Heat Pump Friendly Retail Rate Designs

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Agenda

1- Motivation

2- Approach

3- Results

Motivation

Electrification of space and water heating using heat pumps is a key component of state and city climate action plans. The economics of heat pumps relative to natural gas will be an important driver of customer adoption

- Heat pump installation costs are typically higher than gas furnaces/boilers
- Heat pump operating costs vary by region depending on climate, equipment efficiency, utility rates, and rate structures
- Even in regions where heat pump operating costs are lower than gas costs, the gap will need to be significant to offset the upfront cost premium
- There is support from some stakeholders for the creation of heat pump-specific rates to reduce operating costs and lower barriers for gas customers to electrify

The purpose of this study is to quantify operating cost differences between heat pumps and gas heat for a generic electric and gas utility and evaluate the use of alternative rate structures to reduce heat pump operating costs

- Certain operational characteristics of heat pumps (i.e. better load factors, higher volumetric usage etc.) inform alternative cost-based rate designs that may be better aligned with these operating characteristics
- Alternative cost-reflective rate designs (without subsidies) can be used to improve economics of heat pumps and help increase heat pump adoption

Motivation (cont’d)

- There is a scarcity of rate options that are explicitly designed to address the operating cost gap for heat pumps. In this nascent space, non-rate operating cost incentives also do not yet exist
- We identified several categories of existing rate structures that may be favorable for heat pump operating costs
  - These rates are cost-based and are not subsidized
  - Aligning the design of the rate with operational characteristics of heat pumps, it is possible to address/reduce the operating cost gap
- These rates do not have to be technology-specific and only target HP customers. They could be open to all customers, and customers can opt-in if they think they could achieve savings given their consumption patters
- While offering these rates will be important, it will be equally important to address information barriers, i.e. utility programs targeting customers and pairing them with most favorable rates; contractor training programs in which contractors increase awareness for new rates etc.

Alternative Rate Designs to be Modeled

Understanding operating characteristics of heat pumps will inform which cost based rates might be favorable

- HPs lead to higher electricity consumption (compared to gas heating), therefore lower volumetric rates favor heat pump usage
- Most of the HP load is in the non-summer months, seasonally differentiated rates in summer peaking systems might favor heat pump usage
- A significant portion of the HP load tend to fall into the off-peak periods, which implies that various cost-based TOU rates might favor HP usage
- Heat pumps tend to have high load factors, which implies that demand based rates might favor HP usage

We propose to model operating cost gap under the default rate and three alternative rate designs

Rate 1 (Default Rate): high volumetric rate (cents/kWh) + low monthly customer charge

Rate 2: Low volumetric rate (cents/kWh) + high monthly customer charge

Rate 3: Time varying volumetric supply (cents/kWh) + time-varying volumetric delivery charge (cents/kWh) + low monthly customer charge

Rate 4: Time varying volumetric supply (cents/kWh) + time-varying demand-based delivery charge ($/kW) + low monthly customer charge

Analytical Approach

Customer Usage Data → Gas End Use Estimation → Heat Pump Load Profiles → Customer Bill Modeling

We estimate the heat pump operating cost gap for a sample of 80 residential customers using the following approach:

- Each of these 80 customers currently use natural gas for space heating
- High quality hourly electricity usage and monthly gas usage data is available for each of these customers
- Estimate each customer's gas usage for space heating end use based on a customer-specific regression of their 2021 actual usage against heating degree days in 2021
- Model hourly heat pump electric load profile for each customer based on conversion of their heating gas use, hourly temperatures, and assumed heat pump efficiencies
- Calculate each customer's pre and post electrification gas and electric bills on 3 different rate types
- Analyze changes in both the total energy bill (gas + electric) and in heating cost alone
  - **Total energy bill** captures the impact of both rate migration on non-heating electric load and heating electrification
  - **Heating cost** isolates the operating cost of the heating equipment from other factors like costs/savings that may occur due to rate migration of a customer's non-heating load

