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The cost of outlawing fossil fuel heat in Wisconsin

Switching to heat pumps in a northern climate will prove much more expensive

By Andrew Hanson & Zackary Hawley

BADGER INSTITUTE

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Executive summary

Home builders start an average of around 11,500 new single-family homes annually in Wisconsin, with much of the building in high demand areas in Dane County, St. Croix County, and the suburban Milwaukee area. State and local regulations from building codes to zoning affect Wisconsin's housing market. Recently, several states have implemented policies that regulate home heating sources, while others have come close to mandating that newly constructed homes install electric-run heat pump systems. Wisconsin has not, at least yet.

We created a net present value (NPV) model to estimate the cost of mandating installation of air source heat pumps (ASHP) in newly constructed single-family homes in Wisconsin. The model compares the net present value of air source heat pumps with a traditional natural gas furnace. We also consider that the climate in Wisconsin may necessitate a backup electric resistance heating system. NPV results are an input to a model of the Wisconsin housing market. The housing market model shows the impact of an air source heat pump mandate on single-family home construction in Wisconsin and across market areas of the state, and the impact on initial owner home values.

The NPV cost per new single-family home from a heat pump mandate in Wisconsin is $19,976.14, or over $232 million annually at current building levels. The cost per home in the Superior market is largest, at $29,836.65, and smallest in the Milwaukee market, at $12,842.97. Of the markets we study, the total cost from a heat pump mandate would affect the Madison housing market most substantially at $25.78 million annually.

The heat pump mandate would reduce annual home building by 544 single-family homes in Wisconsin. The largest impact from the mandate is in the Madison area, where we expect a reduction of 57 newly built homes annually. The reduction in building represents a 4.68% decline from current building levels in Wisconsin and between 2.7% (Milwaukee) and 7.3% (Superior).

Statewide, we estimate that the average new home would lose $7,833.78 in value from the heat pump mandate. The average value loss is largest in the Superior market, at $11,195.74, and smallest in the Milwaukee market, at $5,614.41. We estimate that new homeowners would lose $6,675.82 in value in Madison, $6,897.81 in La Crosse, $8,317.46 in Eau Claire, and $8,641.70 in Green Bay. Value loss is a function of the ongoing higher operating costs of an air source heat pump relative to traditional natural gas furnace heating and of local housing market characteristics.

We explore a range of sensitivity analyses for both the NPV model and housing market model. In the NPV model, we explore how our preferred findings change with the discount rate applied to future costs, the reference indoor air temperature, and the outdoor temperature at which an air source heat pump can fully operate. Size of new dwelling, the price per square foot of new housing, and the demand elasticity are considered in the housing model. The sensitivity analysis largely confirms the magnitude of our preferred findings, with changes to the discount rate affecting results most significantly.

I: Introduction

Between 8,700 and 12,300 single family homes have been built annually in Wisconsin since 2018, with much of that activity concentrated in Dane County, St. Croix County, and the suburban counties around Milwaukee. New home building first and foremost helps meet demand for living in the Badger State, but also works to keep a steady flow of housing supply — helping to maintain housing affordability for state residents. Home building is no small part of the state's economy, with industry estimates suggesting that every 1,000 single-family homes built create nearly $300 million in income and over 4,400 jobs in the state.[1]

State and local regulations from building codes to zoning affect Wisconsin's housing market. Many of these are intended to ensure quality construction and keep communities vibrant, but they also can act to increase housing costs and limit the housing supply. This paper presents an analysis of how mandating a home's heat source would affect the housing market in Wisconsin. Specifically, we examine how requiring an air source heat pump (ASHP) in newly constructed single-family homes would affect the market for single-family homes in Wisconsin.

State policies aimed at curbing the use of fossil fuels to heat and cool buildings are becoming more common across the United States. New York recently banned the use of fossil fuels in new buildings starting at the end of 2025, and aggressive greenhouse gas reduction policies in California aim to roll out 6 million heat pump systems by 2030, among other measures. In perhaps the strictest policy to date, the state of Washington recently went back and forth on a heat pump mandate for new homes and apartments, ultimately delaying any changes to the building code.[2] Other states have taken the opposite stance, enacting laws that strictly prevent governments from regulating structure energy sources.[3] The current policy debate is often centered around a tradeoff between economic freedom and environmental protection, but it largely ignores the unintended consequences that may result from strong policy in either direction. This paper aims to fill that gap by examining the housing market consequences that would result from mandating air source heat pumps in new single-family home construction in Wisconsin.

We analyze a heat pump mandate by combining a model of the housing market with a net present value (NPV) model for how such a mandate would impact the cost of providing heat in newly built homes. The detailed NPV model compares traditional home heating using a natural gas furnace with the cost of heating a new home using an electric air source heat pump. Due to the climate in Wisconsin, we also consider that a heat pump may require an electric resistance heater backup system. We use data on local climates across the state, natural gas and electricity pricing, and the initial cost of installation and operation of these units to build our model.

Using the NPV comparison, we connect our model with a model of the Wisconsin housing market. The model incorporates the price change that happens from the NPV model to estimate the reaction to market supply and demand. We estimate how a heat pump mandate would affect new single-family home construction in Wisconsin and across market areas of the state, and how initial-owner home values would be impacted.

Our preferred results show that a heat pump mandate for newly constructed homes in Wisconsin would induce a substantial cost on the market. We estimate the NPV cost per new single-family home in the state to be $19,976.14, or over $232 million annually at current building levels. The cost per home in the Superior market is largest, at $29,836.65, and smallest in the Milwaukee market, at $12,842.97. Of the markets we study, the total cost from a heat pump mandate would affect the Madison housing market most substantially, at $25.78 million. These costs would

[1] Estimates from the National Association of Home Builders Economic Impact of Home Building in Wisconsin (2018).

[2] The Washington State Building Code Council had originally approved a heat pump mandate but paused the imposition of the policy after opposition lawsuits. At the time of this writing, the future of the Washington state heat pump mandate remains uncertain.

[3] Dewey (2023) reports that since 2019, 23 states have enacted policies preventing the limitation of structure energy sources.

of course come in addition to substantial recent increases in Wisconsin home prices of over 50% since 2017, while incomes have risen less than 20%.[4]

We model how imposing these substantial costs for newly constructed homes would be felt in the housing market using a supply and demand model based on market price sensitivity. We model the NPV cost of a heat pump mandate like a tax imposed on the market and find that such a mandate would reduce annual home building by 544 single-family homes in Wisconsin. The largest impact would be in the Madison area, where we expect a reduction of 57 newly built homes annually. This reduction in building represents a 4.68% decline from current building levels in the state, and between 2.7% (Milwaukee) and 7.3% (Superior).

Finally, we use our housing markets model to estimate the lost home value that new homeowners would experience under a heat pump mandate. Sales transactions would still take place between builders and new home buyers, but the value of the home as an asset would be reduced due to the mandate as ownership costs rise. Statewide, we estimate that the average new home would lose $7,833.78 in value. The average value loss is largest in the Superior market, at $11,195.74, and smallest in the Milwaukee market, at $5,614.41.

We also explore a range of sensitivity analyses for both the NPV model and housing market model. This sensitivity analysis focuses on the parameters in our models that are most likely to vary across and within locations. In the housing markets model, we explore sensitivity to the size of new dwellings, the price per square foot of new housing, and the demand elasticity. In the NPV model we explore how our preferred findings change with the discount rate applied to future costs, the reference indoor air temperature, and the outdoor temperature at which an air source heat pump can fully operate. The sensitivity analysis largely shows that our primary results are reasonable, with the discount rate affecting results most significantly.

