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The Customer Bill Impacts of Efficient Building Electrification

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Abstract

Widespread building electrification is critical to achieving deep emissions reductions in the building sector. Building electrification can reduce onsite fossil fuel consumption and lower the carbon intensity of energy consumption by taking advantage of increasing amounts of power sector renewable energy. Despite these societal benefits, regulators, utilities, and consumer advocates are concerned about the potential increases in customer electricity bills from building electrification. This paper shows that prior analyses of the customer bill impacts of electrification may overestimate bill increases by not considering the efficiency improvements from advanced building electrification technologies (e.g., heat pumps, induction cooktops) retiring older, less efficient appliances and other efficiency improvements common in comprehensive energy retrofits.

We quantify residential customer energy and bill impacts for a comprehensive building electrification retrofit package. Importantly, the package includes efficiency improvements that are likely to occur with comprehensive retrofits of end-use technologies (e.g., efficient equipment upgrades for electric technologies and ducting replacement or retrofit for reduced leakage). We use the National Renewable Energy Laboratory's ResStock simulations of residential building end-use consumption to capture the heterogeneity in buildings due to differences in vintage, size, construction practices, installed equipment, appliances, and climate. The results have implications for the design of retail electricity rates and programs to encourage building electrification, including the consideration of the differential prices for electricity and fossil-fuels, the building end-use and technologies that drive bill impacts, and the efficacy of changing volumetric vs. fixed charges.

Introduction

Building electrification is critical to meeting state, utility, and U.S. decarbonization and greenhouse gas (GHG) goals (Williams et al. 2012; Nadel and Ungar 2019; Langevin et al. 2023). Specifically, there is growing policy interest in building electrification to reduce fossil fuel consumption and take advantage of increasing amounts of power sector renewable energy (Inflation Reduction Act 2022). However, regulators, utilities, and consumer advocates are concerned about the potential increases in customer electricity bills from building electrification. In this paper, we explore the extent of this potential issue by estimating the distribution of residential customer energy bill impacts from building electrification investments in four different geographic regions across the United States.

Importantly, this study explores the heterogeneity of customer bill impacts across a large number of building electrification measures, building and household characteristics, and locations. We estimate residential electricity and non-electricity bill savings across different potential building electrification measures (paired with other equipment efficiency upgrades) under actual utility electricity rates in four utility service areas. We use the National Renewable Energy Laboratory (NREL)'s ResStock simulations of residential building end-use consumption to capture the heterogeneity in these results across households due to differences in building vintage, size, construction practices, installed equipment, and appliances. To capture a variety of climates, we analyze building electrification investments in four different geographic and climate regions: the Southwest, Great Plains, Midwest, and Northeast.

This study also advances the literature on the impacts of building electrification on customer energy bills by considering the switch from fossil-based to electrical consumption in conjunction with the influence of corresponding direct and indirect efficiency improvements. For example, installing heat pumps to replace pre-existing fossil fuel space and water heating directly improves the energy efficiency of these end-uses, but there may also be indirect efficiency improvements from replacing paired electric resistance air conditioning and from complementary retrofits, such as improved ducting for space heating and cooling. Much of the prior research on building electrification does not consider the coupling of electrification and efficiency. For example, Davis (2022) focuses on the electrification of new buildings and calculates the costs of electric technologies relative to highly efficient fossil-based technologies. In contrast, we analyze retrofits and consider efficiency gains from retiring older, less efficient appliances. Moreover, unlike prior studies that focus exclusively on the impact of changing the fuel sources of a specific building technology in isolation (e.g., Sergici et al. 2022; Hermine et al. 2022), our analysis also considers additional efficiency improvements that are likely to occur in comprehensive building electrification retrofits. Deetjen et al. (2021) and Wilson et al. (2024) quantify the distribution of the energy bill impacts of heat pump retrofits with a focus on the climate-specific drivers but do not consider electrification of other customer end-uses (e.g., water heating, cooking) and more comprehensive efficiency retrofits beyond envelope improvements. Additionally, Deetjen et al. (2021) and Wilson et al. (2024) use state-level retail energy prices and simplified representation of monthly fixed charges. This study uses current retail electricity and non-electricity rates from actual utility tariffs to quantify total retail energy costs and compute revenue neutral alternative retail electricity rate designs. While this paper is not the first to highlight the importance of comprehensive retrofits (e.g., Wang et al. 2022), it is the first analysis to our knowledge to quantify the resulting bill impacts of these comprehensive retrofits across a large and realistically diverse sample of customers using actual retail energy prices.

Analytical Approach

We quantify the range of customer bill impacts of building electrification investments under default (i.e., flat) retail electricity rate designs. Our analytical approach proceeds in two steps. First, we derive hourly electricity and non-electricity load shapes for building electrification measure packages by end-use. Second, we estimate customer energy bills by multiplying the electric and non-electric building load shapes by the applicable electric and non-electric (i.e., propane, natural gas, and/or fuel oil) prices. We describe each step in more detail below.

Determining building electrification load shapes and energy savings

We first use NREL’s ResStock database to generate hourly baseline energy usage using simulated building characteristics for current building technology deployment and appliance stock. ResStock produces a representative sample of buildings across climate zones with a realistic diversity of building types, vintages, sizes, construction practices, installed equipment, and appliances. Non-electric end-uses in the baseline building stock are based on survey data for location-specific appliance saturation rates where non-electric fuels include natural gas and propane for all regions and fuel oil for the Northeast region only. The hourly load shapes come from a physics-based simulation model that is calibrated and validated using empirical data on actual energy use in buildings, including metered utility data from more than 2.3 million customers throughout the country and circuit-level sub-metered data (Pigman et al. 2022; Wilson et al. 2022). NREL provided custom-generated annual hourly profiles for approximately 10,000 residential buildings using 2019 Actual Meteorological Year (AMY) weather data, which represents the most recent year where data are available, for each of four regions we examine. Within each region, all buildings share the same weather data profile.