Cost Gap Metrics

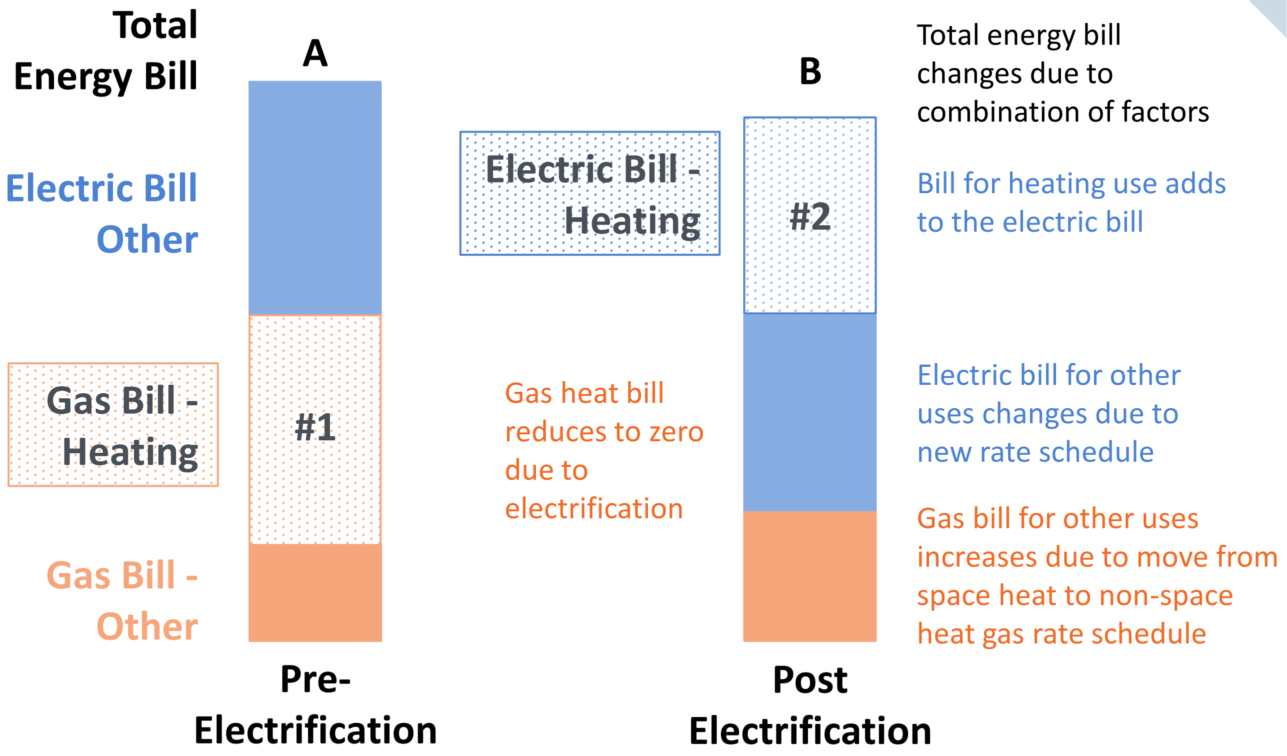
Total Energy Bill

- Defined as the sum of the gas and electric bills
- This metric captures the overall impact of several changes that may occur when a customer electrifies including:
  - Gas rate migration from heating to non-heating rate schedule
  - Voluntary electric rate migration away from the default rate
  - Change in gas and electric usage due to electrification

Heating Operating Cost Gap

- Defined as the difference between the heating portion of the electric bill and heating portion of the gas bill
- This metric isolates heating costs from costs arising from rate migration

