

TWO ESSAYS USING SURVEY INSTRUMENTS TO DERIVE  
PREFERENCES IN THE ENVIRONMENTAL SPHERE

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## Foreword

This thesis presents the results of two studies using survey instruments to explore preferences in the environmental field. The first, *Public Willingness to Pay for a U.S. Carbon Tax and Preferences for Spending the Revenue*, uses a nationally representative survey and stated-preference approach to derive mean willingness to pay estimates to reduce global warming through a carbon tax. The survey also asked respondents how they would like the resulting revenue from such a tax to be distributed, thereby indicating citizen priorities. The chapter then uses willingness to pay and distributional preference estimates, in combination with national statistical data, to arrive at a measure of public support to compensate workers in the coal industry if they are to be displaced by such a policy. The second paper, *Green Building Satisfaction and Adaptive Behaviors: A Comparison of Permanent Occupants to Visitors*, uses a satisfaction and impact-focused survey offered to the entirety of the Yale School of Forestry and Environmental Studies. It attempts to identify under what conditions a green building such as the LEED Platinum certified Kroon Hall improves the welfare of inhabitants relative to conventional structures. The study compares the treatment effect of Kroon Hall on students, who may self-select into the building, and on faculty and staff, who are usually assigned without regard to building preferences. In doing so, the study uses a difference-in-differences approach to address a discrepancy in the built environment literature - why some studies find a statistically significant green building effect while others do not. The self-selecting, public spaces student group reports a benefit with using Kroon Hall while the assigned, office using faculty and staff do not. These projects obviously contribute to different areas of the environmental literature but share the use of survey instruments to answer timely and policy relevant questions.

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Thesis (Chapter 1/2)

PUBLIC WILLINGNESS TO PAY FOR A U.S. CARBON TAX  
AND PREFERENCES FOR SPENDING THE REVENUE

## Abstract

With recent bipartisan interest in carbon taxes to reduce global warming, we query the preferences of American households using a nationally representative sample. Willingness to pay (WTP) in the U.S. to reduce global warming through a tax on fossil fuels that increases household energy bills is estimated at \$177, or a 15-percent energy bill increase on average. Particularly timely, households are asked to identify how they prefer any resulting revenues be spent. The results indicate substantial public support to aid displaced coal workers, fund clean energy development, and improve the nation's infrastructure. Based on the public's preferred allocation, we estimate aggregate support of \$3.47 billion for clean energy development, \$3.0 billion for infrastructure, and \$2.1 billion to aid displaced coal workers *per year*. The latter is more than sufficient to replace the wages of every extraction worker, even if the entire coal industry were to be phased out.

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## Author contributions and acknowledgments:

I conduct the statistical analysis and composition of this study. The survey questions were developed by Matthew Kotchen and Anthony Leiserowitz and included in a large survey instrument implemented by Anthony Leiserowitz. I am grateful for their substantial contributions and feedback. I would also like to thank Joseph Aldy and Stefano Carattini for providing feedback on the academic journal version of this paper. I also gratefully acknowledge the financial support of the 11th Hour Project, the Energy Foundation, the Grantham Foundation for the Protection of the Environment, and the MacArthur Foundation in fielding the survey.

## Public Willingness to Pay for a U.S. Carbon Tax and Preferences for Spending the Revenue

### Introduction

While a proposal for a national carbon tax is neither new nor particularly novel, it reemerged into the spotlight recently by way of a proposal by conservative political academic leaders. In February 2017, the Climate Leadership Council released *The Conservative Case for Carbon Dividends*, in which a case for a carbon tax starting at \$40 per ton is presented. Given the high standing of the conservative contributors (e.g. James Baker, George Schultz, and Henry Paulson Jr.), the report earned substantial media attention from The New York Times and many other news organizations. The plan calls for a carbon dividend to all Americans and projects a rather large \$2,000 payout in the first year alone. This suggests a substantial cost for the policy on carbon intensive energy users. Unfortunately, translating a \$40 per ton carbon tax into more tangible terms accurately ex ante, say in terms of household energy bill increases, is rather difficult and relies on strong incidence assumptions. Rather than debate whether a carbon tax should be used and at what scale, we survey the preferences of the American public for the scale and expenditure preferences. We find a mean national willingness to pay (WTP) through increased energy bills of \$177 and distributional preferences that differ substantially from a lump sum dividend. Respondents instead prefer substantial expenditures on public goods which are otherwise underprovided. I argue in favor of a bottom-up perspective respecting the American public's preferences, rather than top-down setting of the carbon tax rate and distribution plan.

Beyond a commentary on the recent conservative proposal, this paper contributes to a growing literature on WTP to reduce global warming. For example, Greenstone (2016) attempted a similar WTP measure using a monthly increase in energy bills. My thesis advisors also contributed related work in recent years (Aldy, Kotchen, & Leiserowitz, 2012; Kotchen, Boyle, & Leiserowitz, 2013). This study estimates household WTP to reduce global warming by way of a tax on fossil fuels that increases household energy costs and the public's distributional preferences for revenue. This paper then concludes by discussing the level of assistance implied for workers displaced by changes in energy demand resulting from such a tax and availability of funds toward important climate change responses. This clearly has implications in gathering support for a global warming response, particularly from members of the voting public.

We use a nationally representative survey of 1,226 U.S. citizens conducted in late 2016. The survey queries respondents on global warming beliefs, information sources, actual and hypothetical responses to global warming, and a standard set of demographics. Importantly, it also posits that congress may consider a tax on fossil fuels to help reduce global warming, then presents several expenditure categories the respondent may vote in support of or against allotting money to. Immediately following, respondents are asked to allot revenue in percentage terms between their selected categories. The data provides

perspective on public preference for the expenditure of such taxes. It indicates whether respondents believe a carbon tax should be strictly compartmentalized to the global warming fiscal sphere or spent on a variety of public goods and other issues indicating less concern over global warming versus less distant concerns. Once such preferences have been established, a randomized bid is presented and respondents are given a dichotomous choice as to whether it is an acceptable charge following standard stated preference contingent valuation methodologies. The subsequent mean WTP derived from this then allows an aggregate level of support for each expenditure category to be developed.

## **Methodology**

The survey was conducted between 18 November and 05 December 2016 as a collaborative effort between the Yale Program on Climate Change Communication (YPCCC) and the George Mason University Center for Climate Change Communication. It was then collected by research firm GfK. In addition to recruiting panel members to represent the U.S. population, sampling weights are assigned for representativeness against the U.S. Census Bureau's March 2016 Current Population Survey. Table 1 reports respondent summary statistics which include standard demographics, political affiliation, and global warming belief indicators. Of particular interest, a survey weighted 70-percent of respondents believe global warming is occurring, and of them 64-percent are very sure. Only 13-percent do not believe it is occurring, and of that group half are very sure. These figures hint at the wide-ranging support for climate policy among the American public.

The survey asks several questions about respondent beliefs on global warming prior to the survey questions used in this study but it does not intentionally present a basis, scientific or political, to influence views. It is conceivable that preceding questions may have influenced respondent answers to the variables assessed in this analysis, but this is likely minor if at all. For reference, data on the breadth of the survey is available (Leiserowitz et al. 2016). The potential for anchor bias from the bid amounts chosen must also be acknowledged. This implies the respondents construct their beliefs on the severity of the issue based on the bid presented. This is an important point when comparing to Greenstone (2016) where smaller bid amounts are presented on a monthly rather than annual scale and finds lower support for a similar prompt. Given the scale of energy price increases that may occur with the sort of carbon tax proposed by Baker et al. (2017), however, I believe the bid amounts used in this study are appropriate or even lower than what could occur with such a policy. That would imply anchor bias leading to an underestimate of mean WTP if at all.