We then use ResStock to model alternative technology deployment scenarios intended to represent increased building electrification. ResStock combines information about the existing appliances and building characteristics with commercially-available energy efficient and electric alternatives to model feasible upgrade packages. The building electrification package used in this study replaces non-electric space and water heating with efficient electric alternatives, including heat pump water heaters and heat pumps for space heating and cooling (both ducted and mini-split systems), as well as non-electric clothes dryers and cooking ranges. The package also includes improved ducting and energy efficiency upgrades of existing electric appliances, which may be common in a comprehensive retrofit. For this package, we include all buildings with at least one non-electric end-use in the baseline and focus our analysis on the combined impacts of electrification and efficiency improvements. The energy impacts of electrification are, therefore, the difference in annual electricity consumption between the building electrification upgrade package and the baseline profile.

Selecting retail electricity rate designs and calculating bill savings

For electricity rates, we use 2019 residential default retail tariffs in four regions: the Southwest, Great Plains, Midwest, and Northeast. This variety enables us to capture real-world differences in electricity prices and rate designs. We use publicly available tariff data for a representative utility in each region and include all applicable tariff charges, including volumetric energy charges, fixed charges, additional energy supply charges, sales tax, and other adjustment charges (e.g., cost recovery, program fees, cost sharing).

All of the electric rates in this study are two-part tariffs composed of fixed monthly charges ($/month) and volumetric electricity charges ($/kWh). In the Southwest and Northeast utilities, the rate schedule has one electricity price that is constant throughout the year. In the Midwest utility, electricity prices vary by season: one electricity price for the summer months (June-September) and a different electricity price for the other (i.e., “winter”) months. In the Great Plains utility, the rate schedule has a declining block design in the winter and an inclining block design in the summer after customers use 1,400 kWh in a month.

For natural gas prices, we also use 2019 residential retail tariffs available to customers in the four regions. Similar to electricity rates, natural gas prices are two-part tariffs composed of fixed monthly charges and volumetric charges. Natural gas charges are converted from $/therm to $/kWh. For propane and fuel oil prices, we use the Energy Information Administration’s Weekly Heating Oil and Propane Prices reported by state and area. We calculate volumetric charges by taking the average fuel price for all weeks in 2019 for the state or area that corresponds to each region and converting from $/gallon to $/kWh.

The volumetric price of non-electric fuels on a $/kWh basis is lower than the average price of electricity in nearly all cases (see Table 1). The difference between average electricity and natural gas prices is especially pronounced. For example, the natural gas price is as much as ten times lower in the Midwest utility when normalized by unit of energy.

Table 1. Comparison of utility average volumetric energy prices by fuel type

Price ($/kWh)	Midwest	Southwest	Northeast	Great Plains
Electricity (flat rates)	0.19	0.13	0.19	0.07
Average natural gas	0.02	0.05	0.05	0.02
Average propane	0.06	0.07	0.11	0.07
Average fuel oil	N/A	N/A	0.06	N/A

We calculate the total bill for each building before and after electrification using these electricity rates and regional fuel prices with the customer load profiles for the baseline and building electrification package. We include the consumption and cost of all fuels in the total bill saving calculations.

Results

Figure 1 shows the share of non-electric fuels in the baseline building stock (left bars) compared to the building electrification upgrade scenario (right bars) normalized on a kWh/month basis. With the electrification upgrades, monthly average *energy* consumption decreases across all regions. Differences in the size of these reductions across utilities are driven by baseline consumption levels and mix of fossil fuel technologies. Monthly average *electricity* consumption either increases (for the Northeast and Midwest utilities) or decreases (for the Southwest and Great Plains utilities) depending on the cumulative effects of the relative electricity increase from the electrified end-use technology, as well as additional energy efficiency gains from other measures included in the building electrification upgrade package. A large driver for the increase in electricity consumption in the Northeast and Midwest is higher consumption from the heat pump in the winter due to colder temperatures—an end-use with non-electric fuel sources in the baseline. By contrast, the Southwest and Great Plains have hotter temperatures and benefit from efficiency measures for cooling end-uses, which are entirely electric in the baseline.

Across the distribution of customers[1], we find a consistent reduction in total energy consumption with the electrification upgrade portfolio (see left panel of Figure 2). Excluding outliers, customers reduce energy consumption by more than 10% and median customer energy savings range from 39% to 61%.

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[1] We report bill savings as box-and-whisker plots where the box represents the first and third quartile values, the center represents the median value, and the whiskers represent the first and third quartile values with 1.5 times the interquartile range subtracted and added, respectively. Outliers are not shown in plots.

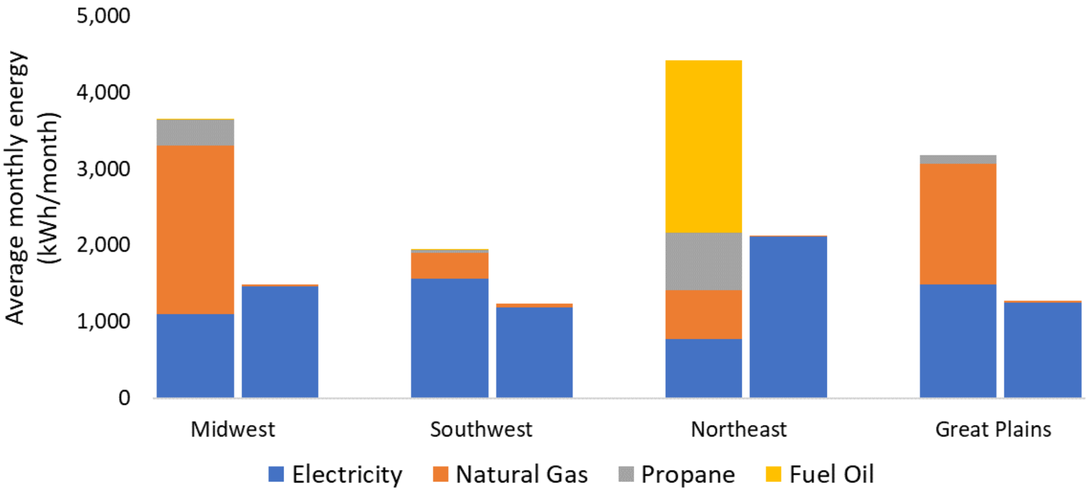

Figure 1. Average monthly energy consumption for baseline (left bar) and building electrification upgrade profiles (right bar)