II: Background and Modeling Comparative Air Source Heat Pump Efficiency

Before describing how we model the NPV of an air source heat pump mandate on new construction homes, we offer a brief explanation of how these units work. This explanation aids in understanding some of the crucial choices in our model and how they may change as technology evolves or are different for homes in climates milder than Wisconsin. Notably, our explanation refers to air source heat pumps; there are also ground source heat pumps that use the temperature difference under the earth's surface to bring heat into a home. Those aren't addressed in this paper.[5]

Davis (2024) summarizes heat pumps as "air conditioners that can be operated in reverse," a succinct and accurate description. The U.S. Department of Energy offers a full menu of the different types of air source heat pumps and distinctions across unit types;[6] we focus here on operation for providing home heating. There are two features of heat pumps that are distinct from traditional home heating sources. First, heat pumps do not actually create heat, they extract it from the outside air and move it inside. Second, air source heat pumps require a unit that sits outside of a home (much like an air conditioning unit). Unlike an air conditioner, however, a heat pump needs to operate in winter, and it needs to be periodically cleared of heavy snow and ice buildup.[7]

The basic operation of the heat pump is to use outside air blown over a refrigerant with a low boiling temperature[8] to boil the refrigerant, turning it to a gas. The refrigerant, now a gas, is moved into a compressor, raising its temperature.

[4] Statistics on Wisconsin home prices and income increases reflect total change between 2017 and 2022 according to the Wisconsin Policy Forum at https://wispolicyforum.org/research/home-prices-outpace-incomes/.

[5] A primary concern with ground source heat pumps is the land area needed to house the underground heat collection for a structure, making them less viable in areas with denser populations. This is a concern with ground source heat pump systems that are laid out in a "horizontal" pattern at minimal depth under the surface. There are also "vertical" ground source heat pumps that are placed deeper into the ground.

[6] See https://www.energy.gov/energysaver/air-source-heat-pumps

[7] ASHPs typically have a defrosting unit that can handle small amounts of snow and ice.

[8] There are refrigerants that boil at various temperatures, including some that boil below 0°F.

This heated refrigerant then is moved inside the home to a heat exchanger, where it transfers its heat, raising the indoor air temperature. The cooled gas then returns to the liquid state, and the process starts again. Crucially, the capacity of the heat pump to heat indoor air is lower when outdoor air temperatures are low. The heat pump is also less energy efficient at lower temperatures. Thus, for our examination of air source heat pumps in Wisconsin, where winter temperatures are often below zero, we consider that heat pumps may need to be combined with a backup heating system.[9]

To understand how consumers would be affected by a mandate that heat pumps be installed in all newly constructed single-family homes in Wisconsin, we model a 15-year cost of ownership difference between air source heat pumps and a traditional heating source. To make the comparison fair, we consider a traditional natural gas furnace combined with a central air conditioning unit compared with an electric air source heat pump that can operate both as a heating and cooling source. The model uses historical data to size each unit, ensuring that it would have been able to handle winter temperatures. Depending on this weather data and the heat pump operation, we also size a backup electric resistance heating system to pair with the heat pump. Because the central air conditioning units operate on electricity and are extremely similar to a heat pump when in cooling mode, the relevant portion of the model is considering initial unit costs and operating costs when heating. Although our model accounts for all features, we discuss results primarily in terms of home heating.

The 15-year cost of ownership includes the up-front cost of the unit, maintenance, and operating costs based on prices of both electricity and natural gas in Wisconsin. The basic format, and many of our assumptions, for our model follow the Electric Power Research Institute's (EPRI) US-REGEN model. As is typical in any model of future costs or payments, we bring the 15-year total costs back to a present value using discounting and then take the difference between traditional natural gas heating and heat pump mandate-induced heating. This gives us a net present value associated with the mandate.

Dwelling and Size of Units

The mandate we explore is on newly constructed single-family homes, and we start by positing how large a home our heating sources will need to make comfortable. Our preferred model is based on a 2,500 square foot home.[10] Although homes are designed to retain heat, there is some amount of heat lost to the outdoors from any structure. Typically, homes in a mild climate will lose around 20% of heat through loss to the outdoors. This notion is measured as shell efficiency of the structure (heat loss of 20% is a shell efficiency of 0.2). Because we are examining new homes and because those homes are built in Wisconsin, where builders are more cognizant of shell efficiency, we increase shell efficiency from a mild climate by 25% and use a shell efficiency of 0.16, meaning that a home in our model loses only 16% of heat to the outdoors.

We use the size of dwelling and shell efficiency, combined with heating degree needs and unit capacity, to determine the size of the heating unit needed based on the equation:[11]

$$\textit{Size of unit}\ [btu] = \frac{\textit{home square footage} \times \textit{shell heating efficiency}}{\textit{capacity}}$$

The heating degrees input is calculated from weather data provided by the National Oceanic and Atmospheric Administration.[12] We use weather data from all covered stations in Wisconsin on hourly average temperatures over the 2006-2022 period.[13] We base the size of the unit on the difference

[9] This paragraph relies on technical explanations of ASHP operation from National Grid, the Department of Energy, and The Engineering Mindset.

[10] The average square footage of floor area for a new, privately owned housing unit completed in the Midwest is 2,368 for 2022 according to the Census at https://www.census.gov/construction/nrc/pdf/quarterly_starts_completions.pdf

[11] Natural gas furnaces operate in terms of BTU or British Thermal Units. ASHP operate on electricity, consumed in kilowatts. We convert BTU to kilowatts by dividing by 3,412.14245.

[12] Available at: https://www.ncei.noaa.gov/data/normals-hourly/2006-2020/access/

[13] Weather data for the Superior, Wisconsin, market is from the Duluth, Minnesota, weather station.

between a reference indoor air temperature of 65 degrees F and the coldest weather experienced in the area. For the coldest area temperature, we use the first percentile of the average hourly 10th percentile temperature. For an area with a coldest recorded temperature in the data of 5 degrees F, heating degrees would be equal to (65 degrees – 5 degrees) = 60 degrees.

Capacity indicates the potential amount of heat generated by the unit. We set capacity of natural gas units at 50% regardless of outdoor temperature as these units operate indoors and are burning a consistent fuel source. We calculate capacity of air source heat pumps to be a function of outdoor air temperature, as these units are using outside air to boil an internal refrigerant, which will be more difficult in colder temperatures. We calculate capacity for air source heat pumps as declining linearly with temperature and averaging over the heating months in Wisconsin. Capacity dictates the share of operating time during the coldest time of year that a unit needs to run to keep up with the reference indoor air temperature. The average air source heat pump capacity in our data is 86.6%.[14]

We also need to determine whether the area would require a backup heating source, given current heat pump technology. This choice would ultimately be left up to a homebuilder and home purchaser discussion, but our model is instructive based on the climate data we observe in Wisconsin. To determine whether a backup is needed, we compare the coldest temperature in our data to the minimum temperature at which an air source heat pump can operate. If the minimum operation temperature is higher than the coldest temperature in the data, then a backup is needed. This method of determination is instructive in our case, as the Milwaukee weather data has a coldest temperature equal to the minimum operating temperature for an air source heat pump (3 degrees F).[15] This means that the primary results for Milwaukee will not include the purchase of a backup heating system. The assumption about minimum temperature and backup installation are both extremely conservative — if homeowners make different choices based on the potential for colder temperatures, we expect backup systems to be more common. This would increase the cost of heat pump mandates in the Milwaukee market relative to our estimates.

Initial Unit Costs

The EPRI US-REGEN model lays out the various components of natural gas, electric resistance, and air source heat pump units, detailing what is necessary for each unit. For example, a heat pump unit requires an outdoor heat exchanger, while a traditional non-electric furnace does not. We use this component list as well as capital and labor cost per component applied to the size of unit calculated above to estimate the initial cost of installing a traditional furnace and air conditioner, an air source heat pump, and in cases where it is deemed necessary, a backup electrical resistance heater. Each component of the unit has both fixed and marginal cost of both capital and labor, so that the total cost function is approximated by the following equation:

$$\text{Unit cost} = \sum_{i=1}^{n} K_i + L_i + f(K, L, size)_i$$

...where i indicates one of the n total components of the unit, K indicates a fixed capital cost of each component, L indicates a fixed labor cost of each component, and the function represents the marginal cost of capital and labor that depend on the size of the unit installed. We separately model a traditional furnace with an air conditioner, an air source heat pump, and a backup electric heat system, and we only add the cost of the backup when the heat pump will not be able to fully function based on climate data. The size of the backup needed depends on the size of the heat pump and the local weather data.[16]

Given our model of unit size and initial unit cost, heat

[14] ASHP capacity declining with temperature comes directly from the EPRI model. Using EPRI information, we estimate a linear relationship between capacity and temperature for ASHP as C=0.5+0.1t, where t is the hourly temperature. We then calculate capacity using hourly weather data when the temperature is colder than 60°F and take the average for each area.

