degree days (CDDs) by state. CDDs are a widely used measure of cooling demand that reflects the number of days of hot weather as well as the intensity of heat on those days. These data come from RECS (2020) and are 30-year annual averages from 1981 to 2010, relative to a base temperature of 65°F. Households are weighted using RECS sampling weights.

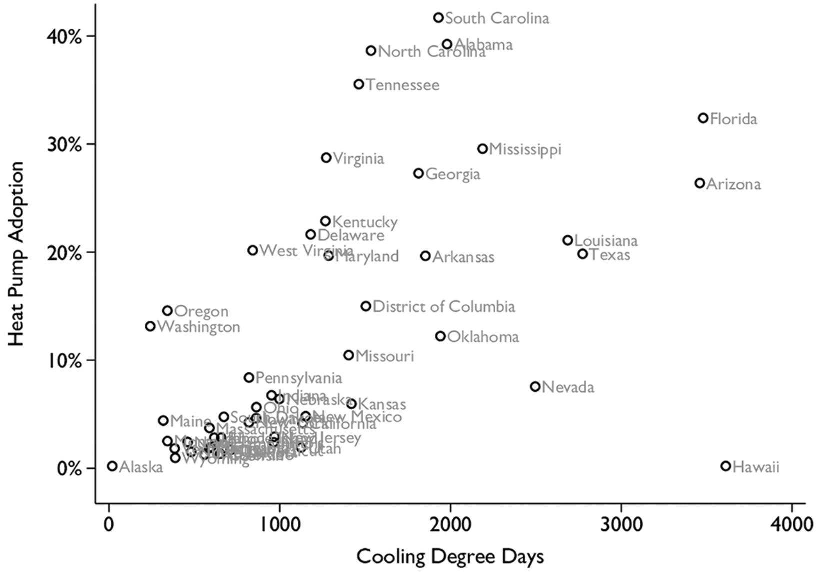


**Fig. A2.** Heat pump adoption versus cooling degree days. Color version available as an online enhancement.

Notes: This scatterplot shows the percentage of households with heat pumps versus annual cooling degree days. Both variables come from RECS (2020). Households are weighted using RECS sampling weights. The correlation between the two variables is positive (0.55) and strongly statistically significant ($p$ value = .00).

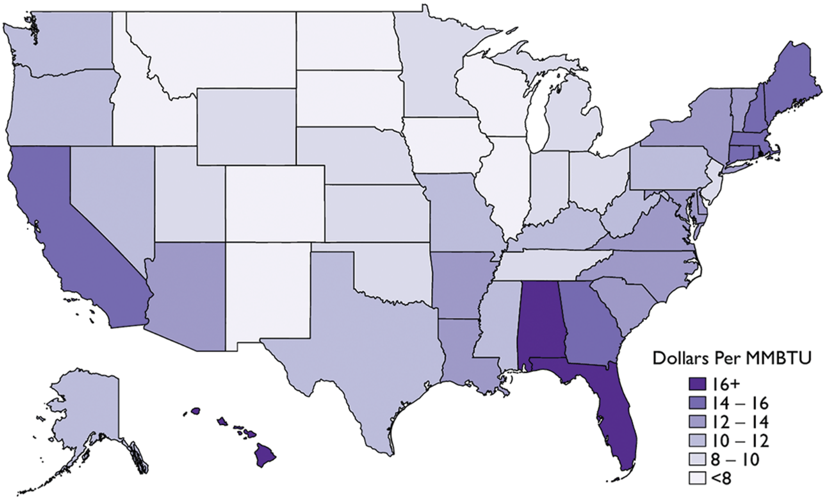


**Fig. A3.** Average residential natural gas prices. Color version available as an online enhancement.

Notes: This map plots average residential natural gas prices in 2020. These data come from the US Department of Energy, *Energy Information Administration* and include all relevant taxes and delivery charges. See https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_a.htm.