**Table 1 | Summary statistics of respondent demographics.**

	Mean	Standard Deviation
Education (years)	13.56	(2.93)
Male (1=yes)	0.48	(0.50)
Household size (# people)	2.85	(1.59)
Income (\$10,000's)	7.60	(5.89)
Age (years)	47.28	(17.40)
White (1=yes)	0.64	(0.48)
Republican (1=yes)	0.37	(0.48)
Democrat (1=yes)	0.44	(0.50)
Independent (1=yes)	0.08	(0.28)
No party (1=yes)	0.11	(0.32)
Global warming 'don't know'	0.17	(0.38)
Global warming 'no'	0.13	(0.33)
Global warming 'yes'	0.70	(0.46)
Global warming 'no, very sure'	0.53	(0.50)
Global warming 'yes, very sure'	0.64	(0.48)

Reported as survey weighted statistics for sample representativeness using standard methodologies. Political affiliation responses include those indicating political leaning rather than formal affiliation. The reported statistics for global warming 'no, very sure' and global warming 'yes, very sure' are conditional on the respondent answering no or yes to believing in global warming (n=169 and 863), respectively. The number of all other observations are 1226 except for political affiliation where one respondent declined to respond.

Among the range of questions on global warming, we ask whether respondents support or oppose a tax on fossil fuels that will impact them through higher energy bills and how they would like to see the revenue spent. Three questions are central to the study. In order, respondents are first prompted on distributional preferences across categories:

*Congress may consider a tax on fossil fuels (coal, oil, and natural gas) to help reduce global warming. If implemented, how would you like to see the tax money used?*  
*"I would like to see the money used to..." (Please respond either "yes" or "no" for each option).*

Respondents are then given the eleven choices presented in Table 2 where the eleventh is a text entry "Other" option and order presented is randomized save for "Other" which always appears last.

Immediately following, respondents are prompted to note their distributional preferences for revenues:

*Displayed below are the ways you said you would like to see fossil fuel tax money spent. What percentage of the total fossil fuel tax revenues would you like to see used for each option?*  
*Enter a number between 0% and 100% for each option. Please make sure your total equals 100%.*

where only the expenditure options the respondent had previously chosen remain. The respondents are provided a running total and requirement that their distribution sums to 100-percent to aid computation. Some of the categories presented would reduce the public's tax burden by offsetting unrelated taxes, while others are related to mitigating the effects of both climate change and the fossil fuel tax directly.



The final core question of our analysis supports development of the WTP estimate. Respondents are asked about willingness to pay to reduce global warming via a tax on fossil fuels following a standard stated preference, dichotomous choice methodology as recommended for contingent valuation (Arrow et al., 1993):

*If a tax on fossil fuels (coal, oil, and natural gas) to help reduce global warming, were to cost your household [insert randomized bid amount] more **each year** in higher energy bills, would you support or oppose it?*

The randomized bid amounts offered are \$5, \$25, \$45, \$65, \$85, \$105, \$135, and \$155 where the middle four are presented at twice the frequency. This distribution was chosen due to ex ante expectations of a mean willingness to pay measure near the middle of the bid spectrum.

The estimation of willingness to pay is performed with a set of logit specifications. In each, the dependent variable is a binary representation of whether the respondent supports (support=1) or opposes the tax policy at the randomly assigned bid amount which is an independent variable in the specification. The models include standard demographics (education, gender, income, etc.) and political affiliation. TO the model are added indicators of whether the respondent believes global warming is happening as collected with the prompt:

*Recently, you may have noticed that global warming has been getting some attention in the news. Global warming refers to the idea that the world's average temperature has been increasing over the past 150 years, may be increasing more in the future, and that the world's climate may change as a result.*

*What do you think: Do you think that global warming is happening?*

A response of “don’t know” is used as the base case (16-percent of respondents) and “yes” and “no” are included as indicator variables. In another specification dummy variables indicating how sure respondents are that global warming is or is not happening are also added. Respondents that did not answer “don’t know” to the previous prompt are queried how strongly they believe their position and those who indicate either “very sure” or “extremely sure” are denoted.

From the logit model estimates, WTP is derived by a few methodologies. The primary result follows Hanemann’s specification (Hanemann, 1984, 1989) for admitting the possibility of negative WTP, or opposition, to the proposed policy. This methodology finds the mean WTP as the bid amount that results in respondents being indifferent between supporting the policy or not on average. To derive this, the coefficient estimates are multiplied by their mean values excluding the bid coefficient, then added to the constant. Divided by the bid coefficient, this then presents mean (equal to median according to the underlying theory) WTP without excluding those with negative values. A confidence interval is also

estimated using the Krinsky and Robb (1986) simulation method. This method makes no assumption of confidence interval symmetry around the point estimate.

As a non-parametric alternative, the Turnbull non-parametric estimator is used (Carson, 1994a) which estimates possible mean WTP without resorting to the logit specification. This is a particularly important check when the logit model based WTP is estimated to be outside the range of bids offered. At a minimum, this estimator establishes a robust lower bound inclusive of any mass of respondents with zero WTP. As an additional check, Kristrom's spike model is also used (Kristrom, 1997). To use, it must first be determined whether the respondent is willing to pay at all to help reduce global warming, then conditionally offer a bid amount to the respondent. For the screening question, a survey prompt is presented to respondents prior to the other questions in this study:

*How much do you support or oppose the following policy?  
Set strict carbon dioxide emission limits on existing coal-fired power plants to reduce global warming and improve public health. Power plants would have to reduce their emissions and/or invest in renewable energy and energy efficiency. The cost of electricity to consumers and companies would likely increase.*

Respondents are given the option to either somewhat or strongly support or oppose the policy and it is taken that any support of the policy indicates at least some willingness to pay. It is noted this is not a 100-percent equivalent prompt. It presents a scenario of government oversight but without suggesting a tax will be imposed. Some respondents may be particularly opposed to such a framework, while others may instead strongly oppose the primary tax scenario prompt. For perspective, in another question it is queried whether respondents prefer taxes or regulation (or are indifferent, uninformed, or opposed to both) and find respondents strictly prefer taxes or regulation in similar shares: 11-percent and 16-percent, respectively. It is also noted that in total respondents prefer either tax, regulation, or both in 75-percent of cases which is similar to the share supporting the near-costless bid of \$5 in the results to follow (77.5-percent support). However, due to the potential mismatch of screening and estimation questions, the Kristrom's spike model is estimated as a check on WTP rather than as the primary result.

## **Results**

This section leads with expenditure preference results, then marginal effect coefficients from a set of regressions used in deriving willingness to pay, and finally the primary and alternative WTP estimates. In context the general levels of support this study finds are not surprising. In a separate question in the study survey respondents are asked for their preferences for policy instruments. They are asked whether they prefer taxes, regulation, freeing the regulator to do both, doing neither, or stating they don't know. In total, 76-percent of respondents report a preference for regulation and/or taxation on fossil fuels to reduce

global warming, and of these 59.3-percent select either using a tax or both. Excluding those that respond “don’t know”, 68.7-percent select a tax or both. This level of support for taxation is in line with the recent, and rather unexpected, proposal by conservative leaders for a tax on CO<sub>2</sub> emissions.