[15] The lowest temperature an ASHP can operate depends on the model installed. Kaufmann et al. (2019) also use a value of 3 degrees F in their baseline model. This parameter is likely to change as technology of ASHPs change, so we show sensitivity analysis to this choice.

[16] To size the backup system, we compare the difference between the heat provided by an ASHP and the required heating degrees needed at the coldest

Table 1

Size of unit and initial cost estimates

	Wisconsin	Superior	Milwaukee	Madison	La Crosse	Green Bay	Eau Claire
Size of gas furnace *(btu)*	59,920	64,000	49,600	54,320	56,800	54,320	59,920
Size of air source heat pump *(kW)*	10.26	11.29	8.22	9.20	9.71	9.24	10.44
Backup required?	yes	yes	no	yes	yes	yes	yes
Initial cost of gas furnace	$4,897.22	$5,140.80	$4,281.12	$4,562.90	$4,710.96	$4,562.90	$4,897.22
Initial cost of heat pump and backup	$3,748.78	$3,975.79	$3,289.31	$3,514.77	$3,625.75	$3,523.32	$3,786.71

Notes: Model based on 2,500 square foot home with shell efficiency of 0.16. Reference indoor air temperature of 65°F. Minimum fully functional unit temperature of 3°F compared with area recorded temperatures to determine necessity of backup electric resistance heater.

pumps compare quite favorably with a traditional gas furnace. Table 1 shows our estimates for unit size and initial cost for Wisconsin as a whole and for specific areas of the state.

At least in terms of the initial cost, the heat pump is favorable relative to a traditional gas furnace in the state, and across all areas covered by the data. This is true in Milwaukee, where the model suggests that a backup is not necessary, and in other parts of the state where the heat pump would not be able to cover the entire winter heating load. For the state, we estimate the initial cost of an appropriately sized gas furnace (with air conditioning) to be $4,897.22, compared to only $3,748.78 for an air source heat pump with electric backup. Across areas of Wisconsin, the initial cost of the heat pump plus backup is about $1,000 cheaper than a traditional gas furnace.

Operation and Maintenance

With initial cost differences, unit sizes, and weather data, we can now model the full cost of operating and maintaining both a traditional gas furnace and a heat pump with electric backup. We model these costs for a 15-year ownership term and calculate them as a present value to make them comparable with initial unit costs.

For the traditional natural gas furnace, we model unit size to run half of the time during the coldest hour, and we assume during the warmest heating hour (60 degrees F) the unit will run for 15 minutes. The duration that the unit runs for each of the temperatures between the coldest and warmest is a linear function connecting these endpoints. Given the historical weather patterns in Wisconsin, this means that the furnace will run for roughly 20 minutes on average during heating hours. The furnace is not fully efficient, so we divide by 0.87 to get the total number of hours the unit will run for a heating season. After we know how many hours the furnace unit will run, we calculate running cost based on natural gas prices. We use the last five-year average (2018 to 2022) for Wisconsin's price of natural gas delivered to residential consumers as reported by the Energy Information Administration (EIA) to estimate fuel costs.

To calculate the heat pump's running costs, we follow a similar calculation. First, we estimate how many hours the

hour of the year in our data. In the data, Wisconsin's minimum temperature is estimated to be -9.9 on average, the estimated capacity and efficiency ratings for the ASHP are 0.429 and 1.65, respectively. This implies that the ASHP unit will only provide roughly 70% of the heat needed. The remaining heat will be produced by the backup electric resistance heating unit with an efficiency rating of 1.

Table 2

Operating costs and net present value

	Wisconsin	Superior	Milwaukee	Madison	La Crosse	Green Bay	Eau Claire
Hours gas furnace runs	2,330	2,699	2,182	2,222	2,173	2,345	2,359
Annual natural gas cost	$1,372.95	$1,698.48	$1,064.25	$1,186.78	$1,213.96	$1,252.90	$1,390.24
Hours heat pump runs	2,218	2,631	2,023	2,099	2,068	2,223	2,283
Hours electric backup runs	247	568	0	168	223	204	382
Annual electricity cost	$3,431.11	$4,708.56	$2,416.96	$2,857.14	$3,003.25	$3,048.20	$3,658.98
Average monthly cost difference	$171.51	$250.84	$112.73	$139.20	$149.11	$149.61	$189.06
Traditional furnace present value (cost)	$20,164.62	$23,837.68	$16,216.39	$17,828.47	$18,289.40	$14,786.65	$20,344.10
Heat pump present value (cost)	$40,140.76	$53,674.33	$29,059.36	$33,900.50	$35,551.16	$35,893.99	$42,551.72
Net present value of heat pump mandate	$19,976.14	$29,836.65	$12,842.97	$16,072.03	$17,261.76	$21,107.34	$22,207.62

Notes: Model based on 2,500 square foot home with shell efficiency of 0.16. Reference indoor air temperature of 65°F. Minimum fully functional unit temperature of 3°F compared with area recorded temperatures to determine necessity of backup electric resistance heater. Operating hours based on unit size and local weather data. Price of natural gas is $8.864 per 1,000 cubic feet. Price of electricity is 14.532 cents per kilowatt hour.

unit will need to run, knowing that at the minimum temperature the unit will run continuously. We use the estimates of efficiency and capacity from EPRI to calculate how long the unit will run during each hour. Further, we recognize that the backup heating unit will run during the hours when the weather data indicate the 10th percentile temperature falls below the full-operation temperature of the unit. We calculate the number of hours the backup heating unit runs for each weather station and for the state. Next, we use EIA data on residential electricity prices from Wisconsin to calculate the running cost of the heat pump and backup unit.

Maintenance costs are 2% of the fixed portion of initial unit costs per year for both the traditional natural gas furnace, the heat pump, and the electric backup. We discount all future costs of maintenance and operation using a 5% discount rate.[17]

Table 2 shows the model results for running hours, annual cost, and present value for a traditional natural gas furnace and the heat pump with electric backup. Running time between a traditional furnace and the combination of a heat pump and electric backup is quite similar across the state, with a traditional furnace running more hours than the heat

[17] We choose a 5% discount rate as it is approximately the 10-year U.S. Treasury interest rate plus a 1 percentage point risk premium. We show how this choice affects our NPV in the sensitivity analysis. For a discussion of discount rates used in the economics literature, see Groom et al. (2005) and Gollier and Hammitt (2014).

pump combination in Milwaukee, but fewer hours in other areas. Overall running time is highest in Superior, at 2,699 hours for a gas furnace and 3,199 hours total for heat pump and backup.

The annual cost of operating a natural gas furnace for Wisconsin is $1,372.95, with a low in Milwaukee of $1,064.25 and a high of $1,698.48 in Superior. The operating cost of the traditional natural gas furnace is based on a cost of $8.864 per 1,000 cubic feet of natural gas. Notably, this price comes from a long-run average; more recent prices in Wisconsin are closer to $5 per 1,000 cubic feet.[18] Using a lower price for natural gas would net less favorable results for the heat pump mandate by lowering operating costs of traditional natural gas heating units.