Due to the opposing effects of higher energy prices and lower energy consumption, we find that the net impact of electrification on bills differs across utilities and customers. We observe consistent positive energy bill savings for the Southwest and Great Plains utilities while the Midwest and Northeast utilities show a range of energy bill savings and energy bill increases (see right panel of Figure 2). Although the efficient electrification measures produce total energy savings across the distribution of customers of the Midwest and Northeast utilities (see left panel of Figure 2), the much higher price of electricity relative to fossil fuel prices results in energy bill increases for some customers (see Table 1 and Figure 2). This is most evident for Midwest utility customers, who see a 61% *decrease* in median energy consumption but a 3% *increase* in median energy bills due to the much higher cost of electricity compared to natural gas. The range of customer energy bill savings within a utility service area is large and varies significantly across utilities. While most customers experience energy bill reductions, these results suggest that a large proportion of customers in some regions may face substantial increases in energy bills when adopting building electrification measures. For example, 25% of Northeast utility and Midwest utility customers experience energy bill increases of at least 27% and 38%, respectively.

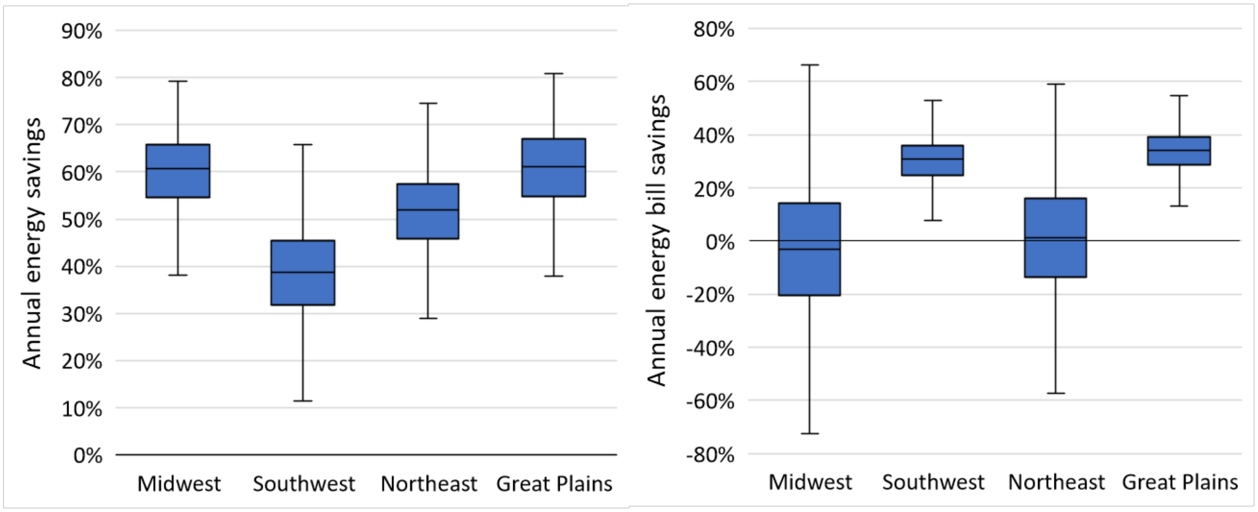

Figure 2. Distribution of energy savings (left panel) and energy bill savings (right panel) for building electrification upgrades

We further explore these bill savings by separately quantifying the energy bill impacts from electrifying heating, cooling, and water heating end-uses. This analysis allows us to disentangle the impact of the electrification retrofit itself from any additional energy efficiency measures in our comprehensive package. Figure 3 shows the distributions of customer bill savings for the portion of the energy bill associated with space heating (top panel), water heating (middle panel), and cooling (bottom panel) end-uses. Accounting for energy bill savings on an end-use basis reveals significant differences across utilities due to differences in electricity price, climate, and baseline saturation of fossil-based technologies.

Importantly, the results suggest that the electrification measures can, in many cases, improve the efficiency of end-use energy consumption without any additional efficiency upgrades. In fact, for both space heating and water heating, nearly all customers for all utilities (~95% of the sample size) save energy with the modeled electrification package compared to the baseline. Replacing fossil-based space heating or water heating technologies with heat pumps is much more energy efficient (e.g., heat pumps can transfer 300-400% of energy they consume compared to 90-95% for a natural gas furnace). Similarly, replacing electric resistance space heating and water heating with heat pumps is more efficient.

Notwithstanding the importance of these efficiency gains from older equipment, there are still instances in which space heating and water heating electrification results in higher customer energy bills due to the higher cost of electricity. For example, Figure 3 shows that most Midwest utility and Northeast utility customers experience increases in their space heating costs. The results reinforce the importance of the differences between electricity prices and non-electric fuel prices in driving customer energy bill outcomes.