The results on tax allocation preferences are presented in Table 2. It reports both the binary response of whether respondents support an expenditure from the tax on the category, and an average percent allotment measure. The mean allotment to each category including respondents who allot zero funds by not supporting the expenditure category and so represents the preferences of all respondents. By asking respondents to allocate between several expenditure schemes, this reports on the sort of tax revenue uses Americans find appropriate for a carbon tax. These can loosely be divided into global warming specific—those assisting communities and individuals displaced by the tax or global warming, and non-global warming specific. This allows a limited exploration of respondent mental accounting - do they see a tax on fossil fuels as only appropriately spent on energy concerns, or as fluid within the full set of budget concerns? Expenditure possibilities include public goods provision such as infrastructure and national debt, as well as private such as reduction in other taxes or use as an income source. Some results are not surprising - those that support a tax on fossil fuels also support clean energy (17.3-percent allotment). The general public also has little interest in reducing corporate tax burdens (3.2-percent). More interesting and telling of the public’s concerns, however, may be other spending preferences. The public overwhelmingly supports infrastructure spending and national debt reduction from this unrelated source of potential tax revenue.

Of particular interest is the category “Assist workers in the coal industry that may lose their jobs as a result of the tax”. In combination with a mean willingness to pay measure, it suggests the financial scale of public support for assisting fossil fuel extractors in transitioning out of the field. While respondents place a lower priority on helping this group, at 10.4-percent allotment, than developing clean energy (17.3-percent), repairing the nation’s infrastructure (14.5-percent), and paying down the national debt (12.7-percent), it receives substantial attention. At 10.4-percent, the public appears to support substantial compensation to displaced coal workers.

It is also important to note that while at first sight it may appear respondents place low priority on helping communities that are vulnerable to global warming, this may be a result of how the questions are formulated. Respondents could choose from both “Assist low-income communities that are most vulnerable to the impacts of global warming”, and “Fund programs to help American communities prepare for and adapt to global warming.” These likely compete for the same social concern and sum to a 15.0-percent allotment placing it second to clean energy development.

**Table 2 | Respondent preferences for the expenditure of revenues from a fossil fuel tax to help reduce global warming.**

	Support (%)	Allotment (%)	Support (\$ billions)
Support the development of clean energy (solar, wind)	79.8	17.3	3.84
Fund improvements to America's infrastructure (roads, bridges, etc.)	77.4	14.5	3.22
Pay down the national debt	65.5	12.7	2.83
Assist workers in the coal industry that may lose their jobs as a result of the tax	71.9	10.4	2.32
Reduce Federal income taxes	59.3	9.9	2.19
Return the money to all American households in equal amounts	45.9	8.1	1.81
Assist low-income communities that are most vulnerable to the impacts of global warming	57.3	7.8	1.73
Fund programs to help American communities prepare for and adapt to global warming	54.6	7.2	1.61
Reduce Federal payroll taxes (Social Security and Medicare taxes that are deducted from paychecks)	44.2	7.2	1.60
Reduce corporate taxes	24.4	3.2	0.72
Other (please specify)	7.8	1.7	0.39

Reported as survey weighted statistics. Support (%) indicates share of respondents that support using the revenue generated in the stated manner. Allotment (%) reports the mean allotment including both those that support the revenue's use on the expenditure category and those that do not support it and would allot nothing. Support (\$ billions) is the implied aggregate support for the category based on our mean WTP of \$177 and U.S. Census Bureau estimate of 125,819,000 U.S. households.

To ascertain willingness to pay to reduce global warming, respondents are then offered randomly selected annual bid amounts following recommended contingent valuation methodologies. The randomly offered bid ranges from \$5 to \$155- this is from 0.4-percent to 11.3-percent of the average residential energy bill in the United States. As point of reference, the national average monthly energy bill is \$114.03 at the time of survey and there is wide variability, from \$79.23 in New Mexico to \$153.13 in Connecticut. The support at each bid, in both dollar terms as presented to the panel, and as percent increases in mean state energy bills, are presented in Table 3 along with the percent of respondents that were queried and opted to support.

It is found that the percent of respondents supporting the proposal exceeds 50-percent at each bid amount offered. This presents certain complications in deriving a point estimate for WTP as the mean exceeds the range of bids presented and thus relies on the functional form used in estimation to project it. However, it also suggests a lower bound on WTP of at least \$155 annually, the highest bid presented. This scale is not unprecedented as Aldy, Kotchen, and Leiserowitz (2012) find a similar WTP.

**Table 3 | Distribution of support responses by bid amount.**

<b>Bid amount</b>	<b>Household bill increase (%)</b>	<b>Respondents queried (#)</b>	<b>Support (%)</b>
\$5	0.4	99	77.5
\$25	1.8	104	63.6
\$45	3.3	180	53.3
\$65	4.8	222	52.0
\$85	6.2	205	60.5
\$105	7.7	184	52.4
\$135	9.9	108	59.3
\$155	11.3	119	61.4

Five respondents refused to answer the prompt and are not included, note this did not occur more than once per bid amount.  
Percentage household bill increase based on the 2015 national average monthly residential energy bill of \$114.03 (EIA).

Using a logit model that includes the randomized bid amount as an explanatory variable, the bid result as a dichotomous dependent variable, demographic covariates, and global warming belief indicators, the probability of supporting the tax on fossil fuels to reduce global warming is estimated. The results in Table 4 are the marginal effects of each variable. Model 1 presents results specifying demographics, political affiliation, and bid but not addressing global warming beliefs which are then added in Model 2. Model 3 further breaks out global warming beliefs by indicators for respondents who report being at least “very sure” in their respective global warming stance. This specification expands on Kotchen, Boyle, and Leiserowitz (2013) where strength of attitudes on global warming is a statistically significant indicator of willingness to pay in support for a national clean energy standard (NCES) rather than political affiliation alone. A similar result is found - Republican party alone is not a statistically significant indicator of opposition to a global warming focused tax when the certainty of global warming beliefs are separately controlled for.

Model 2 is the preferred specification for simplicity, however, and the analysis of willingness to pay and discussion extends from it. Analyzing marginal effects, a \$10 increase in household energy bills results in a 1-percent decrease in the probability of supporting a tax on fossil fuels to combat global warming for the average household. Statistically insignificant effects on support probability are found for education, gender, household size. A \$10,000 increase in income increases the probability of support, as expected. Republicans, independents, and those claiming no party affiliation or leaning are each substantially less likely to support such a proposal than the base Democrat group, with magnitudes of 11.2, 20.1, and 17.6-percent decreases, respectively. Model 4 is also estimated which differs in how the variable “bid amount” is specified. Rather than in dollar terms, bids offered are transformed into percentage increases in the average energy bill in each respondent’s home state using data from the Energy Information Administration (EIA). This provides a particularly easy interpretation of the bid coefficient- a 1-percent increase in household energy bills results in a 1-percent decrease in support for the tax.

By far the largest effect on the probability of support comes with beliefs on whether global warming is happening. Those who claim global warming is not happening are 25.4-percent less likely to support the proposal. In comparison, those that do believe global warming is happening, representing most the U.S. population, are 35.2-percent more likely to support such a proposal than the ‘don’t know’ base. These beliefs, more than any demographic or political indicator, appear to account for the most opposition or support of a carbon tax among the public. Finally, the point estimates of mean WTP derived from each model are reported at the bottom of Table 4.