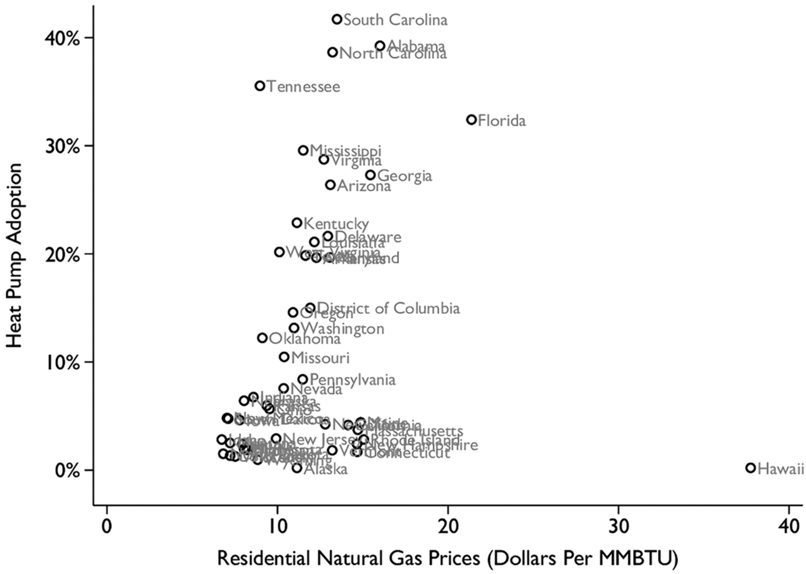


**Fig. A4.** Heat pump adoption versus natural gas prices. Color version available as an online enhancement.

Notes: This scatterplot shows the percentage of households with heat pumps versus residential natural gas prices. The percentage of households with heat pumps by state comes from RECS (2020) and was calculated using RECS sampling weights. Average residential natural gas prices by state come from the US Department of Energy, Energy Information Administration and include all relevant taxes and delivery charges. See https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_a.htm. The correlation between the two variables is positive (0.18) but not statistically significant ($p$ value = .20).

**Table A1**
Heat Pump Adoption by State, Ranked by Percentage

| | | Percent | Total (Millions) | | | Percent | Total (Millions) |
|---|---|---|---|---|---|---|---|
| 1. | South Carolina | 42 | .8 | 26. | Ohio | 6 | .3 |
| 2. | Alabama | 39 | .7 | 27. | New Mexico | 5 | 0 |
| 3. | North Carolina | 39 | 1.6 | 28. | South Dakota | 5 | 0 |
| 4. | Tennessee | 36 | .9 | 29. | Iowa | 5 | .1 |
| 5. | Florida | 32 | 2.6 | 30. | Maine | 4 | 0 |
| 6. | Mississippi | 30 | .3 | 31. | New York | 4 | .3 |
| 7. | Virginia | 29 | .9 | 32. | California | 4 | .5 |
| 8. | Georgia | 27 | 1.1 | 33. | Massachusetts | 4 | .1 |
| 9. | Arizona | 26 | .7 | 34. | New Jersey | 3 | .1 |
| 10. | Kentucky | 23 | .4 | 35. | Rhode Island | 3 | 0 |
| 11. | Delaware | 22 | .1 | 36. | Idaho | 3 | 0 |
| 12. | Louisiana | 21 | .4 | 37. | Montana | 3 | 0 |
| 13. | West Virginia | 20 | .1 | 38. | New Hampshire | 2 | 0 |
| 14. | Texas | 20 | 2.0 | 39. | Illinois | 2 | .1 |
| 15. | Maryland | 20 | .4 | 40. | Minnesota | 2 | 0 |
| 16. | Arkansas | 20 | .2 | 41. | Utah | 2 | 0 |
| 17. | Oregon | 15 | .2 | 42. | Michigan | 2 | .1 |
| 18. | Washington | 13 | .4 | 43. | Vermont | 2 | 0 |
| 19. | Oklahoma | 12 | .2 | 44. | Connecticut | 2 | 0 |
| 20. | Missouri | 10 | .3 | 45. | North Dakota | 2 | 0 |
| 21. | Pennsylvania | 8 | .4 | 46. | Colorado | 1 | 0 |
| 22. | Nevada | 8 | .1 | 47. | Wisconsin | 1 | 0 |
| 23. | Indiana | 7 | .2 | 48. | Wyoming | 1 | 0 |
| 24. | Nebraska | 6 | 0 | 49. | Hawaii | 0 | 0 |
| 25. | Kansas | 6 | .1 | 50. | Alaska | 0 | 0 |