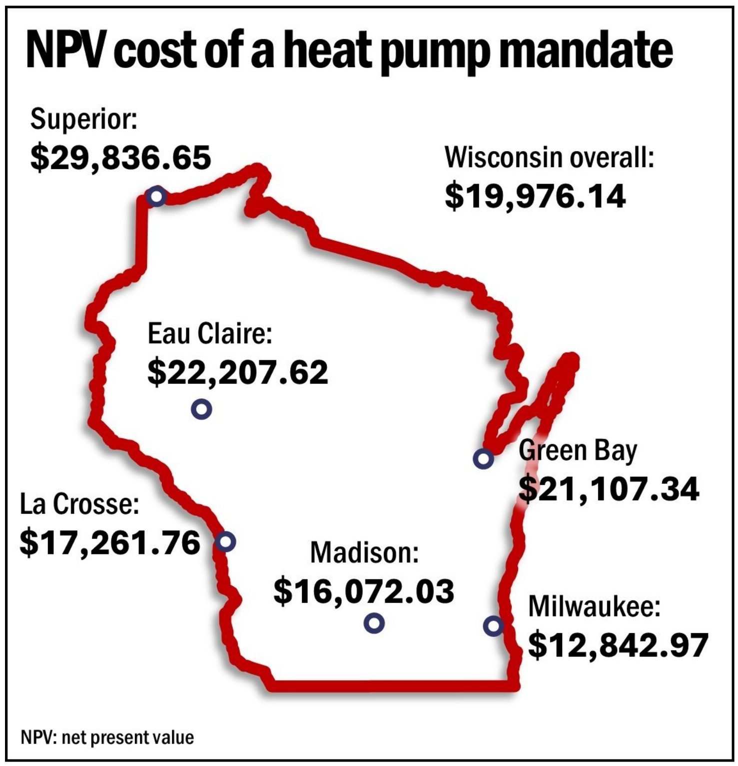
The annual cost of operating a heat pump with electric resistance backup in the model for Wisconsin is $3,431.11, with a low in Milwaukee (where no electric backup is necessary) of $2,416.96 and a high of $4,708.56 in Superior. Operating costs for the heat pump and backup are based on a cost of 14.532 cents per kilowatt-hour of electricity. As with prices for natural gas, this input comes from a long-run average. The most recent price per kilowatt-hour for residential electricity in Wisconsin is 16.48 cents.[19] Using a higher price for electricity would net less favorable results for the heat pump mandate by raising operating costs of the heat pump heating unit.

III: ASHP Mandate NPV Results and Sensitivity Analysis

The full cost of a heat pump mandate, expressed in today's dollars, would be $19,976.14 for each new home built in Wisconsin. This includes the initial cost, operation and maintenance cost of an air source heat pump with electric resistance backup relative to traditional gas furnace heating. This net cost comes from a present value of traditional heat over a 15-year period of $20,164.62 and a present value of the heat pump of $40,140.76.

Across the state, all areas show that the heat pump mandate would be a net present cost to new home construction. This cost is lowest in Milwaukee, at $12,842.97, owing to Milwaukee not requiring a backup resistance heater in the model and the relatively warmer winter temperatures observed in the weather data. At the other end, the mandate net cost would be highest in Superior, at $29,836.65, due to needing more electricity for the colder climate. Eau Claire and Green Bay net similar costs, with Eau Claire at $22,207.62 and Green Bay at $21,107.34. La Crosse and Madison net out lower than the state, with a net cost from the heat pump mandate of $17,261.76 and $16,072.03, respectively.

Figure 1



The primary driver for the NPV model producing a higher cost from heat pump use is the difference in annual operating costs resulting from the difference in observed prices of electricity and natural gas. Table 2 shows the average monthly cost difference, averaged over the 15-year window of our analysis. This shows that monthly operating cost differences would be $171.51 higher with a heat pump than with a traditional gas furnace. Monthly cost differences are

[18] The latest data available at the time of this writing from the U.S. Energy Information Administration lists the November 2023 price for 1,000 cubic feet of natural gas at $5.21.

[19] Data from December 2023 from the U.S. Energy Information Administration.

Table 3

Net present value sensitivity analysis

	Wisconsin	Superior	Milwaukee	Madison	La Crosse	Green Bay	Eau Claire
Preferred estimate	$19,976.14	$29,836.65	$12,842.97	$16,072.03	$17,261.76	$21,107.34	$22,207.62
Lower indoor air temperature (63°)	$19,451.05	$29,098.52	$12,438.73	$15,607.80	$16,784.29	$20,496.96	$21,622.95
Higher indoor air temperature (67°)	$20,501.22	$30,574.78	$13,247.21	$16,536.26	$17,739.22	$21,717.73	$22,792.30
Colder minimum heat pump operation (1°)	$19,707.71	$29,428.38	$12,842.97	$15,895.62	$17,058.15	$20,906.20	$21,845.25
Warmer minimum heat pump operation (5°)	$20,300.67	$30,234.12	$12,976.85	$16,226.20	$17,503.25	$21,314.00	$22,596.38
Discount the future more (7%)	$17,387.89	$26,038.24	$11,147.90	$13,974.42	$15,013.84	$17,141.20	$19,350.62
Discount the future less (3%)	$23,147.52	$34,490.87	$14,919.96	$18,642.25	$20,016.16	$25,967.08	$25,708.33

Notes: Preferred model based on 2,500 square foot home with shell efficiency of 0.16. Reference indoor air temperature of 65°F. Minimum fully functional unit temperature of 3°F compared with area recorded temperatures to determine necessity of backup electric resistance heater. Operating hours based on unit size and local weather data.

largest in Superior, at $250.84, and smallest in Milwaukee at $112.73. This average monthly cost would be concentrated in the winter months for homeowners, but our table shows the average over the full sample.

Our preferred model results presented in Figure 1 and Table 2 represent the best available data for our model, but there are some inputs where we feel it is important to show sensitivity analysis, as they require subjective judgement.

The preferred model is based on a reference indoor air temperature of 65 degrees F. Of course some homeowners will set their thermostat below this level, and some will set it above. We will show how the results of our model change as the reference indoor air temperature changes. The minimum fully functioning temperature for an air source heat pump is also something that can change depending on the model. Our preferred model uses 3 degrees F, the same base scenario in Kaufman et al. (2019), but it is possible that technological improvements allow for lower temperatures in the future, or that less sophisticated units will not be able to fully operate at higher temperatures.[20] Finally, the rate at which future costs are discounted back to today's dollars is a topic that has long been a point of contention among economists. Our preferred model uses a figure based on financial markets, but other work incorporates environmental costs of future generations.

Table 3 shows results of model sensitivity for reference indoor air temperature, minimum operating temperature, and the discount rate used to bring future costs to today's dollars. These results are all compared to the preferred estimates, shown in the top row of Table 3.

Using a lower reference indoor air temperature means that any heating unit will not have to work as hard. Across Wisconsin, lowering the reference indoor air temperature to 63 degrees F in our model reduces the NPV from a heat

[20] Under a builder mandate scenario, one might expect that "builder grade" systems are installed as the default option, in which case we would expect that these units would have a higher fully functioning minimum temperature.

pump mandate to $19,451.05 from $19,976.14, or about $500 over the 15-year period. The magnitude of the difference for this sensitivity analysis is similar across the six areas of the state we examine, with slightly more savings in Superior, Green Bay and Eau Claire and slightly less in Milwaukee, Madison and La Crosse. The mirror opposite is true for raising the reference indoor air temperature by an equivalent amount to 67 degrees F — this caused the NPV cost of the mandate to rise by approximately $500 in Wisconsin, with an increase ranging from about $400 in Milwaukee to a bit over $700 in Superior.

Modeling a heat pump with the ability to be fully operational at a higher or lower temperature in our model does not change our preferred results much at all. The primary change this makes is switching on the purchase of a backup in Milwaukee, which happens at 3 degrees F. The reason the model is not very sensitive to this parameter choice is that it only dictates the purchase of a backup system, and only changes heat pump use when that system is in place. To make a backup unnecessary in other areas of Wisconsin, the minimum operating temperature would have to be -3 degrees in Madison and Green Bay, -6 degrees in La Crosse, -10 degrees in Eau Claire, -15 degrees in Superior, and -7 degrees statewide. There are some modest savings from running the backup heater less, and these compound in the coldest area (Superior) to about $400 in NPV savings when the heat pump can fully operate down to 1 degree. The opposite is true if the heat pump is fully functional only at a higher temperature, but again these differences are minor — amounting to about a $320 increase in total cost statewide, and as much as $400 in Superior.