**Table 4 | Marginal effects from logit models of support for a tax on fossil fuels to reduce global warming that result in higher household energy bills.**

	(1)	(2)	(3)	(4) (percent)
Bid amount	-0.000704* (0.000380)	-0.000845** (0.000421)	-0.000966** (0.000426)	-0.00982* (0.00536)
Education (years)	0.0137** (0.00643)	0.0101 (0.00678)	0.00801 (0.00683)	0.0102 (0.00679)
Male (1=yes)	-0.0242 (0.0331)	-0.0329 (0.0357)	-0.0352 (0.0362)	-0.0320 (0.0357)
Household size (# people)	-0.00918 (0.0124)	-0.00981 (0.0133)	-0.00644 (0.0137)	-0.0101 (0.0133)
Income (\$10,000's)	0.00923*** (0.00329)	0.00864** (0.00352)	0.00800** (0.00368)	0.00878** (0.00350)
Age (years)	-0.000903 (0.00102)	-0.00107 (0.00109)	-0.000751 (0.00111)	-0.00110 (0.00109)
White (1=yes)	0.0791** (0.0396)	0.0738* (0.0418)	0.0508 (0.0431)	0.0736* (0.0419)
Republican (1=yes)	-0.268*** (0.0369)	-0.112** (0.0436)	-0.0648 (0.0451)	-0.112** (0.0436)
Independent (1=yes)	-0.303*** (0.0529)	-0.201*** (0.0574)	-0.186*** (0.0587)	-0.201*** (0.0572)
No party (1=yes)	-0.220*** (0.0588)	-0.176*** (0.0659)	-0.152** (0.0693)	-0.175*** (0.0659)
Global warming (no=1)		-0.254*** (0.0693)	-0.154* (0.0826)	-0.254*** (0.0693)
Global warming (yes=1)		0.352*** (0.0440)	0.247*** (0.0522)	0.352*** (0.0439)
Global warming (no, very sure=1)			-0.245** (0.120)	
Global warming (yes, very sure=1)			0.200*** (0.0422)	
Implied mean WTP	\$204	\$177	\$168	14.4-pct

The dependent variable indicates whether the respondent supports a tax on fossil fuels at the randomized bid amount. The bid is in dollars in models 1-3 and transformed to a percentage increase in average household energy bills in the respondent's state in model 4. Each model includes 1,220 observations which exclude six respondents who refused political affiliation or other questions and is weighted for survey representativeness. Democrat, and global warming 'don't know' are the omitted categories for their respective contributions. Global warming 'no, very sure' and 'yes, very sure' include responses indicating either 'very sure' or 'extremely sure'. The mean WTP coefficient estimates are included in Appendix A. Standard errors are in parentheses and follow conventional notation: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Mean willingness to pay is estimated while admitting the possibility of respondents having negative WTP for each model. The possibility of negative WTP conceptually includes the wishes of respondents who are opposed to the tax on fossil fuels to an extent that they would be willing to pay some amount to avoid imposition. Table 5 provides results from estimating mean (theoretically equal to median) willingness to

pay using the standard and alternative methodologies noted for the preferred specification in model 2. As the resulting mean WTP exceeds the highest bid amount offered in the survey, not an ex ante expectation, a diversity of estimation methods are undertaken to arrive at a robust picture of public support for the proposed fossil fuel tax. Regardless of method, the results derived are similar in point estimate and generally have overlapping confidence intervals.

At a minimum, it is found that for all bid values offered, including the \$155 maximum, more than half of respondents support the policy. This suggests a WTP lower bound of at least \$155 which is not particularly different from the derived estimate. To check this, a 95-percent confidence interval following the methodology employed by Krinsky and Robb (1986) is used. Around the \$177 mean WTP a 95-percent confidence interval of \$101 to \$587 clearly contains the conservative \$155 median WTP measure. As an alternative, the Turnbull empirical estimator (Carson, 1994a,b) is also employed to arrive at alternative lower and upper bounds of \$28 and \$272. This non-parametric approach allows for negative WTP as well by accommodating a large density of zero WTP responses in the data without making any assumption about distributional form. Given that our mean WTP is outside the bid range, this is an important check that arrives at reassuring results. The Turnbull estimator results bound the primary mean WTP result, the naïve \$155 median WTP lower bound, and has substantial overlap with the Krinsky and Robb confidence interval.

As a final check the spike model from Kristrom (1997) is implemented. Using the described screening question, WTP is estimated at \$136 with 26-percent of respondents having a WTP of zero. The spike model confidence interval of \$122 to \$150 implies this method underestimates WTP as it does not include our naïve lower bound of \$155. Meanwhile, the 26-percent projection of zero WTP matches well with the level of rejection found at the minimum bid of \$5. Despite the critique, it is noted the spike model confidence interval also falls entirely within those of the Krinsky and Robb 95-percent and Turnbull confidence intervals.



**Table 5 | Willingness to pay measures through a tax on fossil fuels to reduce global warming.**

Method	Lower bound (\$)	Mean WTP (\$)	Upper bound (\$)	Source
Point estimate	-	177	-	Hanemann (1989)
Krinsky and Robb confidence interval	101	177	587	Krinsky & Robb (1986)
Turnbull non-parametric estimator	28	-	272	Carson et al. (1994a)
Spike model	122	136	150	Kristrom (1997)

### Disaggregating WTP measures

WTP differs substantially between individuals, from potentially negative suggesting opposition to carbon tax policies, to large positives indicating relative indifference to the price of combating global warming. This section uses the econometric model results to compare willingness to pay by subpopulation. These are WTP estimated by political affiliation or leaning, stated global warming beliefs, and the Global Warming's Six Americas groups from the Yale Program on Climate Change Communication and George Mason University Center for Climate Change Communication (Leiserowitz, Maibach, & Roser-Renouf, 2009). All other variables are held at their means and the results are consolidated into Table 6.

First, WTP is derived by political leaning. These categories represent both respondents who identify with a political party or indicate a preference or leaning. The base group, Democrats, have a mean WTP of \$269 while Republicans have a mean \$40 lower than the \$177 result when climate change beliefs are held at survey means. In fact, each group has a mean WTP that is positive when the covariates are held at means. Recall instead that climate change beliefs, independent of political affiliation, have the largest impact on WTP in Table 4.

Following, WTP is then disaggregated by global warming beliefs. For a member of the population who is otherwise at the mean, these beliefs substantially impact the result. Here, WTP is estimated negative for both those who don't believe in climate change and who reply 'don't know' to a query of their beliefs. This is an interesting result- it would be reasonable to have a willingness to pay of zero for a new policy, but a negative suggests a willingness to increase their taxes without an increase in benefit. It may also imply a belief that such a policy would cost them substantially more and so they have a WTP against the policy which they think would still save them money versus implementation. However, it would seem like an extreme suspicion to believe a new carbon tax would result in greater than a \$379 a year, or 28-percent increase in average household energy bills.

As a third specification, the Global Warming's Six Americas categories derived during the survey process are substituted in place of the global warming belief indicators in the estimation. They represent a

spectrum of beliefs on climate change. On one end, the Alarmed are thoroughly convinced that global warming is occurring and are strongly in favor of policy to curtail it. On the other end of the spectrum, the Dismissive are equally convinced against global warming, its causes, and whether any action is warranted. This latter group also tend to report a belief in various forms of conspiracy theory regarding the reality of global warming. Due to these firmly held beliefs, the Dismissive tend to be motivated to spend against a carbon tax as opposition to an attack on their core beliefs - a strong motivator. The results of the Six Americas alternative in Table 6 suggest global warming beliefs are entirely driving the WTP result as can be expected. It is also found that respondents who are Disengaged- those who have little knowledge, interest, or belief in global warming one way or the other, have a mean WTP of nearly zero. They appear truly disengaged.

It should be noted that these WTP measures are interpretable as net of any carbon tax rebate. As the Climate Leadership Council's proposal includes large cash rebates, if they exceed the cost to the Dismissive audience many may very well come to support the policy. The Dismissive subgroup requires a rebate in excess of \$361, or a 26-percent offset in average energy bills to overcome strongly held reservations. Unfortunately, making such predictions of how the conservative proposal will impact the Dismissive and other groups is beyond the capacity of the current survey to answer. It is an interesting question, however, that may warrant later work.