Note: This table reports by state the percentage of households with heat pumps and the implied total number of households with heat pumps. This information comes from RECS (2020) and was calculated using RECS sampling weights. These percentages are slightly higher than state-level percentages reported in the US Department of Energy, Energy Information Administration (EIA) report "Highlights for Space Heating in US Homes by State, 2020" (final release March 2023) because the EIA table includes only central heat pumps, whereas this table includes both central heat pumps and mini-splits. Percentages are rounded to the nearest percent, and totals are rounded to the nearest 100,000.

## Endnotes

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relies entirely on publicly available data, and all data and code are available on the author's website. For acknowledgments, sources of research support, and disclosure of the author's material financial relationships, if any, please see https://www.nber.org/books-and-chapters/environmental-and-energy-policy-and-economy-volume-5/economic-determinants-heat-pump-adoption.

1. That is, the 2020 RECS was implemented entirely via online and paper questionnaires. Prior waves of the RECS used a combination of in-person interviews and these self-administered modes. See U.S. Department of Energy, Energy Information Administration (2022), for details.

2. Sexton and Sexton (2014), for example, find that green communities have higher market shares of the Toyota Prius relative to less conspicuous hybrids like the Toyota Camry hybrid, consistent with what they call "conspicuous conservation." This builds on earlier work showing increased registrations of hybrid vehicles like the Toyota Prius in green communities (Kahn 2007): "In green communities, social pressure may reinforce the urge to take green actions such as driving a Toyota Prius."

3. Formally, this is implemented using a regression-based statistical test. Separate regressions are estimated for each technology. In each case, the dependent variable is an indicator variable for whether the household has a particular technology, and the independent variables are indicator variables for seven of the eight income bins. Following each regression, a Wald test is performed to assess whether the seven coefficients are equal to zero; that is, equal to the value for the excluded category.

4. See, for example, *Washington Post*, "US Home Heating Is Fractured in Surprising Ways: Look Up Your Neighborhood," March 6, 2023, by John Muyskens, Shannon Osaka, and Naema Ahmed. See also US Department of Energy, Energy Information Administration, "US Households' Heating Equipment Choices Are Diverse and Vary by Climate Region," April 6, 2017.

5. This back-of-the-envelope calculation is based on national average residential prices of $12.18 per thousand cubic feet for natural gas and 13.7 cents per kWh for electricity. One kWh is equivalent to 3,412 Btu, or 0.003412 MMBtu, and 1,000 cubic feet is equivalent to 1.037 MMBtu. Electric resistance and natural gas heating are assumed to be 100% and 90% efficient, respectively.

6. It is hard to say whether a COP of 3.0 is representative. The US federal minimum efficiency standard for air-source heat pumps was 2.40 between 2015 and 2022, before increasing to 2.58 in 2023. US federal minimum efficiency standards for heat pumps are measured using the heating seasonal performance factor (HSPF), which is average heating (in Btu) per watt-hour. The minimum standard was HSPF 8.2 between 2015 and 2022 and then HSPF 8.8 starting in 2023. There are 3,412 Btu per kWh of electricity, so HSPF 8.2 and 8.8 correspond to average COP of 2.4 and 2.58, respectively. Borenstein and Bushnell (2022b) assume for their calculations a COP of 2.5 (i.e., 0.4 kWh of electricity per 1 kWh of heat). Other studies report results for a range of different COP values. See, for example, Kaufman et al. (2019) and Walker, Less, and Casquero-Modrego (2022).

7. This trade-off between up-front and operating costs is a central theme in previous economic analyses of residential heating and cooling. See, for example, Hausman (1979), Dubin and McFadden (1984), Mansur, Mendelsohn, and Morrison (2008), and Rapson (2014). None of these four studies considers heat pumps, which points to their relatively recent rise to prominence.