The NPV model is most sensitive to changes in the discount rate that applies to future costs. This sensitivity results from the heat pump being initially cheaper, with initial costs not facing a discount rate, and the operating costs of the heat pump being substantially higher than traditional gas heating year after year. If those future costs are discounted more, the heat pump mandate becomes less costly today. If those future costs are discounted less, the heat pump mandate becomes more costly today. Statewide, using a 7% discount rate, the NPV cost of the heat pump mandate would be $17,387.89 ($2,588.25 less than the preferred estimate), and would range from $11,147.90 in Milwaukee to $26,038.24 in Superior.

There is not an equivalency between raising and lowering the discount rate, as lowering the discount rate by the same amount to 3% raises the NPV cost by more than raising the rate to 7% reduces cost. If future costs are discounted at a 3% rate, the heat pump mandate will result in an NPV cost of $23,147.52, or $3,171.38 more than in the preferred model. Costs would rise the most in Green Bay to $25,967.08 and rise the least in Milwaukee to $14,919.96.

IV: Housing Market Model

We model how the NPV associated with a heat pump mandate would affect the housing market in Wisconsin through a supply and demand framework. The basic model starts from an approximation of the current market equilibrium price and quantity for newly constructed single-family homes. We then shock that model with the heat pump mandate by imposing a tax equivalent to the NPV modeled in the previous section. Imposing an equivalent tax is a common way to model regulations in any market, and we believe that approach is appropriate here for two reasons. First, we are using a net present value, meaning that we are already comparing costs with any benefits that accrue, so what is left is just added costs. Second, a heat pump mandate would likely be statutorily imposed on builders, but it is the market that will determine the economic incidence of the mandate, meaning that prices will adjust based on market conditions (as they would with the imposition of a tax in the market).

Figure 2 depicts a standard supply and demand model for housing that would be used for predicting price and quantity changes in the market. The model depicts market supply, as indicated by the upward sloping line, showing a positive relationship between prices and quantity, and market demand, as indicated by the downward sloping line, showing a negative relationship between prices and quantity. Market supply is determined by factors such as material building input costs, labor costs, land costs, natural terrain, the regulatory environment, interest rates and any other factors that go into the construction decision-making process. Market demand is determined by factors such as population, employment, income, local amenities, the price and availability of credit for borrowers, and any other factors that go into the home purchase decision.

The existing market supply and demand are represented by the shape of the supply and demand lines in Figure 2 — this shows how sensitive each side of the market is to a price change, which is called the market price elasticity. There is a market elasticity of supply, and a separate market elasticity of demand. The standard working of the model is that the intersection of market supply and market demand predicts the current market price (P*) and market quantity (Q*). The price elasticities enable us to make a prediction about what will happen to market price and quantity when there are changes to the market, which we will use to predict the outcome of imposing a heat pump mandate on new home construction in Wisconsin.

Figure 3 is a modification of Figure 2 depicting how the housing market would change with the imposition of a heat pump mandate. The thick, vertical, black line represents the NPV of heat pumps for new homes in Wisconsin. The vertical length of the line is equivalent to the size in dollars of the NPV. [21]

As the model depicts, the mandate drives a wedge between market supply and demand in the housing market. The result is that quantity in the market is reduced from Q* to Q^M. The net price that buyers pay is equal to P^M_B, which is equal to the price paid to homebuilders, P^M_S, plus the NPV cost of the heat pump. We can see that homebuilders will be forced to accept lower prices than the original market price P*, and homebuyers will pay a higher net price than the original market price ($P^M_B = P^M_S +$ NPV). Transactions in the market will happen at P^M_S, but with the heat pump now replacing traditional heat sources, buyers will effectively pay P^M_B.

Figure 2

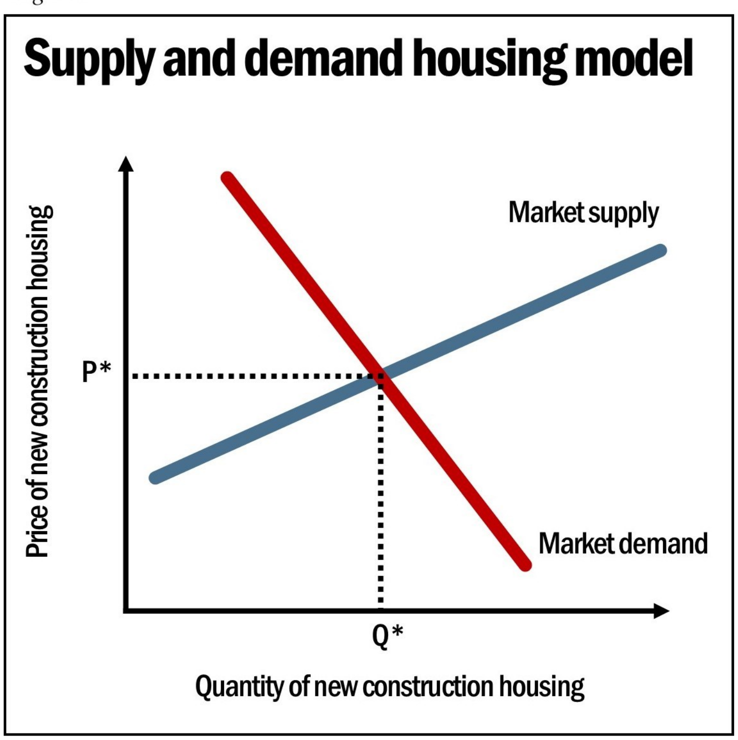
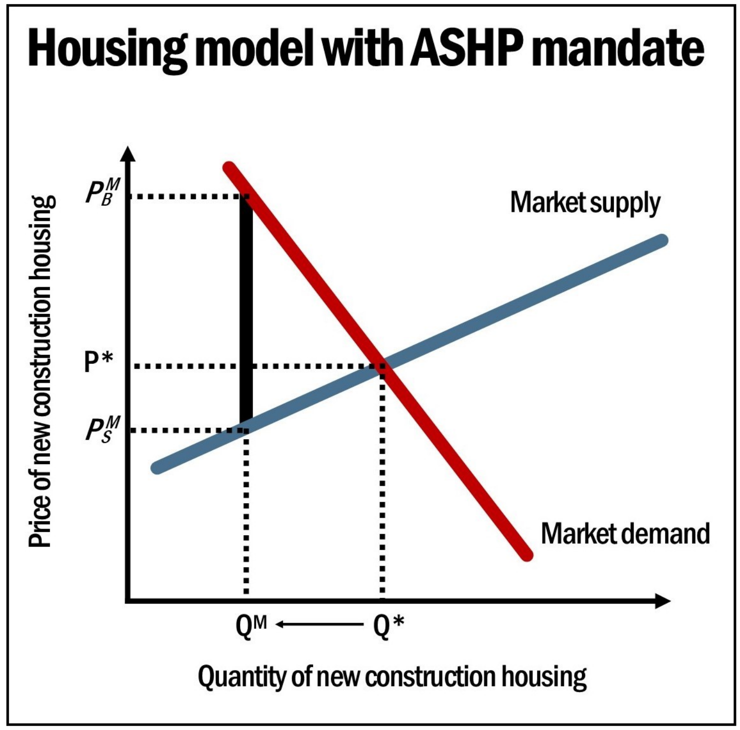