**Table 6 | Willingness to pay by subgroup**

	mean WTP (\$)	Share of respondents (%)
<u>Political affiliation or leaning</u>		
Democrats	269	43.8
Republicans	137	36.5
Independents	35	8.4
No party	65	11.2
<u>Global warming beliefs</u>		
Yes	342	70.1
No	-379	12.6
Don't know	-81	17.3
<u>Six Americas indicator</u>		
Alarmed	435	18.4
Concerned	318	34.0
Cautious	77	22.8
Disengaged	-2	5.2
Doubtful	-173	10.5
Dismissive	-361	9.1

## Conclusion

The primary result, a mean WTP of \$177, informs on average support for the proposed measure in the United States. In combination with the distributional preferences from Table 2, it estimates support for climate change mitigation and subsequent compensatory measures. A particularly important consideration in garnering approval for such a policy is whether support to assist workers in the coal industry who are displaced is sufficient to fully compensate for lost wages.

Using the mean WTP measure of \$177 and data on the number of U.S. households from the Current Population Survey (U.S. Census Bureau, 2016), nationally aggregated support of \$22.3 billion to help reduce global warming is derived. Of this, the study suggests the public prefers roughly \$2.3 billion be directed to assist displaced coal workers. The Bureau of Labor Statistics (BLS) estimates total coal mining sector employment at 69,460 including all managerial, transport, and front office jobs. As an estimate of sectoral employment of workers requiring a higher degree of retraining to transition- the BLS measure of 15,900 workers specifically in extraction roles (BLS, 2015) is also used. The aggregate WTP estimate then implies public support of \$33,110 for every single person, or \$144,650 per extraction worker *every year* in the extreme case that the entire sector is regulated out of the workforce. Clearly then, support for any displaced coal workers is even more substantial as it is unlikely that such a tax

would eliminate the sector. At this scale, there may even be a real risk of overcompensation well in excess of losses.

By the same method, our study finds \$3.8 billion in support for further clean energy development and \$3.2 billion in support of infrastructure development from this potential revenue stream alone. It is important to put these aggregate support measures in appropriate context. While clean energy development support of \$3.8 billion is small in comparison to the share spent in the American Recovery and Reinvestment Act (ARRA) of \$92 billion by some estimates (Mundaca and Richter, 2015), the ARRA was foremost a stimulus measure. A more appropriate comparison is to individual programs such as the Department of Energy's Advanced Energy Manufacturing Tax Credit which promotes investment in clean energy manufacturing. Initially funded at \$2.3 billion by ARRA, an additional \$150 million recently came available in a second phase (Department of Energy, 2013). Our estimate of *per year* support for clean energy projects could fund several of these sorts of adjustments to clean energy outlays. This same argument is applicable to the often-presented infrastructure spending deficit of \$1 trillion. The \$3.2 billion *per year* of public support by way of a carbon tax could address pressing deficits.

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US Census Bureau *March 2016 Annual Social and Economic Supplement (ASEC)*; available at <https://www.census.gov/programs-surveys/cps/technical-documentation/complete.html>

## **Appendix A: Coefficient estimates from multinomial regressions**

Table 4 reports the marginal effects of the variables included in the model, however the model coefficients are need to compute mean WTP. These coefficient results are included in this section and their use along with the Table 1 summary statistics allows replication.

**Table A1 | Coefficient estimates for the logit model results in Table 3.**

	(1)	(2)	(3)	(4)
Bid amount	-0.00291*	-0.00348**	-0.00399**	-0.0405*
	(0.00157)	(0.00174)	(0.00177)	(0.0221)
Education (years)	0.0566**	0.0418	0.0331	0.0419
	(0.0265)	(0.0279)	(0.0282)	(0.0280)
Male (1=yes)	-0.100	-0.136	-0.146	-0.132
	(0.137)	(0.147)	(0.150)	(0.147)
Household size (# people)	-0.0380	-0.0405	-0.0266	-0.0415
	(0.0512)	(0.0550)	(0.0565)	(0.0549)
Income (\$10,000's)	0.0382***	0.0357**	0.0331**	0.0362**
	(0.0137)	(0.0145)	(0.0153)	(0.0145)
Age (years)	-0.00374	-0.00441	-0.00311	-0.00452
	(0.00423)	(0.00452)	(0.00459)	(0.00451)
White (1=yes)	0.325**	0.303*	0.209	0.302*
	(0.162)	(0.170)	(0.176)	(0.171)
Republican (1=yes)	-1.110***	-0.461**	-0.267	-0.460**
	(0.158)	(0.179)	(0.185)	(0.179)
Independent (1=yes)	-1.257***	-0.813***	-0.755***	-0.814***
	(0.243)	(0.239)	(0.242)	(0.238)
No party (1=yes)	-0.894***	-0.711***	-0.615**	-0.708***
	(0.246)	(0.270)	(0.281)	(0.270)
Global warming (no=1)		-1.038***	-0.623*	-1.039***
		(0.298)	(0.335)	(0.299)
Global warming (yes=1)		1.473***	1.014***	1.472***
		(0.200)	(0.220)	(0.199)
Global warming (no, very sure=1)			-1.001*	
			(0.520)	
Global warming (yes, very sure=1)			0.843***	
			(0.186)	
Constant	0.271	-0.610	-0.587	-0.646
	(0.511)	(0.548)	(0.555)	(0.547)
F-statistic	8.87	15.93	13.97	15.84

The dependent variable indicates whether the respondent supports a tax on fossil fuels at the randomized bid amount presented. The bid amount is in dollars in models 1-3 and as a percentage increase in average household energy bills in the respondent's state in model 4. Each model includes 1,220 observations which excludes six respondents who refused political affiliation or other questions and are weighted for survey representativeness. Democrat and global warming 'don't know' are the omitted categories for their respective contributions. Global warming 'no, very sure' and 'yes, very sure' include responses indicating either 'very sure' or 'extremely sure'. F-statistics reported rather than R-squared because the conditions necessary to calculate the latter are violated with survey data. Standard errors are in parentheses and follow conventional notation: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

## Appendix B: Multinomial logit regression on policy preferences

As an additional contribution, a survey prompt querying policy instrument preference- whether respondents prefer a tax to regulation, both, or neither is used to explore policy tool preference. A multinomial regression on respondent's categorical preference is used where the base case is first the reply "don't know". The results in Table B1 suggest characteristics related to either support or opposition of different policy tools used to regulate energy sector emissions. The dependent variable is specified as the respondent's stated policy preference to reduce global warming and was collected with the prompt:

*Governments can reduce the pollution that causes global warming in two main ways:*

*1) Regulate pollution (legally require companies to limit the amount of pollution they emit)*

*2) Tax pollution (require companies to pay a tax on the pollution they emit, which encourages them to reduce their emissions)*

*In general, which of these two approaches to reducing the pollution that causes global warming do you prefer, if either?*

The respondent is then presented options to control pollution levels by regulating, taxing, doing both, neither, or opting that they don't know. In both the prompt and reply options the order of whether "regulate pollution" or "tax pollution" appears first and is randomized. The results in Table B1 suggest education and male contribute to a higher probability of having a policy preference, either for or against the policy tools. Political affiliation also behaves as expected- republicans, independents, and those claiming no party affiliation or leaning are more likely to prefer taking no action. Global warming beliefs, in contrast, result in a higher preference for any sort of action.