Bill Components and Cost Gap Definitions



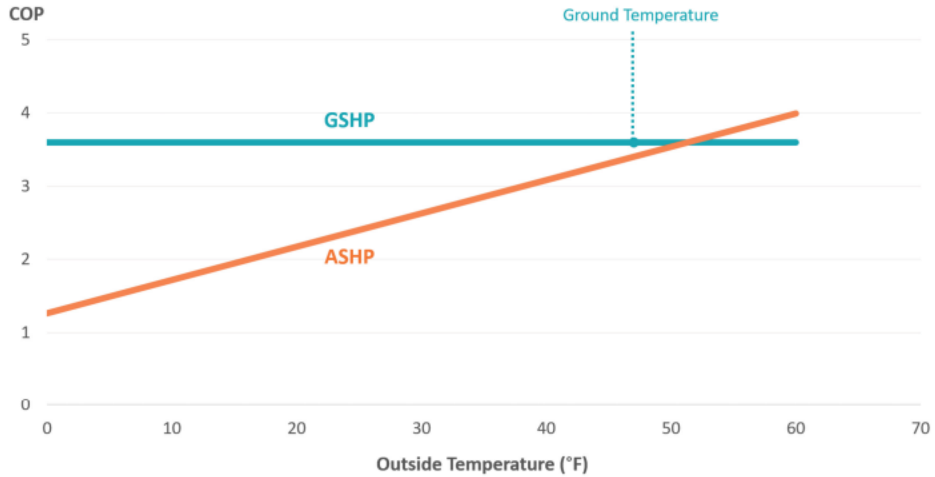
Change in Total Energy Bill = B - A

Heating Operating Cost Gap = #2 - #1

Heating Equipment Overview

	Single Family Home
Natural Gas	• **80% efficiency** for both space and water heating
ASHP	• COP based on temperature vs. COP relationship meeting NEEP's cold climate ASHP standard • Results in average **COP of around 3**
GSHP	• GSHP provides only space heating • COP does not vary with outdoor temperature • **COP of 3.6**
HPWH	• Assumed integrated HPWH with **COP of 3.3**

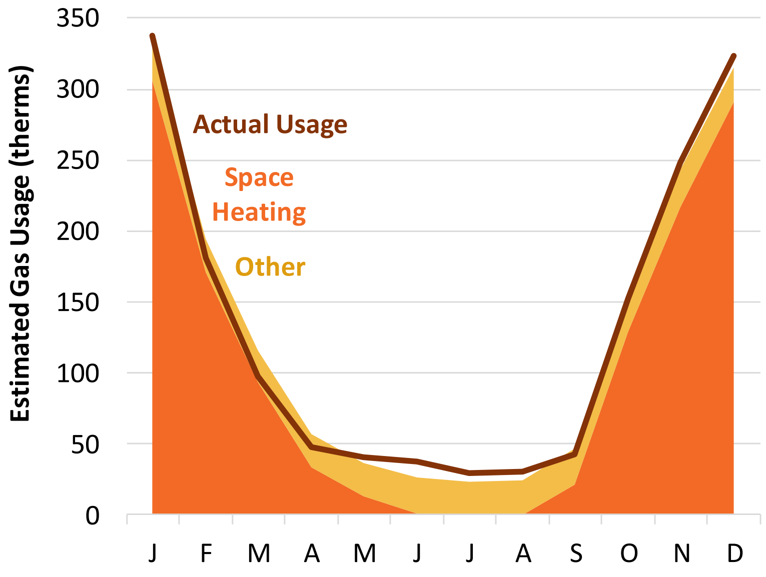
ASHP COP vs. Temperature Curve



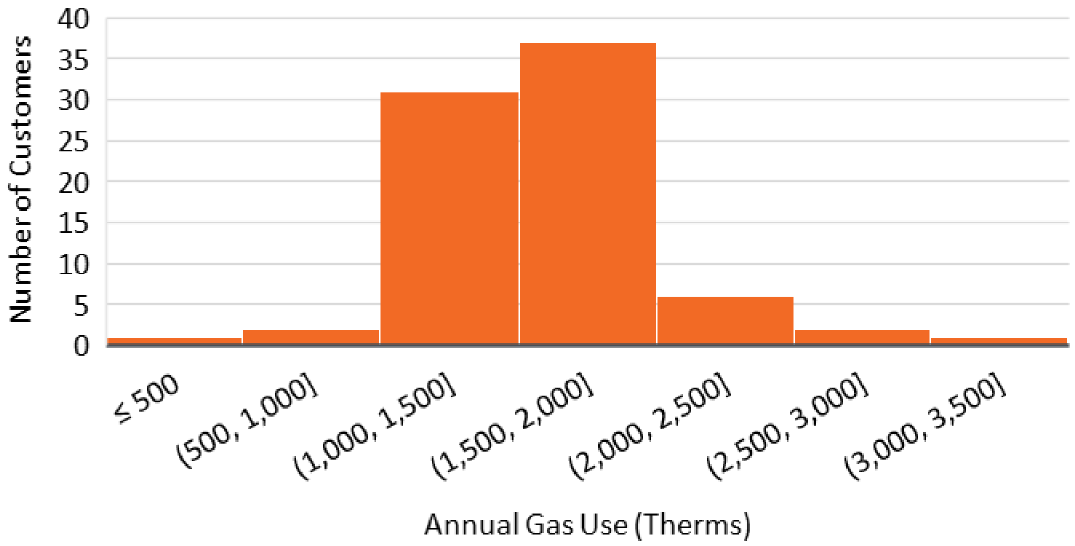
Estimated Customer Heating Requirement

We apply a three-parameter "change-point linear model" to estimate the customer's gas usage for heating based on their total usage, outdoor temperature, and an assumed change-point temperature