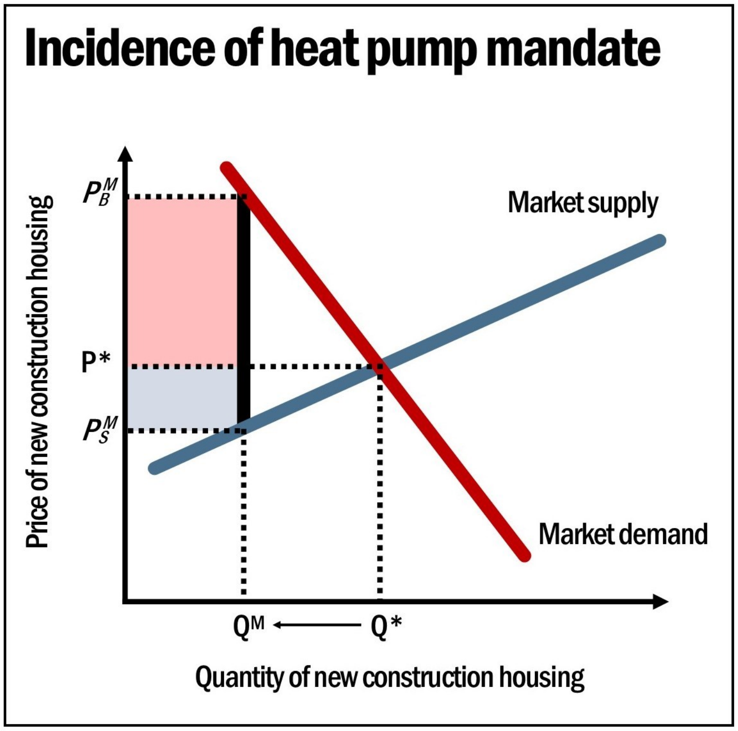
Figure 3



After using our heat pump model to calculate an NPV for the state of Wisconsin and each of the six areas covered by our weather data, we use the housing market model to estimate the change in new homes that will be built if the mandate were to become law. For this, we estimate the one-, five- and 10-year expected loss in the construction of new homes across the state and in each of the six covered areas. We also use the model to estimate how much the heat pump mandate would reduce the value of new homes. We do this by relating the relative price change for buyers and sellers in the markets model to determine what side of the market

[21] Our NPV calculations are done in terms of the added cost of an ASHP mandate so that this number is positive.

Figure 4



pays for the mandate. Figure 4 depicts our method for determining the effect of the heat pump mandate on home values.

The filled in boxes of Figure 4 represent how different sides of the market will pay for the mandate, depending on market conditions. The share of the mandate paid by sellers is determined by the difference between the original market price (P*) and price that sellers are now able to sell their homes at (P_S^M). The share of the mandate paid by buyers is determined by the difference between the original market price (P*) and the net price that buyers now pay for housing (P_B^M). In the figure, it is buyers that bear more of the burden than sellers — their share of the box is larger — but in a real market this is determined by the price sensitivity of each side of the market, or market supply and demand elasticity.

We use estimates of the elasticity of housing supply and demand to determine how much of the mandate burden falls on buyers with the following incidence formula:

$$\text{Buyers' burden} = \frac{E_D}{(E_D + E_S)} * NPV$$

where E_D is the market demand elasticity for housing, and E_S is the market supply elasticity of housing. Once the initial burden is split, we use this as an estimate for how much value is lost from the mandate for owners of new homes, assuming that the policy is permanent.

The primary inputs for the housing market model are the elasticity of housing supply, the elasticity of housing demand, and the price per square foot of new housing. The square footage of a typical new build home is carried over from the NPV model to make them consistent.

We use market-specific housing supply elasticities from Saiz (2010) for the Milwaukee-Waukesha metropolitan area and the Minneapolis-St. Paul metropolitan area[22] in our model. Because Saiz estimates an elasticity directly for Milwaukee, we use that for Milwaukee (E_S = 1.03). Saiz does not estimate state-level supply elasticities or smaller market elasticities, but given the difference between Milwaukee and the estimated elasticity for Minneapolis-St. Paul (E_S = 1.45), we do not build in a wide range of difference across our areas. We weight the elasticities by distance between Milwaukee and Minneapolis, using the following housing market supply elasticities in our analysis: Wisconsin (E_S = 1.24), Madison (E_S = 1.126), La Crosse (E_S = 1.202), Green Bay (E_S = 1.154), Eau Claire (E_S = 1.336), Superior (E_S = 1.332).

Our preferred estimates use a housing demand elasticity of E_D = -0.80 following a review of the academic literature and modeling in Martin and Hanson (2016). As noted in the Martin and Hanson paper, the academic work on housing demand is not as developed as the work on housing supply and does not include reliable area specific estimates. This literature also suffers from data and methodology problems, producing a wide range of estimates. Our base-case estimate of E_D = -0.80 is probably closer to a national housing demand elasticity than a state or local housing demand elasticity. Due to the uncertainty in this parameter, and the fact that state and local areas should have more elastic housing demand as there are more substitutes for these markets for consumers to choose from, we will show sensitivity analysis to our estimates that uses a substantially larger E_D.

We carry over all inputs from the heat pump NPV model to the housing model, most notably the square footage of a new home. We use price per square foot and the total number of square feet to equilibrate our estimates between the heat pump NPV model and the housing markets model. Our

[22] The Minneapolis-St. Paul metropolitan area includes St. Croix County, Wisconsin.

starting point for the price per square foot of new housing is based on Census data that reports the average price per square foot of new housing in the Midwest region in 2022. The Census data is truncated at $150 per square foot, but 54% of the distribution exists in the truncated region. We use current listings of new construction homes for sale in Wisconsin to fill in this gap, taking the average for 100 randomly selected new homes for sale in the state. Using the listings sample and the Census data gives us an average price per square foot for new construction homes of $174.33. We use this figure for our preferred estimate, but it is quite a bit lower than advertised home sales, so we will show sensitivity analysis to our estimates that varies this input.

Finally, we use data from the Wisconsin Builders Association on single-family housing permits as a starting point for quantity in the housing market. We take an average of the number of starts for 2019, 2020, 2021 and 2022 for the state and each area as our estimate of pre-mandate new housing quantity. Each area is constructed from county-level data on housing permits to add up to the metropolitan total.[23] The state total includes permits for homes allocated to one of the six metropolitan areas.

Table 4

Housing market estimates for heat pump mandate

	Wisconsin	Superior	Milwaukee	Madison	La Crosse	Green Bay	Eau Claire
NPV of mandate (cost)	$19,976.14	$29,836.65	$12,842.97	$16,072.03	$17,261.76	$21,107.34	$22,207.62
Pre-mandate annual building	11,634	75	1,568	1,605	212	785	494
Total cost at current building levels	$232,397,419	$2,222,830	$20,140,989	$25,787,572	$3,650,863	$16,558,709	$10,970,566
Relative price change	4.58%	6.85%	2.95%	3.69%	3.96%	4.84%	5.10%
Relative quantity change	-4.68%	-7.30%	-2.70%	-3.55%	-3.96%	-4.73%	-5.44%
Annual building loss	544	5	42	57	8	37	27
5-year building loss	2,720	27	211	285	42	186	134
10-year building loss	5,439	54	423	570	84	371	269
Homeowner value loss per home	$7,833.78	$11,195.74	$5,614.41	$6,675.82	$6,897.81	$8,641.70	$8,317.46

Preferred estimates use the following key parameters: 2,500 square foot home, $173.33 price per square foot, demand elasticity of -0.80, reference indoor air temperature of 65°F, air source heat pump minimum functional temperature 3°F, and a discount rate of 5%. State of Wisconsin totals include all counties.

[23] We use only counties from Wisconsin, even though some Wisconsin counties are part of metropolitan areas in other states. For example, Kenosha County is part of the Chicago metropolitan area. In our data, Milwaukee includes Milwaukee, Ozaukee, Washington and Waukesha counties. Madison includes Dane, Columbia, Green and Iowa counties. Green Bay includes Brown, Kewaunee and Oconto counties. Eau Claire includes Chippewa and Eau Claire counties. La Crosse is only La Crosse County. Superior is only Douglas County.

V: Housing Market Results

Preferred Model Estimates

Our preferred estimates for how a heat pump mandate will affect the housing market in Wisconsin are shown in Table 4. These estimates reflect the following key parameter choices: 2,500 square foot home, $174.33 price per square foot, and new housing demand elasticity of E_D = -0.80. We will show how each of these key parameters changes our preferred estimates.