8. The Inflation Reduction Act was signed into law by President Biden on August 16, 2022. See Inflation Reduction Act of 2022, HR 5376, 117th Congress, Public Law 117-169. See also Congressional Research Service, "Residential Energy Tax Credits: Changes in 2023," November 21, 2022, and Internal Revenue Service, "Frequently Asked Questions about Energy Efficient Home Improvements and Residential Clean Energy Property Credits," December 2022.

9. US Department of Energy, *Residential Energy Consumption Survey 2020*, Table HC6.1 "Space Heating in US Homes," released May 2022.

10. US Department of Energy, Energy Information Administration, 2015 Residential Energy Consumption and Expenditures Tables, Table CE3.1 "Annual Household Site End-Use Consumption in the US—Total and Averages" reports that the average US household uses 35.3 MMBtu annually for space heating. This approach of assuming a

fixed level of heating consumption implicitly ignores the potential for a "rebound effect," or the idea that lower operating costs would cause a household to consume more heating (Dubin, Miedema, and Chandran 1986), which would be a refinement worth incorporating in future research.

11. The assumption of 90% efficiency for natural gas, propane, and heating oil is based on US DOE (2023) and reflects typical efficiency for new furnaces. The current federal minimum efficiency standard for gas furnaces (including both natural gas and propane) is 80% annual fuel utilization efficiency (AFUE). Pages 8 and 9 of US DOE (2023) report "typical" and "high" efficiencies of 92% and 99% in the North, and 80% and 99% in the rest of the country. The current federal minimum efficiency standard for oil-burning furnaces is 83% AFUE, and page 12 of US DOE (2023) reports "typical" and "high" efficiencies of 83% and 97%.

12. These calculations are based on standard conversion factors from the US Department of Energy, Energy Information Administration, "Energy Units and Calculators Explained," https://www.eia.gov/energyexplained/units-and-calculators/. Electricity consumption for heating with a heat pump is calculated using the COP of 3.0 and the conversion rate 1kWh = 3,412 Btu. Electric resistance heating in kWh is calculated using the conversion rate 1 kWh = 3,412 Btu. Natural gas consumption in Mcf (thousand cubic feet) is calculated using the conversion rate 1Mcf = 1.039 MMBtu. Propane consumption in gallons is calculated using the conversion rate 1 gallon = 0.091452 MMBtu. Heating oil consumption in gallons is calculated using the conversion rate 1 gallon = 0.1385 MMBtu.

13. Holland et al. (2022) find that current marginal carbon dioxide emissions for the Western grid are about 1 pound of carbon dioxide per kWh (0.5 tons per MWh), which is equivalent to 293 pounds of carbon dioxide per MMBtu. This reflects typical emissions for electricity generation from natural gas. From this same source, the emissions factor for the entire United States is about 1.3 pounds per kWh. The lower value is used in the baseline assumptions to reflect the widespread view that the US grid will continue getting cleaner over time. Finally, these emissions are scaled up by 5% following US Department of Energy, Energy Information Administration, "How Much Electricity Is Lost in Electricity Transmission and Distribution in the United States?" to reflect that approximately 5% of electricity is lost between the power plant and the point of consumption.

14. These coefficients are from US Department of Energy, Energy Information Administration, "Carbon Dioxide Emissions Coefficients," released October 2022, https://www.eia.gov/environment/emissions/co2_vol_mass.php. These emissions factors do not account for the assumed 90% efficiency; these are emissions factors per MMBtu of energy, not MMBtu of heat.

15. See, for example, US DOE, "More Than 60% of Energy Used for Electricity Generation is Lost in Conversion," July 21, 2020.

16. The assumption that 25% of subsidy recipients is additional is probably optimistic. Muehlegger and Rapson (2022) estimate that the price elasticity of demand for electric vehicles is –2.1. Thus, a subsidy that decreases the up-front cost of electric vehicles by 10% would increase demand by 21%. In their study, the baseline price of an electric vehicle is $26,000, so a $2,000 subsidy would be an 8% decrease in up-front cost, expected to increase demand by 16%. Their study focuses on a California electric vehicle subsidy program aimed at low- and middle-income households.

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