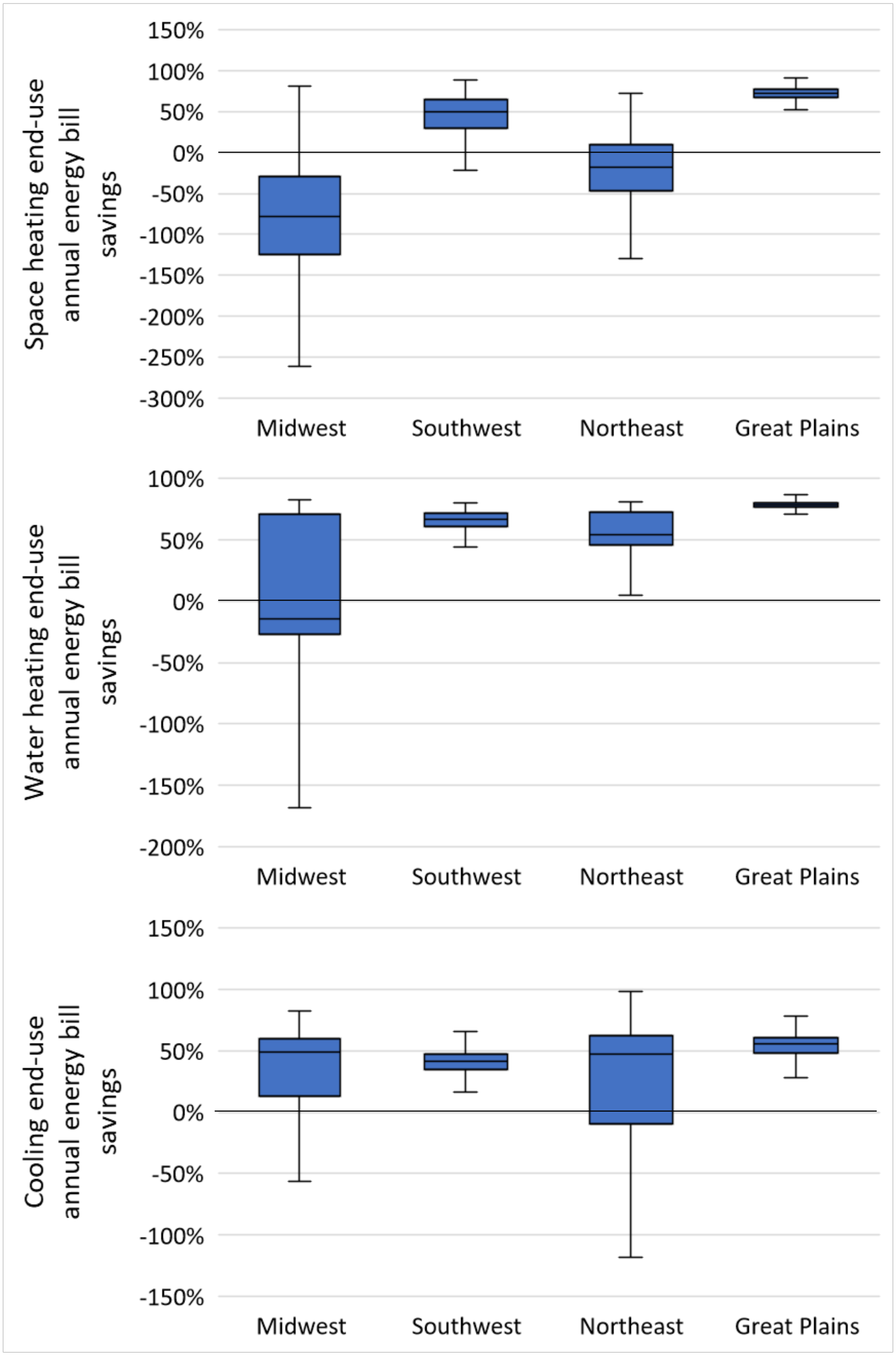

Figure 3. Distribution of building electrification energy bill savings for flat rates separated by space heating (top), water heating (middle), and cooling (bottom) end-uses

In practice, customers investing in building electrification are replacing and retrofitting different combinations of building equipment and baseline efficiency levels. We further segment the buildings in our ResStock dataset across different groupings of pre-electrification baseline equipment to identify what electrification upgrades drive the highest amount of energy bill savings and where coupled electric efficiency upgrades may be most beneficial for improving energy bill savings. We analyze the impacts of different building characteristics by creating seven customer groups based on the following equipment present in the baseline:

1. Electric resistance space heating and electric resistance water heating
2. Electric resistance space heating (i.e., any electric space heating besides heat pumps)
3. Electric resistance water heating (i.e., any electric water heating besides heat pumps)[2]
4. Non-electric space heating, electric resistance water heating, and cooling
5. Non-electric space heating, electric resistance water heating, and no cooling
6. Non-electric space heating, non-electric water heating, and cooling
7. Non-electric space heating, non-electric water heating, and no cooling

Figures 4 through 7 show the distribution of customer energy bill savings for each utility and customer group. For comparison, the figures also include the results for all simulated buildings ("all buildings") that are shown in the right panel of Figure 2.

The results show that a key driver of energy bill increases is the introduction of air conditioning for customers who previously did not have cooling. While nearly 90% of U.S. households have space cooling (Beall and McNary 2022), some homes still lack air conditioning, especially in highly populated areas of coastal California with ambitious heat pump adoption goals. Heat pump technologies provide more efficient space heating *and* cooling, resulting in the introduction of new cooling loads to customers without cooling in the baseline. Customers *without* cooling in the baseline are more likely to experience increases in energy bills compared to customers *with* cooling in the baseline (i.e., comparing customer groups 5 to 4 and 7 to 6). This result is especially pronounced for the Southwest utility because the climate requires large cooling demand and is somewhat muted for the Northeast utility with minimal cooling demand.

Among all the utilities, customers with electric resistance space and/or water heating in the baseline experience the highest bill savings (i.e., comparing customer groups 1, 2 and 3 to all other groups). Regardless of the climate characteristics, the efficiency gains from replacing electric resistance end-uses with heat pumps reduce electricity consumption. Most customers with either baseline electric resistance space heating or water heating (or both) experience overall energy bill reductions due to the large energy efficiency gains and despite higher electricity prices relative to fossil fuel prices. In fact, Figures 4-7 show that much of the variation in bill impacts among customers *with* pre-existing space cooling can be explained by the relative difference in electricity prices and the relative share of electrification versus paired electric efficiency. In areas with relatively low electricity prices (i.e., the Southwest and Great Plain utilities), the efficiency gains lead to energy bill savings regardless of baseline technology fuel uses. In areas with relatively high electricity prices, bill impacts are highly sensitive to whether there is preexisting electric water or space heating. The customers at the highest risk of experiencing bill increases are customers with non-electric space and water heating in areas with

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[2] We consider buildings with both baseline electric space heating and water heating in the electrification scenario if other end-uses are electrified, such as clothes dryers or stoves.

high electricity prices. Although heat pump technologies offer more efficient energy conversion relative to fossil-based space heating and water heating technologies, these efficiency gains may not be large enough to outweigh the much higher electricity prices (see Table 1).