Our primary results show that a heat pump mandate would have a large, negative effect on the market for new homes in Wisconsin, driven by the substantial NPV added cost over traditional forms of home heating. Statewide, we estimate that the net present added cost of a heat pump mandate is $19,976.14. For a 2,500 square foot new construction build at a price per square foot of $173.33, this would represent a 4.58% increase in price. Given the market characteristics in our housing model, this change would result in a decline in annual building of 4.68%, or 544 new homes that would go unbuilt. Extrapolating over a five-year period, the loss would be 2,720 homes, and 5,439 fewer homes in a 10-year period across Wisconsin.

At current levels of building, the mandate would have an NPV cost of over $232 million annually across Wisconsin. This is the total burden of the policy, shared by new home builders and new home buyers. The total cost is highest in the Madison market, at $25.78 million annually, and ranges from a low of $2.2 million in the Superior market. The total burden exceeds $20 million annually in the Milwaukee market and nearly $11 million in Eau Claire, with the Green Bay market experiencing a total cost of more than $16.5 million annually and La Crosse losing $3.6 million annually.

We expect that some of the incidence of these losses is borne by builders in the form of lost profits but that some of the burden is borne by those who purchase a new home. New home purchases will transact at a lower price than the current market — this is the price that builders receive, but buyers will now become owners of a structure that carries substantial increased heating costs (as shown in our NPV model). Using our housing markets model, we estimate that new homeowners would see a reduction in home value of $7,833.78 from a heat pump mandate. This loss is relative to what home values would be in the absence of a mandate, or in current markets. This estimate implies that statewide, homeowners would pay for about 40% of the mandate through a loss in home value, while builders would absorb the remaining 60%.

Across Wisconsin, our model predicts a differential impact on housing markets from a heat pump mandate. The primary factor driving across metro results is the difference in NPV from the mandate, and this difference is driven by differences in minimum temperature, most importantly how this minimum temperature relates to the temperature at which an air source heat pump can fully function. Notably, in Milwaukee, we make the extremely conservative assumption that a heat pump is fully functional for the entire year, so that a backup system is unnecessary. Housing market differences are also a function of the supply elasticity varying across markets — this parameter suggests the least price responsive market is Milwaukee and the most price responsive market is Eau Claire.

Milwaukee, Madison and La Crosse all have an NPV of added cost from a heat pump mandate that is lower than the state as a whole, with Milwaukee's NPV substantially lower at $12,842.97. Madison would experience an NPV cost increase of $16,072.03, while La Crosse is closer to the state as a whole at $17,261.76. The model predicts that Green Bay ($21,107.34), Eau Claire ($22,207.62), and Superior ($29,836.65) would experience a substantial cost increase from the mandate, between 18% and 49% larger than the state as a whole.

Relative to the price of new home construction today, the mandate would increase costs the most on a percentage basis in Superior (6.85%), resulting in the largest percentage decline in new home construction in that market (7.3%). Milwaukee would experience the smallest relative price change from the mandate at 2.95%, resulting in a 2.7% decline in new home construction for the metro area. The Green Bay (4.84%) and Eau Claire (5.1%) areas would both experience close to a 5% rise in construction price, resulting in a 4.73% reduction in new home construction in Green Bay and a 5.44% reduction in Eau Claire. The Madison market (3.69% relative price change) and La Crosse market (3.96% relative price change) are in the middle of the distribution, resulting in a slightly more moderate loss of new

Table 5

Housing market after a heat pump mandate: alternate home size estimates

	Preferred estimate	1,500 sq ft	2,000 sq ft	3,000 sq ft	3,500 sq ft
NPV of heat pump mandate (cost)	$19,976.14	$12,110.30	$16,043.22	$23,909.05	$27,841.96
Pre-mandate annual building	11,634	–	–	–	–
Relative price change	4.58%	4.63%	4.60%	4.57%	4.56%
Relative quantity change	-4.68%	-4.72%	-4.69%	-4.66%	-4.65%
Annual building loss	544	550	546	542	541
5-year building loss	2,720	2,748	2,730	2,712	2,707
10-year building loss	5,439	5,496	5,460	5,425	5,415
Homeowner value loss per home	$7,833.78	$4,749.14	$6,291.46	$9,376.10	$10,918.42

Estimates show changes to the square footage input in both the NPV and Housing Markets model. All estimates use the same other parameters from the preferred models: $173.33 price per square foot, demand elasticity of -0.80, reference indoor air temperature of 65°F, ASHP minimum functional temperature 3°F, and a discount rate of 5%. All estimates are state of Wisconsin totals.

home construction at 3.55% and 3.96%, respectively.

The relative loss of new home construction results in different levels of homes that would no longer be built under a heat pump mandate. In absolute terms, the building loss is largest in the Madison area market, at 57 homes annually, and smallest in Superior, at 5 homes annually, with La Crosse also seeing a small loss of 8 homes. The Milwaukee area would lose 42 newly constructed homes on an annual basis, with Green Bay losing 37 and Eau Claire losing 27. These losses would occur annually across markets, resulting in a growing stock of homes that are not built over time as shown in the five-year and 10-year building loss estimates of Table 4. At the top end, Madison would lose 285 new homes in five years and 570 homes over a 10-year window. At the bottom end, Superior would lose 27 newly constructed homes in five years, and 54 over a 10-year period.

Sensitivity Analysis

The housing market model that produces our preferred set of results relies on three primary inputs, in addition to other parameters, that drive our findings. The primary inputs are the square footage of a newly constructed home, the price per square foot of a newly constructed home, and the elasticity of market demand for new homes. While our preferred estimates reflect what we believe are conservative, reasonable and defensible choices for these parameters, we show how altering these choices drives change in our estimates in this section.

The first parameter that we examine is the square footage of newly constructed single-family homes, which our preferred model pegs at 2,500. Table 5 shows how using a square footage input between 1,500 and 3,500 would change our preferred results. This exercise is particularly useful because of the variation in new home construction sizes that occurs in the market. Table 5 shows how the mandate would likely play out across that distribution.

Table 5 shows that although the choice of home size is a primary driver of NPV differences, this translates to only a small impact on housing market estimates. The reason for this is because the square footage parameter feeds into both the NPV model (the need to heat a different sized structure) and the housing market model directly through its effect on the initial market price. The sensitivity analysis shows that modeling for smaller homes produces a smaller NPV, but that this translates to a slightly larger impact on prices because the base home price is now smaller. In turn, this produces a slightly larger estimate for the annual building loss expected from a heat pump mandate. Overall, the alternative home size calculations produce housing market estimates that are expected and in line with the preferred estimates.

Next, we examine how the price per square foot of housing changes our estimates of the housing market in Wisconsin. Our preferred model uses a conservative estimate of $174.33 per square foot for newly constructed homes. The conservative estimate is based on an average of Census data and current listings in Wisconsin, but the Census data is censured from homes over $150 per square foot, so beyond that we do not have full information about the price distribution. Table 6 shows how a range of different price values would change our primary housing results.

The price per square foot of housing only enters estimates for the housing model, and the heat pump model is based only on the size of home, so changing the price per square foot input will not change the NPV estimate. The price per square foot operates in the housing model by changing the baseline total price of housing prior to the mandate. When the mandate is introduced in the model, a different baseline total price results in a different percentage price change from the same NPV estimate. Table 6 shows that using a lower price per square foot ($150 per square foot) results in a larger percentage price increase in the model, leading to larger quantity changes — meaning even fewer new homes being built compared to the preferred model.