**Table B1 | Multinomial logistic model of regulation preference.**

	(1) Do neither	(2) Regulate pollution	(3) Tax pollution	(4) Do both
Education (years)	0.230*** (0.0616)	0.160*** (0.0536)	0.171*** (0.0589)	0.128*** (0.0481)
Male (1=yes)	1.225*** (0.325)	0.602** (0.249)	0.642** (0.278)	0.588*** (0.223)
Household size (# people)	0.0528 (0.115)	-0.0228 (0.0924)	0.0384 (0.100)	0.0765 (0.0852)
Income (\$10,000's)	0.0310 (0.0332)	0.0195 (0.0261)	-0.00414 (0.0272)	-0.0186 (0.0237)
Age (years)	0.0292*** (0.00969)	0.0112 (0.00807)	0.00935 (0.00858)	0.0169** (0.00723)
White (1=yes)	0.876** (0.414)	0.700** (0.278)	0.400 (0.307)	0.904*** (0.239)
Republican (1=yes)	1.298** (0.534)	0.0388 (0.309)	0.321 (0.353)	-0.567** (0.273)
Independent (1=yes)	1.084* (0.637)	-0.454 (0.435)	-0.625 (0.545)	-0.578 (0.383)
No party (1=yes)	0.647 (0.803)	-0.986** (0.441)	-1.185** (0.551)	-1.080*** (0.353)
Global warming (no=1)	1.415*** (0.490)	0.0346 (0.464)	0.207 (0.519)	-0.118 (0.446)
Global warming (no, very sure=1)	1.303** (0.588)	-0.533 (0.702)	-0.234 (0.919)	0.322 (0.675)
Global warming (yes=1)	1.010** (0.446)	1.124*** (0.336)	1.323*** (0.396)	1.447*** (0.293)
Global warming (yes, very sure=1)	-0.341 (0.533)	0.508 (0.346)	0.576 (0.368)	1.101*** (0.312)
Constant	-8.779*** (1.357)	-3.948*** (1.052)	-4.490*** (1.123)	-3.171*** (0.843)
Observations	10.4%	16.7%	10.8%	48.5%

In the multinomial model, the base case is respondents selecting “don’t know” representing 13.6-percent of responses.  
Observations for each column are the percent of respondents selecting the regulation preference out of 1,226 respondents.  
Standard errors are in parentheses and follow conventional notation: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table B2 repeats the process where only respondents who have an opinion- those not selecting “don’t know” as a response, are included in the model. This gives another perspective as the base case is now to take no action- those selecting “do neither”.



**Table B2 | Multinomial logistic model of regulation preference.**

	(1) Regulate pollution	(2) Tax pollution	(3) Do both
Education (years)	-0.0468 (0.0521)	-0.0361 (0.0578)	-0.0811 (0.0495)
Male (1=yes)	-0.700** (0.310)	-0.654** (0.330)	-0.722** (0.294)
Household size (# people)	-0.119 (0.118)	-0.0542 (0.128)	-0.0280 (0.110)
Income (\$10,000's)	-0.0284 (0.0260)	-0.0519* (0.0273)	-0.0674*** (0.0234)
Age (years)	-0.0157* (0.00925)	-0.0176* (0.00970)	-0.0101 (0.00881)
White (1=yes)	-0.318 (0.419)	-0.596 (0.435)	-0.128 (0.407)
Republican (1=yes)	-1.348*** (0.508)	-1.075** (0.536)	-1.953*** (0.485)
Independent (1=yes)	-1.628*** (0.628)	-1.811*** (0.693)	-1.789*** (0.574)
No party (1=yes)	-1.400 (0.938)	-1.606 (1.024)	-1.528* (0.918)
Global warming (no=1)	-1.382*** (0.505)	-1.194** (0.564)	-1.522*** (0.482)
Global warming (no, very sure=1)	-1.911*** (0.621)	-1.639** (0.727)	-1.111** (0.510)
Global warming (yes=1)	0.107 (0.440)	0.302 (0.487)	0.450 (0.428)
Global warming (yes, very sure=1)	0.864* (0.484)	0.938* (0.501)	1.459*** (0.464)
Constant	4.861*** (1.327)	4.313*** (1.417)	5.718*** (1.262)
Observations	19.4%	12.5%	56.2%

In this model, the base case is respondents selecting “do neither” which represent 12.0-percent of 1,059 responses. This regression only includes respondents who indicate having an opinion by not selecting “don’t know” as their response. Standard errors are in parentheses and follow conventional notation: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

### Appendix C: Respondent preferences expanded table

In the main body respondent preferences for the distribution of fossil fuel tax revenues are presented. The percent that support the category and the mean allotment from all respondents including those with zero interest in the category are presented in Table 2. Here I also include the distributional preferences of just the respondents who support the category. This is the added middle column “Conditional allotment (%)”

which is the distributional preferences, conditional on the respondent first replying that they support the category.

**Table C1 | Respondent preferences for the expenditure of revenues from a fossil fuel tax to help reduce global warming.**

	Support (%)	Conditional allotment (%)	Allotment (%)
Support the development of clean energy (solar, wind)	79.8	20.5	17.3
Fund improvements to America's infrastructure (roads, bridges, etc.)	77.4	18.0	14.5
Pay down the national debt	65.5	18.4	12.7
Assist workers in the coal industry that may lose their jobs as a result of the tax	71.9	14.0	10.4
Reduce Federal income taxes	59.3	15.3	9.9
Return the money to all American households in equal amounts	45.9	15.6	8.1
Assist low-income communities that are most vulnerable to the impacts of global warming	57.3	12.7	7.8
Fund programs to help American communities prepare for and adapt to global warming	54.6	12.1	7.2
Reduce Federal payroll taxes (Social Security and Medicare taxes that are deducted from paychecks)	44.2	14.2	7.2
Reduce corporate taxes	24.4	11.2	3.2
Other (please specify)	7.8	23.1	1.7

Reported as survey weighted statistics. Support (%) indicates share of respondents that support using the revenue generated in the stated manner. Conditional allotment (%) reports the mean allotment by the respondents who support its use on the category and so does not include the preferences of respondents who do not want money spent in the indicated way. Allotment (%) is the mean revenue allocation accounting for both respondents that do and do not support the revenue's use on the expenditure category.

#### **Appendix D: State-level average household energy bill data**

As bid amounts were also presented in terms of average household energy bills and a WTP measure subsequently estimated in percent terms, this appendix presents household energy data by state. To the data publicly available from the EIA (2015), I add the implied increase in average state energy bills from a policy set at the derived mean WTP measure of \$177. The impact of a uniform policy in dollar terms varies substantially in percent terms, from increases in household energy bills of 18.6-percent in New Mexico to 9.6-percent in Connecticut.

**Table C1 | Average household energy bill by state**

State	Average monthly energy bill (\$)	Increase based on \$177 WTP (%)	State	Average monthly energy bill (\$)	Increase based on \$177 WTP (%)
Alabama	142.48	10.4%	Montana	89.03	16.6%
Alaska	119.64	12.3%	Nebraska	101.96	14.5%
Arizona	124.67	11.8%	Nevada	116.47	12.7%
Arkansas	110.22	13.4%	New Hampshire	114.90	12.8%
California	94.59	15.6%	New Jersey	110.04	13.4%
Colorado	83.42	17.7%	New Mexico	79.23	18.6%
Connecticut	153.13	9.6%	New York	111.32	13.3%
Delaware	131.18	11.2%	North Carolina	125.51	11.8%
District of Columbia	109.21	13.5%	North Dakota	104.96	14.1%
Florida	132.16	11.2%	Ohio	112.25	13.1%
Georgia	129.46	11.4%	Oklahoma	110.87	13.3%
Hawaii	152.12	9.7%	Oregon	96.24	15.3%
Idaho	95.01	15.5%	Pennsylvania	116.62	12.6%
Illinois	89.91	16.4%	Rhode Island	114.50	12.9%
Indiana	111.51	13.2%	South Carolina	144.04	10.2%
Iowa	98.53	15.0%	South Dakota	108.68	13.6%
Kansas	110.58	13.3%	Tennessee	128.51	11.5%
Kentucky	114.72	12.9%	Texas	136.00	10.8%
Louisiana	120.02	12.3%	Utah	80.92	18.2%
Maine	86.75	17.0%	Vermont	95.33	15.5%
Maryland	139.91	10.5%	Virginia	130.58	11.3%
Massachusetts	119.26	12.4%	Washington	87.64	16.8%
Michigan	93.61	15.8%	West Virginia	111.59	13.2%
Minnesota	92.32	16.0%	Wisconsin	94.26	15.6%
Mississippi	137.24	10.7%	Wyoming	91.19	16.2%
Missouri	115.80	12.7%	U.S. Total	114.03	12.9%