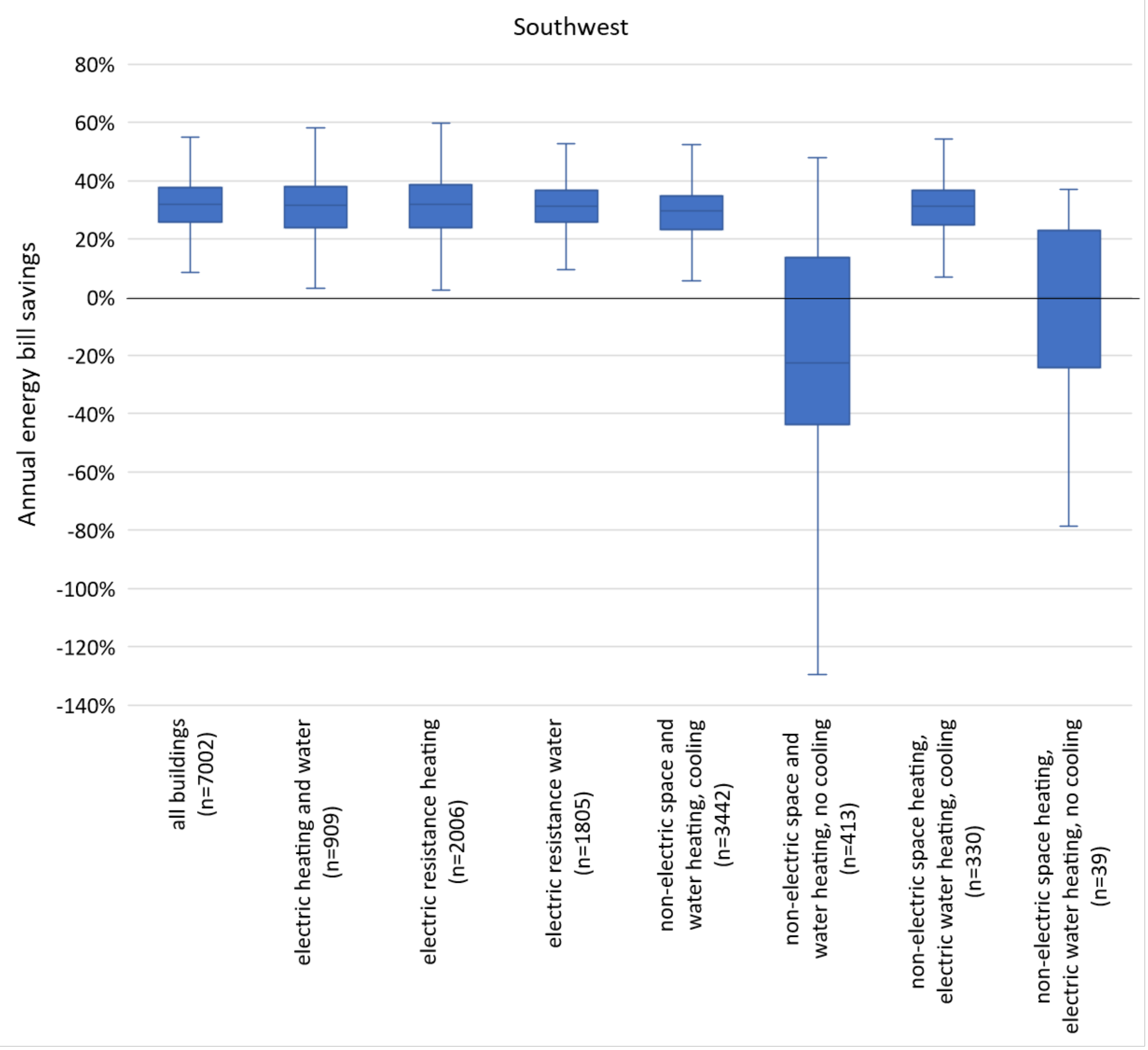

Figure 4. Distribution of building electrification energy bill savings for Southwest Utility by customer baseline building technology group