Actual Whole-Premise Gas Usage and Estimates Heating Gas Usage for a Sample Customer



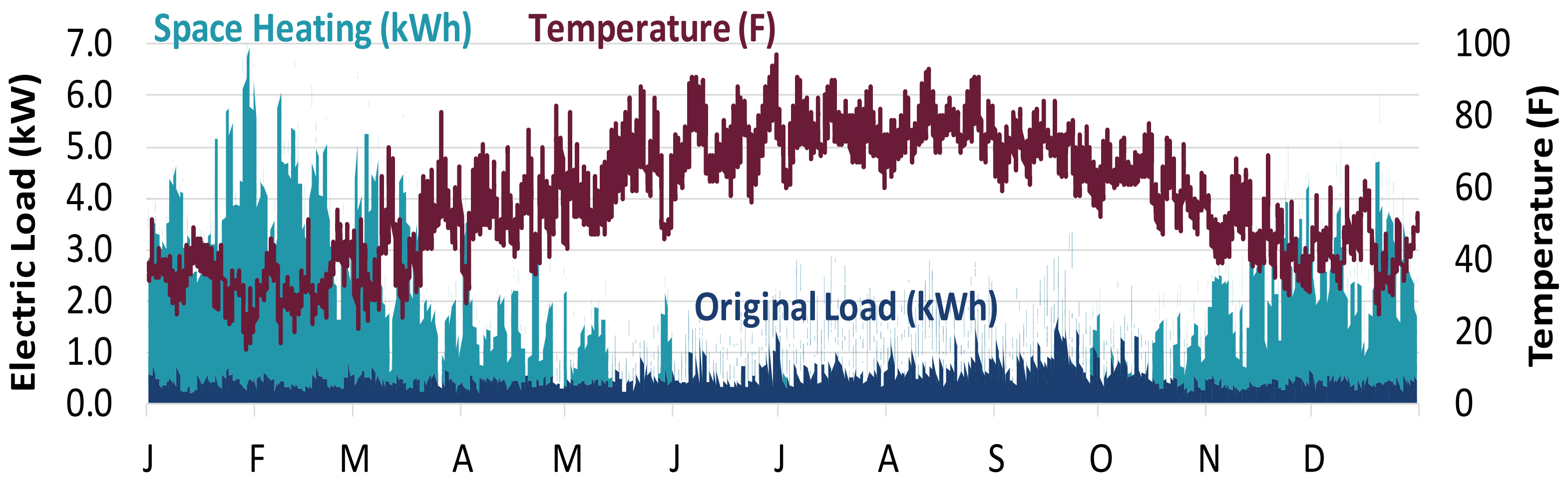
Histogram of Estimated Heating Gas Use in the 80-customer Sample



Modeling of Heat Pump Electric Load

We utilize the customer-specific heating requirement estimates, historical hourly temperature data, and assumed air source heat pump specifications to model hourly electric demand

Modeled Hourly Post-electrification Load for a Sample Customer



Gas Rate Assumptions

We model a default gas rate option and assume that all customers are on this rate pre- and post-electrification

- We assume that customers stay connected to the gas system post-electrification and continue to use gas for other end-uses besides space heating such as cooking, water heating, or cooling

	Season	Gas Rate (Default)
Customer Charge ($/month)	All year	$24
Commodity Charges ($/therms)	Summer	$0.60
	Non-Summer	$0.55
Delivery Charges ($/therms)	Summer	5 to 90 therms: $1.34 90 to 3000 therms: $0.99 Over 3000 therms: $0.79
	Non-Summer	5 to 90 therms: $1.32 90 to 3000 therms: $0.97 Over 3000 therms: $0.77

Electric Rate Assumptions

Rate I is a default rate that is commonly offered to residential customers across many utilities