The results from changing the price per square foot of housing in the model also show that using a higher price per square foot of housing results in smaller percentage price increases in the model, leading to smaller quantity changes — meaning a smaller reduction in building than estimated in the preferred model. Table 6 shows estimates using $200

Table 6

Housing market after a mandate: alternate price per square foot estimates

	Preferred estimate	$150 / sq ft	$200 / sq ft	$225 / sq ft
NPV of heat pump mandate (cost)	$19,976.14	–	–	–
Pre-mandate annual building	11,634	–	–	–
Relative price change	4.58%	5.33%	4.00%	3.55%
Relative quantity change	-4.68%	-5.43%	-4.08%	-3.62%
Annual building loss	544	632	474	421
5-year building loss	2,720	3,161	2,370	2,107
10-year building loss	5,439	6,321	4,741	4,214
Homeowner value loss per home	$7,833.78	–	–	–

Estimates show changes to the price per square footage input in the Housing Markets model. All estimates use the same other parameters from the preferred models: 2,500 square foot structure, demand elasticity of -0.80, reference indoor air temperature of 65°F, air source heat pump minimum functional temperature 3°F, and a discount rate of 5%. All estimates are state of Wisconsin totals.

Table 7

Housing market after a mandate: alternate demand elasticity estimates

	Preferred estimate	E = -0.7	E = -0.9	E = -1.0
NPV of heat pump mandate (cost)	$19,976.14	–	–	–
Pre-mandate annual building	11,634	–	–	–
Relative price change	4.58%	–	–	–
Relative quantity change	-4.68%	-4.45%	-4.90%	-5.13%
Annual building loss	544	517	571	597
5-year building loss	2,720	2,586	2,853	2,986
10-year building loss	5,439	5,172	5,706	5,972
Homeowner value loss per home	$7,833.78	$7,207.88	$8,401.18	$8,917.92

Estimates show changes to the price elasticity of demand input in the Housing Markets model. All estimates use the same other parameters from the preferred models: 2,500 square foot structure, price per square foot $174.33, reference indoor air temperature of 65°F, air source heat pump minimum functional temperature 3°F, and a discount rate of 5%. All estimates are state of Wisconsin totals.

per square foot and $225 per square foot as examples of higher price estimates. Even using the higher price, estimates suggest an annual new home building loss of between 421 and 474 homes, with five- and 10-year estimates into the thousands.

The final sensitivity analysis we perform varies the elasticity of housing demand in the model. This is a key parameter as it dictates how responsive consumers are to price changes in the housing market. Our preferred estimates use a demand elasticity from the previous academic literature modeling housing markets, but that literature focuses on a national price elasticity, and our model estimates market changes in Wisconsin, making this parameter an important one on which to check sensitivity. In general, the smaller the geographic scope of a market, the larger the absolute value of demand elasticity, but we show results using both smaller absolute value (-0.7) and larger absolute value (-0.9 and -1.0) elasticities in Table 7.

The housing demand elasticity parameter enters the model after the NPV estimate and after the price change estimate, so it only changes quantity estimates and homeowner value losses. Using all other preferred inputs to both models, Table 7 shows how changing demand elasticity changes the estimates. In general, a less sensitive elasticity (smaller absolute value), results in smaller quantity change estimates, meaning the model produces smaller estimates of annual building loss. A more sensitive elasticity (larger absolute value), results in larger quantity change estimates, meaning the model produces larger estimates of annual building loss.

Using the more sensitive (higher absolute value) demand elasticity input also results in more value loss to homeowners from the heat pump mandate. This happens because owners of new homes will pay relatively more for the same homes, but when they go to sell them, new buyers will be more price-sensitive to the added costs of ownership induced by the mandate. While the demand elasticity does change estimates of the housing market outcomes to some degree, even using a much more sensitive parameter here does not make for drastically different outcomes.

In general, the sensitivity analysis shows stability in our estimates for the key parameters. The model is most sensitive to the price per square foot parameter and least sensitive to the square footage of the typical home built parameter. This gives us confidence that we have a reasonable model and demonstrates that results are not being driven by small changes in parameter choices.

VI: Conclusions and Discussion

This paper provides a blueprint for modeling how mandating the installation of an air source heat pump would affect the single-family housing market in Wisconsin. We start with a net present value model to estimate the cost of mandating installation of air source heat pumps in newly constructed single-family homes in Wisconsin. The model compares NPV of heat pumps with a traditional natural gas furnace and air-conditioning unit. We use the NPV results as an input to model the Wisconsin housing market, examining single-family home construction and home values across market areas of the state and for Wisconsin as a whole.

We find substantial costs associated with a heat pump mandate in Wisconsin. The NPV cost per new single-family home from a heat pump mandate in Wisconsin is $19,976.14, or over $232 million annually at current building levels. The cost per home in the Superior market is largest, at $29,836.65, and smallest in the Milwaukee market, at $12,842.97. Of the markets we study, the total cost from a heat pump mandate would affect the Madison housing market most substantially, at $25.78 million annually. These substantial costs drive changes in the housing market — we estimate annual home building would fall by 544 single-family homes in Wisconsin. Again, the largest impact from the mandate is in the Madison area, where we expect a reduction of 57 newly built homes annually. The reduction in building represents a 4.17% decline from current building levels in Wisconsin and between 2.7% (Milwaukee) and 7.3% (Superior).

Beyond the initial cost increases and building reductions from a heat pump mandate, we estimate that the average new home would lose $7,833.78 in value. The average value loss is largest in the Superior market, at $11,195.74, and smallest in the Milwaukee market, at $5,614.41. We estimate that new homeowners would lose $8,641.70 in Green Bay, $6,675.82 in Madison, $6,897.81 in La Crosse, and $8,317.46 in Eau Claire. We explore a range of sensitivity analyses for our estimated outcomes from both the NPV model and housing market model. The sensitivity analysis largely confirms the magnitude of our preferred findings, with the discount rate affecting results most significantly.

The most important caveat of any modeling exercise is that it relies on past data and some predictions for what will happen in future markets. We see two areas of change that would alter our estimates beyond those covered by sensitivity analysis. First is the rate of improvement in home heating technology — this could be either advances in traditional furnace efficiency or in heat pump function. If either technology becomes dramatically better, this will change future operating costs and thus the outcomes of our model. The second is the future energy price paths both of natural gas and electricity. Currently in Wisconsin natural gas is inexpensive relative to electricity, and this drives future operating costs, but these markets change based on factors that are

A heat pump outdoor unit.

out of the range of consideration in our models.

There are other policies that may interact with the mandate that we have not considered here. These could come on the building code and zoning side of housing, as fossil fuel regulations, in tax policy, or in other areas. For example, the federal government currently offers a 30% tax credit for the installation of a home heat pump system (up to $2,000). A tax credit policy mitigates initial costs for qualifying taxpayers, but our findings show that initial air source heat pump costs are already favorable to a traditional natural gas furnace. Perhaps a policy that mitigates future operating costs would be more effective in a climate like Wisconsin's if the goal is to increase adoption of heat pumps. Other policies that lower operating costs but do not require the use of electricity may end up cost competitive over the longer term, such as encouraging solar panel installation. Of course, offering government subsidies comes with its own costs and benefits, including increased tax burdens, and an analysis of how heat pump subsidies work is beyond the scope of the current analysis.

Finally, our results are not meant as an all-encompassing cost-benefit analysis of heat pump mandates. They do not consider how such a policy would reduce greenhouse gas emissions or other externalities associated with home building. Our work is meant to point out that while there are likely intended environmental benefits, and in some areas real NPV savings to heat pump adoption, these benefits do not necessarily accrue to those living in Wisconsin or other areas where air source heat pumps are not privately cost effective. If heat pumps are not a more cost-effective way to provide home climate control but this technology is mandated, then our work shows the subsequent unintended consequences on local housing markets. A full accounting of the environmental costs and benefits associated with any heat pump policy should consider the implications of our housing market findings. Fewer new homes likely means a growing stock of housing with older appliances, windows, insulation and technology — adding to the carbon footprint of any heat pump policy. On the other hand, newer homes are larger and often farther from traditional work destinations, factors that would further reduce the carbon footprint of a heat pump policy.

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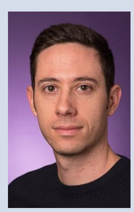

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