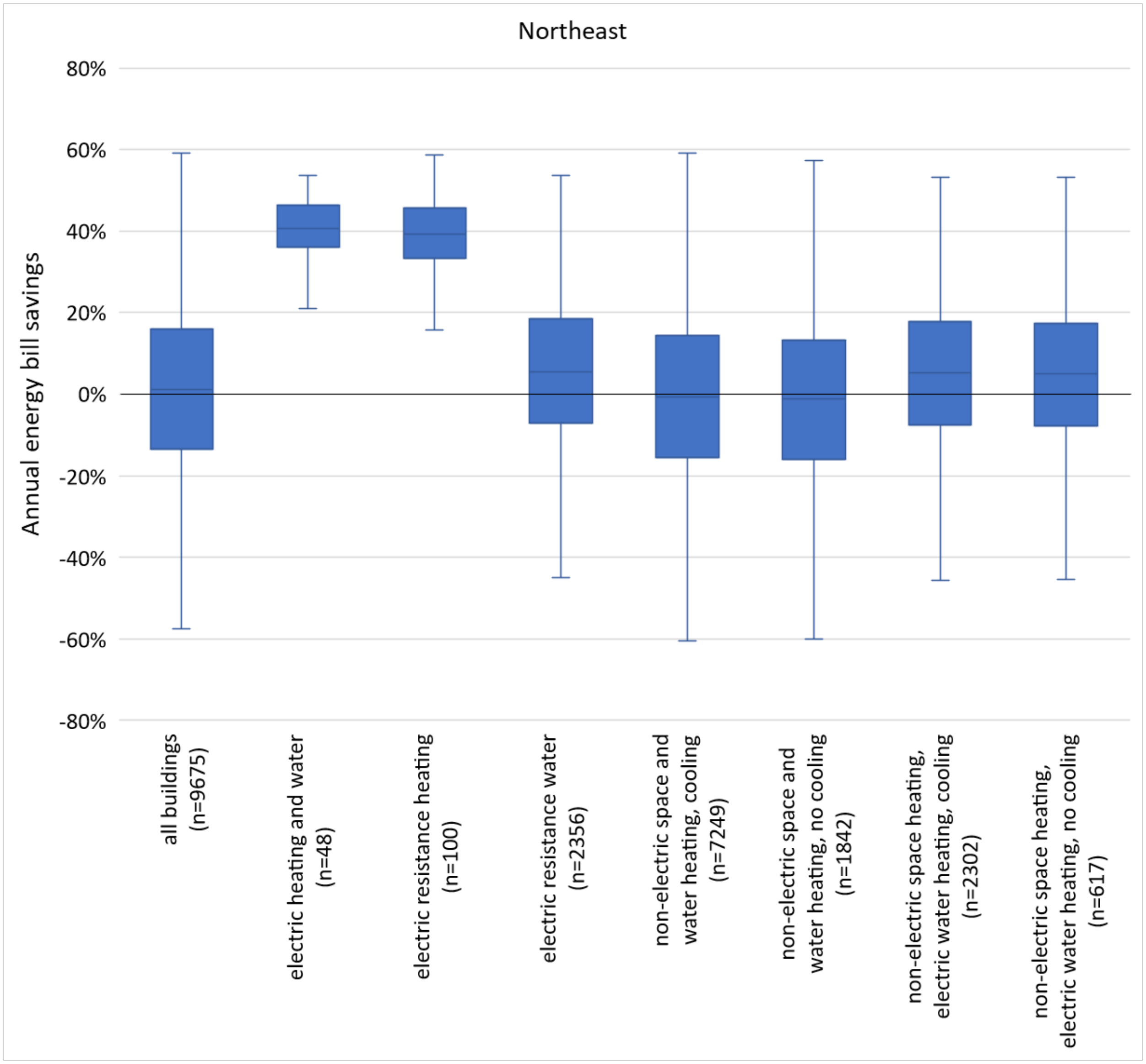

Figure 5. Distribution of building electrification energy bill savings for Northeast Utility by customer baseline building technology group

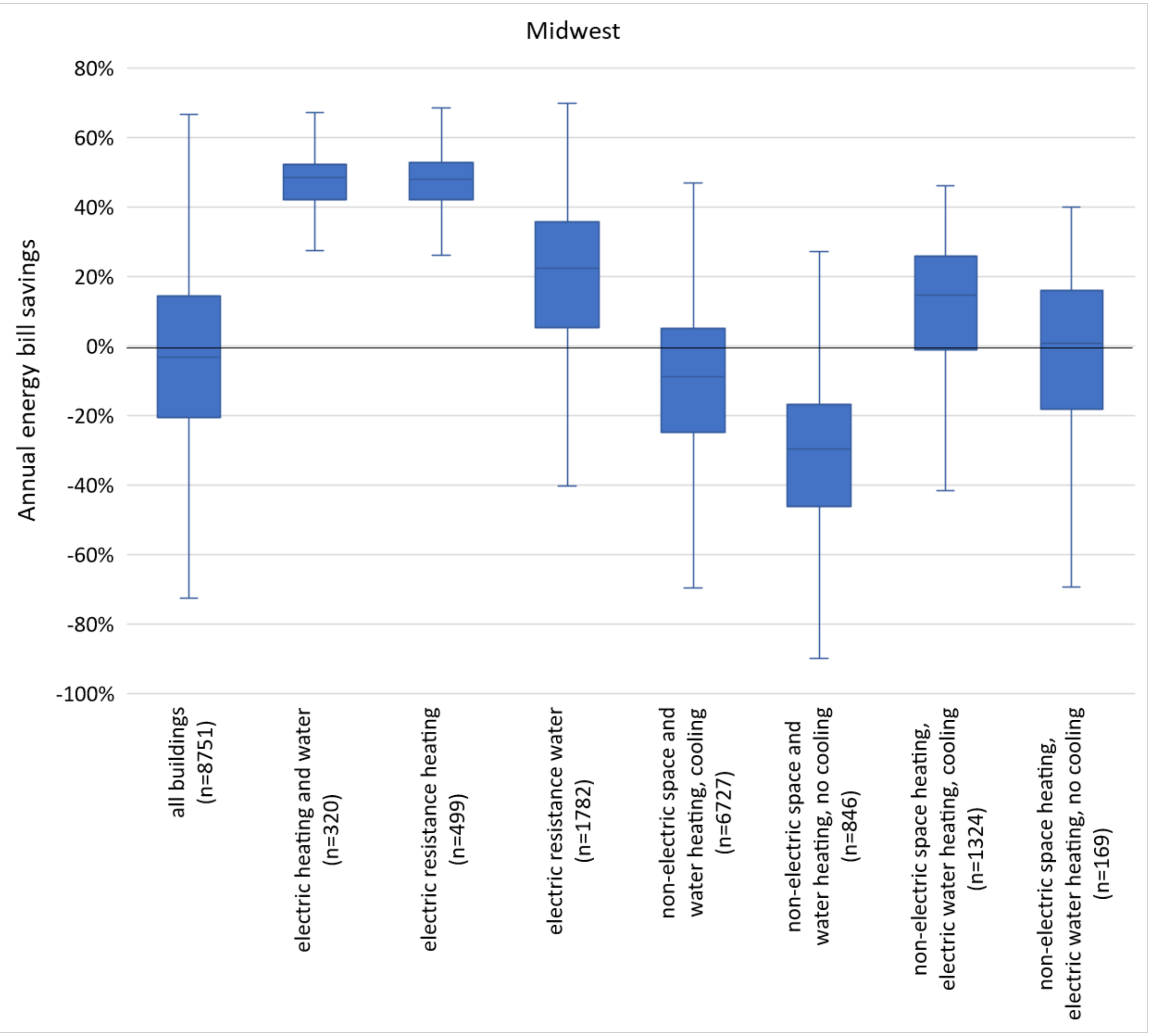

Figure 6. Distribution of building electrification energy bill savings for Midwest Utility by customer baseline building technology group