2015 average monthly residential energy bill data from the U.S. Energy  
Information Administration, retrieved from:  
[http://www.eia.gov/electricity/sales\\_revenue\\_price/index.cfm](http://www.eia.gov/electricity/sales_revenue_price/index.cfm)

Thesis (Chapter 2/2)

GREEN BUILDING SATISFACTION AND ADAPTIVE BEHAVIORS:

A COMPARISON OF PERMANENT OCCUPANTS TO VISITORS

## Abstract

A survey of the faculty, staff, and students of the Yale School of Forestry and Environmental Studies is used to explore the impact of a green building on occupant satisfaction, work, and time impact. By comparing the treatment effect between occupants who can self-select into LEED Platinum Kroon Hall to those assigned to it, this paper sheds light on disagreement in the green built environment literature using a difference-in-differences approach. The self-selecting student group receives a statistically significant benefit from the green building while the faculty and staff who are assigned report being no more satisfied than their counterparts on average. One possible cause is self-selection improves satisfaction and welfare when the buildings of an organization are heterogeneous. Another is that the value of green ‘vanity architecture’- structure built to impress visitors with greenness, has not been shared by the permanent staff of Kroon Hall who use different spaces in the building.

Keywords: LEED, comfort survey, green building, vanity architecture, quasi-experimental

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I conduct the statistical analysis and composition of this study. The survey questions were developed by Matthew Kotchen and James Ball (a fellow student), and the survey instrument was implemented by James Ball. I am grateful for their substantial contributions and feedback as well as that of Anthony Leiserowitz

## **Green Building Satisfaction and Adaptive Behaviors: A Comparison of Permanent Occupants to Visitors**

### **Introduction**

This study explores the concern that green buildings trade comfort for energy efficiency to such an extent that productivity is adversely impacted. In such extremum, building occupants may even engage in adaptive behavior that undermines energy efficiency goals. The study analyzes whether tradeoffs occur between energy efficiency, or greenness, and user satisfaction in a modern green building through a survey instrument. It also reports whether members of the workforce in a green building adapt and undermine energy efficiency goals. The analysis uses feedback from comparable residents of green and traditional buildings. Importantly, the analysis is differentiated by whether respondents self-select into the green building or are assigned primarily without regard to building preference. As a result, the study also weighs in on a discrepancy in the green building literature - why some studies find a statistically significant green building benefit and others do not.

For this study, we conduct a survey of the entire student and faculty body at the Yale School of Forestry and Environmental Studies (F&ES) in New Haven, Connecticut. This is a particularly appropriate population for study for three reasons. First, F&ES members are spread about evenly between a fairly standard set of university structures built and renovated over the last century, and Kroon Hall which is one of the “greenest” buildings in the United States. Controlling for any differences between users of Kroon Hall and the standard, or baseline set of buildings, approximates a treatment on resident comfort and productivity from the green building.

Second, the population is identifiable as students, who primarily use public spaces, versus faculty and staff who use offices. This has several possible interpretations. As students are inherently transient (or at least should be), the comparison may be a short run versus long run effect of a green building on satisfaction. Turnover rates of faculty and staff are particularly small at F&ES while most students graduate after two years. An alternative is that it is a comparison of the benefit of green office architecture versus that prepared for the public. This is the impact of green ‘vanity architecture’- an emphasis on design to impress visitors to a building with grandeur and greenness at the expense of underwhelming the long-term building inhabitants- the staff.

Importantly, there is also a difference in being able to self-select into and out of the green space. Students may select to use whatever spaces they prefer to work in, not an option for faculty, staff, and those in research roles. It enables a more rigorous treatment argument for the faculty and staff group, a contrast to the student group who may choose the environment best suited and thus potentially increase satisfaction.

The reality is that each of these factors is likely important to some extent. This also makes comparisons of faculty to students difficult so the study compares faculty to faculty and students to students between the green building and traditional building counterparts.

A third reason is the general characteristics of the population of survey. F&ES is a graduate school with a significant number of young professionals and early to mid-career researchers and staff. The findings then inform on the interests and preferences of the U.S., office-bound workforce of coming decades. This must be caveated that F&ES students are predominantly “green” students- young professionals studying environmental concerns.

This paper follows standard structure: A review of the green building satisfaction literature is presented. A detailed methodological discussion is then followed by a statistical analysis, discussion, and conclusion. The main body focuses on the results from questions on thermal comfort and adaptation strategies while an appendix presents extended tables covering nine other categories of building satisfaction, preferences, and work impact.

### **Literature review**

Building satisfaction surveys as well as laboratory experiments occur frequently in the built environment literature. Frontczak and Wargocki (2011) provide a sound introduction to the literature discussing occupant and building factors impacting comfort. From the meta-analysis, comfort is particularly sensitive to gender and age and so these are included as controls in this study. They also find that thermal comfort can substantially impact other factors, i.e. when a space is thermally uncomfortable, occupants report noise levels and other distractions more irritating. Frontczak and Wargocki (2011) also review studies where the subjects are transient and where they are assigned without discussing this important difference. They compare the results without considering the self-selection issue and so find sometimes conflicting outcomes.

A rather interesting study by Kingma and van Marken Lichtenbelt (2015) further emphasizes the role of gender, focusing on thermal comfort. They advocate for a better model of thermal demand that represents the actual occupants of buildings. Citing evidence that women prefer warmer temperatures on average, they argue that buildings are typically set to match standards based on male metabolic rates and that these are fundamentally different from women’s. In a context of comparing green to conventional buildings, men and women may be impacted differently if a green building is too hot (initially favoring women) or too cold (having little impact on men initially).

As an example of the green building literature, the Center for the Built Environment conducted a large analysis of green versus conventional building comfort (Center for the Built Environment, 2006). Of the 181 buildings in the survey, 21 were either LEED certified or owner designated as ‘green’. They find green buildings better in some categories (thermal comfort, air quality) but doing poorly in others such as acoustical quality. Like much of the literature, they survey building occupants without any identifying information about whether they are able to self-select in or out of buildings. This is a recurring issue in the literature- a lack of comparison and inclusion of both assigned and transient occupants.

Holmgren, Kabanshi, and Sorqvist (2017) conduct a more rigorous approach to questions of building comfort and green labels. They conduct a small laboratory experiment where labelling of a laboratory workspace as having a “low carbon footprint” is interacted with temperature. They find that environmentally concerned participants tend to like the low carbon, or green labeled space more. They are also willing to tolerate higher temperatures in the green space (give higher acceptability scores) relative to otherwise same non-green spaces within limits. An unfortunate limitation on this research is that it only measures a short-term situation- the green effect they find may dissipate with long, repeat exposure to only mildly uncomfortable spaces consistent with most building occupant behavior.