Rates II-IV were chosen to represent the various alternatives that are being considered in the industry as potential cost-based rate structures that can support heating electrification, *without subsidizing these end-use technologies*

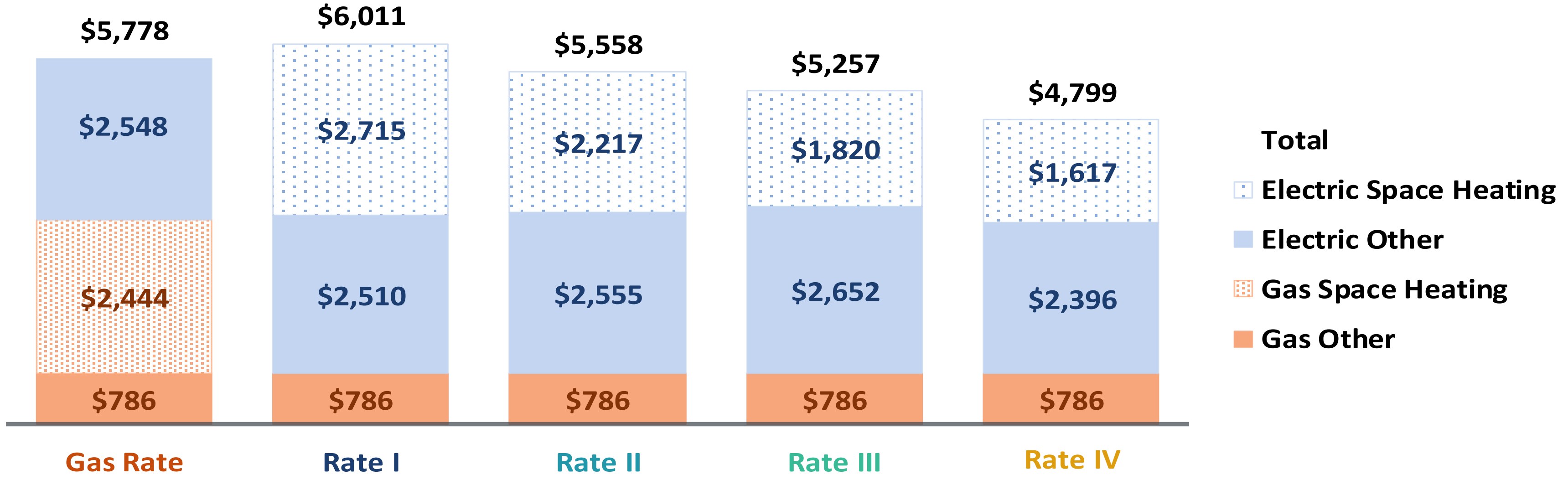
	Season	Rate I	Rate II	Rate III	Rate IV
Customer Charge ($/month)	All year	$18	$45	$23	$28
Supply Charges ($/kWh)	Summer	$0.09	$0.09	Peak: $0.265 Off-peak: $0.035	Peak: $0.215 Off-Peak: $0.065
	Non-Summer	$0.09	$0.09	Peak: $0.115 Off-peak: $0.035	Peak: $0.165 Off-Peak: $0.065
Delivery Charges Volumetric ($/kWh)	Summer	$0.155	$0.125	Peak: $0.215 Off-peak: $0.055	$0.015
	Non-Summer	$0.145	$0.105	Peak: $0.075 Off-peak: $0.055	$0.015
Delivery Charges Demand ($/kW)	Summer	-	-	-	Peak: $20.00 Off-Peak: $5.50
	Non-Summer	-	-	-	Peak: $15.00 Off-Peak: $5.50
Peak Definition	All year			8 AM-Midnight All days including holidays	Noon-8 PM on weekdays except holidays

Change in Customer Bills under Alternative Rate Designs

Both electrification and migration from the default rate to an alternative rate structure (even if it were to happen without electrification) affect customer bills

- To provide a holistic view of the impact of these two changes, we analyze annual "Total Energy Bills", defined as the sum of the natural gas and electricity bills
- In addition, we break up the bills into a "Space Heating" component and a non-space heating "Other" component in order to isolate electrification-related costs.