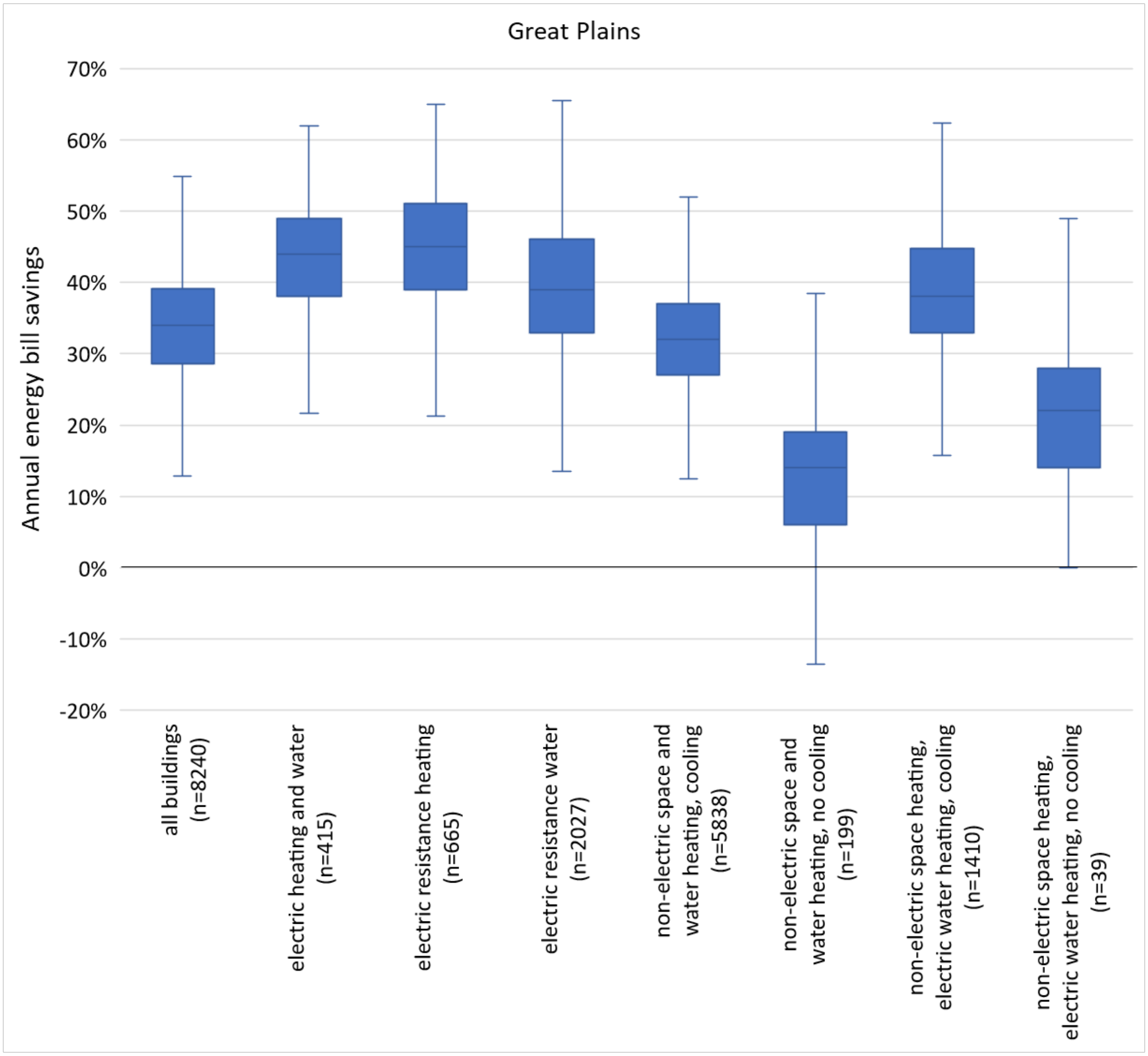

Figure 7. Distribution of building electrification energy bill savings for Great Plains Utility by customer baseline building technology group

Finally, we explore how shifting customer costs to fixed charges for electricity impact bill savings, which ultimately might influence how customers invest in electrification. Shifting customer electricity costs from volumetric-based charges to fixed charges has been identified as a strategy to mitigate electricity bill increases from electrification investments (Borenstein et al. 2021) as well as to improve alignment with utility cost structures (Faruqui and Leyshon 2017). To explore this alternative retail electricity rate design, we develop revenue neutral retail electricity rates for the four regional utilities that collect the same total residential class revenue (i.e., total residential customer bills) in the baseline (pre-electrification) case using the current volumetric and fixed charges as a starting point, which is consistent with how utilities design alternative rates. In order to calculate the alternative retail electricity rates, we either increase fixed charges with proportional decreases in volumetric charges such that a portion of total revenues collected from volumetric charges shifts to fixed charges, or vice-versa. We then apply the alternative retail electricity rates to calculate energy bill savings (i.e., including non-electric fuel costs) for each customer in our dataset.

For all utilities, we see a convergence in the distribution of energy bill savings as fixed charges increase (see Figure 8). Compared to the original rate design, increasing the fixed charge reduces the variance in potential bill impacts with a large reduction in the share of customers who experience especially large bill increases or reductions. This implies that an increased fixed charge may reduce customer uncertainty about the resulting bill impacts of an electrification investment. For example, about a quarter of customers of the Midwest utility would experience bill increases of more than 25% under a 5% fixed charge. In contrast, under a fixed charge of 30% or greater, fewer than a quarter of customers would experience bill increases greater than 10%.

Whether an increased fixed charge mitigates energy bill increases from electrification among utilities depends largely on climate differences. The utilities with higher winter loads and where electrification generally results in a net increase in electricity consumption (e.g., Midwest and Northeast utilities) see greater mitigation of energy bill increases under higher fixed charges compared to utilities with higher cooling loads and higher electric baseline consumption (e.g., Southwest utility) where the efficiency gains - and energy savings opportunities - from electrification are high.