Energy Bill Before/After Electrification



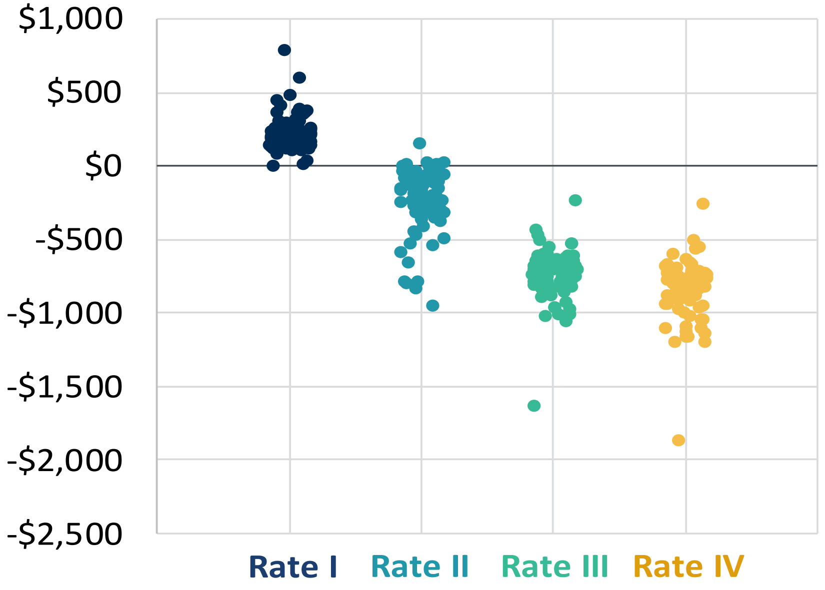
- Replacing gas space heating with an ASHP on the default electric rate would increases annual total energy bill increasing by about $233
- Switching to any of the three alternative electric rates, average annual total energy bill is $220 to $979 lower than the pre-electrification average annual total energy bill

Change in Customer Bills (cont'd)

Post-electrification, switching from Rate I to the alternative rates largely results in customers saving

- Out of 80 customers, 71 have lower bills on Rate II, 80 on Rates III and Rate IV
- Rate IV results in the lowest bills overall, followed by Rate III and Rate II, respectively
- The scale of bill reduction is much more variable for Rate IV than for Rate II, i.e., it is easier to predict the change in a customer's bill when switching to Rate II

Distribution of Total Energy Bill Changes Post-electrification



Heating Operating Cost Gap

Under the default electric rate (Rate I), the operating cost gap is positive for all 80 customers and ranges from $12-$790 per year

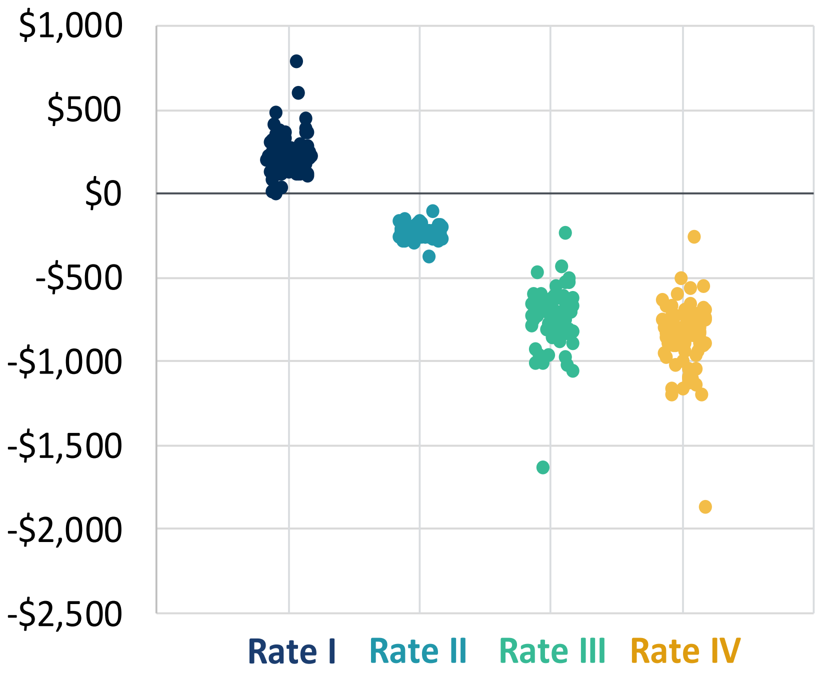
- A positive operating cost gap means the electric heating bill is higher than the gas heating bill.

Increasing the fixed charge and lowering the volumetric charge (Rate II) reduces the electric heating bill to a sufficient extent that the operating cost gap turns negative for all customers

Further, switching to a TOU day/night structure (Rate III) or a demand based structure (Rate IV) result in even lower operating cost gaps.

Rate IV is the most effective rate for reducing electric heating bills, for our sample of 80 single-family residential customers.

Distribution of Heating Operating Cost Gap



Impact on the Payback Period

We use the average operating cost gap on each rate to calculate the number of years needed to recoup the *upfront cost premium* of an ASHP relative to a gas furnace

- Significant degree of variance in payback periods based on the ASHP cost, the addition of the IRA incentive, and selection of the electric rate schedule
- Under the default Rate I, no scope for payback because heat pump operating costs are greater than gas furnace operating costs
- The alternative rates greatly reduce payback periods across cases. For example, under the base cost assumptions with the IRA incentive, a heat pump can be paid back well within its lifespan (~15 years) under any of the three alternative rate schedules
- Rates III and IV are particularly beneficial, as ASHPs can be successfully paid back even in the high ASHP installation cost scenario.

ASHP PAYBACK PERIODS, BY ELECTRIC RATE SCHEDULE
WITHOUT IRA INCENTIVE | WITH IRA INCENTIVE

ASHP Cost Case	Rate I	Rate II	Rate III	Rate IV
Base	NA | NA	>15 | 11	15 | 5	9 | 2
Low	NA | NA	>15 | 3	9 | 1	5 | 1
High	NA | NA	>15 | >15	>15 | 10	12 | 5

Takeaways

The analysis shows that selecting the most beneficial electric rate can result in significant cost savings for heat pump customers.

- Rate design is a powerful tool in addressing the operating cost gap between heat pumps and gas furnaces. A change in electric rate structure is shown to flip all 80 customers from a positive cost gap to a negative cost gap
- Most importantly, these impacts are possible to achieve with alternative rates that are cost-based, and revenue neutral to the default rate.

Rate migration can create costs or savings independent of heating electrification, due to non-heating loads. This must be an important consideration when marketing alternative rates to customers.

- For some of the customers in the sample, even before any electrification, switching to the TOU rate would increase their electric bill by ~$200/year (this increase could be reduced/eliminated through load response to TOU rates). On the other hand, switching to one of the demand-based rates would reduce the bill by ~$100/year – While customers will initially see these costs/savings, they may revert to zero over time (on average) as rates are adjusted to maintain revenue neutrality.
- Customers who only partially electrify would remain gas customers and pay fixed gas charges.. This implies that fully electrifying a customer would create additional savings by allowing them to avoid all gas charges (additional $350/yr for a single family customer).

Information barriers could be addressed through utility programs targeting customers and pairing them with most favorable rates

Appendix

Estimating gas usage for space and water heating

Methodology

- **Space heating:** Three-parameter changepoint model from ASHRAE Guideline 14 provides a HDD coefficient and a baseline for each customer's gas load
- **Water heating:** Based on percentage of usage according to NREL ResStock data
  - NREL ResStock tool provides modeled residential demand profiles by fuel and end use at the county level

The model is defined as

$$E = C + B_1(HDD_{BT})$$

Where

E = total gas use

C = constant gas use below the changepoint

B_1= coefficient describing linear dependency on heating degree days

HDD_{BT}= heating degree days using a balance temperature of BT

Heating degree days are calculated as

$HDD_{BT} = BT – T$ for $T < BT$

$HDD_{BT} = 0$ for $T >= BT$

Application of the Change Point model

We used the Change Point Linear Model to estimate customer gas usage for heating with the following steps:

1. Run the regression for each customer using a balance temperature of 65F (this is the standard for calculating HDDs)
2. Remove customers for whom the model is not a good fit (low R^2)
3. We now have a C (constant load) and B_1 (HDD coefficient of load) for each customer
   a) Space Heating Load = B_1 x HDD
   b) Constant Load = C
   c) Water Heating Load = C x Water heating % of non-space heating load
   d) From NREL ResStock water heating % of non-space heating gas use is 73% and 88% for single and multi-family homes respectively)