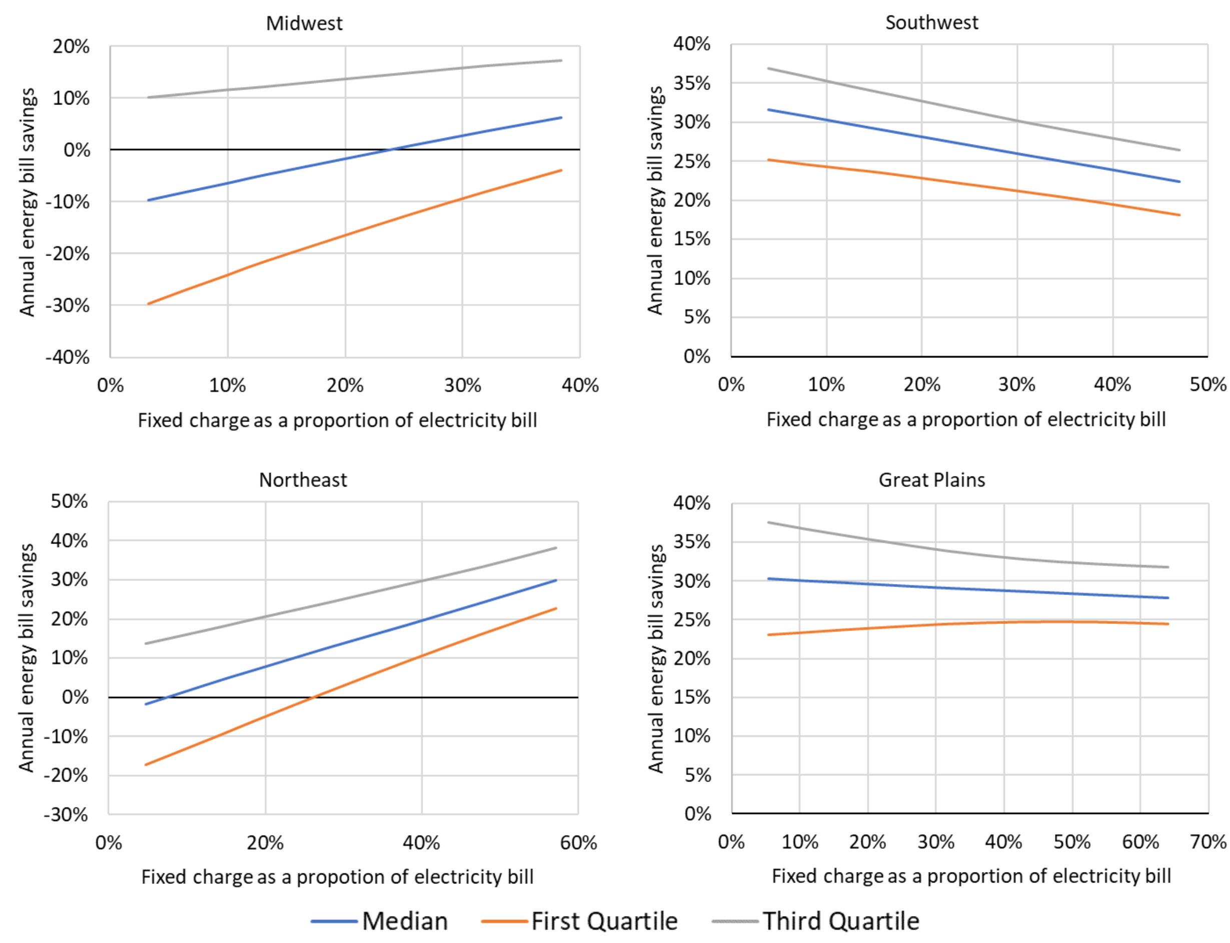

Figure 8. Energy bill savings for building electrification by the proportion of fixed charges to total electricity cost for each region

Discussion and Conclusions

We explored changes in building electrification customer energy bills across a large number of simulated building profiles in four regions under default electric rates. The study captured heterogeneity in hourly savings shapes across different building technologies and measures, as well as the large differences in residential building characteristics (e.g., vintage, appliance saturation) and weather.

Changes in energy bills with building electrification varied noticeably by utility. The electrification package modeled in this study resulted in substantial energy savings from replacing older equipment with much higher efficiency heat pumps (in addition to efficiency gains from new ducting as part of a comprehensive retrofit package). Yet, despite reductions in building energy consumption, median customer energy bills for some utilities increased because of the much higher price of electricity compared to fossil fuel prices. The portfolio of customer baseline building technologies was a strong determinant of energy bill increases or decreases, and in many cases a more impactful driver than climate. Importantly, customers with either or both electric resistance space heating and water heating in the baseline typically experienced bill savings by converting to more energy efficient heat pump technologies. In addition, the heat pump-driven introduction of cooling load for customers without previous cooling caused noticeable increases in energy bills for some customers. However, the benefits to these customers of improved indoor air quality, increased comfort in summer, and better health may outweigh the cost of higher bills.

Shifting customer electricity costs to fixed charges with commensurate decreases in volumetric charges can reduce extreme cases of bill increases under electrification. However, as volumetric charges decrease and a larger portion of the bill is fixed, there is a potential reduction in energy bill savings and a disincentive to make energy efficiency investments. Importantly, increasing fixed charges may not mitigate bill increases from electrification for all utilities, and certainly not for all customers. The extent to which higher fixed charges mitigate electricity bill increases from electrification depend on the customer-specific mix of fossil- and electricity-based end-uses, as well as their actual electricity and fossil fuel prices.

The results have several implications for promoting the adoption of heat pump technologies. First, there are areas of the country where electricity rates are sufficiently low that retrofitting existing buildings with heat pumps may benefit all customers. Second, in areas with higher electricity rates, utilities, program administrators, and contractors may use targeted marketing to customers with some electric resistance technologies who are likely to experience aggregate energy bill savings and favorable payback times by pairing electrification with electric efficiency. Likewise, the results suggest targeted programs to customers with fossil-based baseline technologies or no pre-existing space cooling may benefit from additional education about the potential financial costs and health and comfort benefits of electrification. Third, lowering average retail volumetric electricity rates, either by changing the allocation of cost recovery from variable to fixed costs or through other ratemaking decisions, may decrease the risk of electricity bill increases and increase the potential for energy bill savings for building electrification customers by reducing the difference between variable fossil fuel and electricity prices. However, the same decrease in average retail volumetric electricity rates may also reduce energy bill savings by lowering the value of electricity savings. Fourth, the heterogeneity in bill impacts among customer groups imply that additional, non-rate incentives may be necessary to incentivize heat pump adoption among some customer populations, especially for customers replacing predominantly fossil-based technologies in areas with high electricity rates.

Acknowledgements

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