As another example, Paul and Taylor (2008) study a mix of one green and two conventional buildings on university campuses with a similar variety of questions to the survey used in this study. However, Paul and Taylor do not analyze the impact on the more transient students and only sample university employees who are assigned space. While this places their study on the more stringent side of the green building research spectrum, it is limited by this. Still, they do find similar results for our assigned subgroup- little to no difference in satisfaction from being placed in a green building versus conventional. It appears that if green buildings do have some advantage for occupants, it comes from being able to self-select into the right environment rather than being placed without regard to preferences.

Finally, green buildings have other value than building comfort. Kok and Quigley (2013) note substantial energy savings potential relative to matching conventional buildings. These savings are found to be well incorporated into the rents of green spaces and so is less of a direct remunerative advantage to occupants, even if good for the environment.

## **Methodology**

This section outlines the study methodology in four parts. First, the general research environment- the buildings that occupants use are discussed. Then, the population surveyed is outlined and contrasted to the general population. The survey design is then highlighted and finally the statistical approach is outlined in greater depth.



## Research Environment

Yale F&ES owns a variety of valuable resources. In addition to a reputation for excellence in research and teaching and several thousand acres of productive forest, it owns and occupies six buildings on the Yale University campus. These buildings, built between 1878 and 2009 and continually updated, have a contrasting characteristic that provides the basis for research on the impact of green buildings on productivity and satisfaction. The set of buildings in comparison is novel due to the inclusion of Yale University's greenest building- Kroon Hall. Designed in 2005 by Hopkins Architects, Kroon Hall is intended to be at the very forefront of sustainability and environmental innovation. After its construction, it was awarded the US Green Building Council's (USGBC) highest certification for green building- LEED Platinum. The certification is based on points received by implementing a checklist of green features. For Kroon Hall, these include geothermal wells, adiabatic cooling, exotic air handlers, high efficiency heat pumps, and a 100-kilowatt photovoltaic system. In total, Kroon received 97 points on the LEED checklist, far exceeding the 80 points needed for Platinum certification

The key source of identifying variation on the green building effect in this study is a comparison of satisfaction, work impact, etc. ratings by Kroon Hall users to those from respondents who primarily use the other five buildings at Yale F&ES. These other buildings are relatively standard institutional structures. While some are aged, they have undergone sufficient renovation that they remain comparable to many U.S. office spaces, at least on the interior. In the econometric model, the replies from occupants of these buildings, which constitute roughly half of the FES faculty, staff, and student body, are grouped to form a baseline. Despite differences in age and design, the five structures are comparatively similar relative to Kroon Hall. The six structures occupied in this study are outlined:

Kroon Hall at 195 Prospect Street was completed in 2009. It's the largest structure at F&ES at 52,635 square feet and is four-stories in height. In addition to LEED status, it is known for imposing natural wood and concrete and an open floor plan. Kroon Hall contains the college dean and several faculty and staff offices. A large auditorium, classrooms, and student spaces are distributed throughout as are three research centers. This structure is serviced by central heat and cooling and utilizes an integrated open plenum ventilation system for distribution with several hundred floor-mount low flow vents. Heating and cooling is aided by guided occupant response- a system informs occupants when windows should be opened or closed to assist the central system based on a comparison of indoor and outdoor environments.

Sage Hall at 205 Prospect Street is F&ES's next largest building. Built in 1924, it is four-stories and 27,698 square feet such that it houses several faculty, staff, and student researchers. It also houses a large auditorium, classrooms, lounges, a computing lab, and research centers. Heating and air conditioning are accomplished by a mix of radiators, window units, and wall systems as space allows and conditions

warrant. While perhaps not the most efficient system from a central planner perspective, it allows a great deal of tailoring to the occupant.

Greeley Memorial Laboratory at 370 Prospect Street was built in 1959 but recently underwent extensive renovation. It is a two-story, 24,246 square foot structure served by central heating and air conditioning. It houses several faculty and staff in both open and closed office floor plans. It also has one classroom, ten laboratory spaces, and an adjacent 4,278 square foot greenhouse.

Marsh Hall at 360 Prospect Street is thought of as the original home of the School of Forestry. As such, public spaces have preserved the extensive wood interior from 1878 and furniture. Updates to offices have occurred over the years and is not different from many offices in these spaces. It is a 3-1/2 story structure with 13,048 square feet of functional space built in the Victorian style. It houses several faculty, staff, a seminar room, two research centers, and the world's creakiest staircase. Marsh Hall is serviced by radiator heating controlled by central thermostats on each floor. Air conditioning comes from several window units throughout.

301 Prospect Street is a 12,932-square foot, three-story structure built in 1907. It houses faculty, staff, and one seminar space. It is also home to four active Yale F&ES research centers. The public spaces remain dated while offices have undergone modest renovation. Heat is provided by radiators that are approximately controlled by central, locked thermostats, and then can be individually adjusted down. Window air conditioners are pervasive, as with Marsh Hall, resulting in the usual northeastern chestnut or porcupine appearance.

380 Edwards Street is a four-story structure with 10,475 square feet of space built in 1907. It too maintains public spaces in classic form while housing faculty, staff, researchers, a seminar space, research center, and resident journal in updated fashion. Unlike its aged counterparts, 380 Edwards is served by updated central heating and air conditioning throughout. But as with the other structure, this has not prevented the appears of supplemental heating and cooling devices.

#### Survey population and response rate

The opportunity to contribute to the survey in this study was extended to the entire population of Yale F&ES using an online collection platform. Of the F&ES population of 602 at the survey moment, including students, faculty, staff, and visiting researchers, a response rate of 53.7-percent was achieved. The response rate is similar for faculty and staff at 55.0-percent, and students and visiting researchers at 52.4-percent. The response rate is also similar along gender lines, at 51.2-percent and 49.7-percent for women and men, respectively. Nevertheless, the survey data is weighted for responsiveness along these characteristics using nonresponse and post-stratification weights following standard survey

methodologies. This is undertaken as the former is expected to substantially impact how respondents interact with the building and the latter is an important factor in comfort according to the literature (i.e. Kingma and Lichtenbelt, 2015).

Survey weighting ensures the data represent the F&ES population rather than the general U.S. population. This supports internal validity rather than attempting to address external validity concerns while using a small sample. The results are generally found at a high level of statistical significance, however. The student subpopulation at F&ES surveyed has also already entered the workforce and so this study informs on at least some share of the general workforce. The limited scope of the survey means complex stratification or clustering techniques are not needed - a single strata and a cluster of one is applicable. The simple weighting strategy follows standard convention:

$\text{Weight}(\text{Final},i) = \text{Weight}(\text{Selection},i) * \text{Weight}(\text{Nonresponse},i) * \text{Weight}(\text{Poststratification},i)$  where  $\text{Weight}(\text{Selection},i) = 1$  in our survey due to full sampling of the population,  $\text{Weight}(\text{Nonresponse},i)$  is the inverse of the response rate for key response categories of faculty and staff versus student body, and  $\text{Weight}(\text{Poststratification},i)$  is used to account for small proportional differences in gender response rates relative to the F&ES population (Heeringa, West, & Berglund; 2010). While the use of strata is known to reduce standard errors, and clustering and weighting increase standard errors, only weighting is applied in this survey. The standard errors are then equal or greater than would be derived in a perfect survey and the statistical significance of results are a lower bound. Finally, due to the simple survey design, Taylor series linearization, the generally accepted default, is retained in computing sampling variance.

Table 1 presents survey weighted summary statistics. 60-percent of respondents report Kroon Hall as their primary F&ES building- this is 34-percent of faculty & staff and 84-percent of students. 90-percent of faculty & staff have a dedicated office while only 2-percent of students indicate so. The faculty & staff are also slightly older than the U.S. population and the students younger. The nature of the school also implies levels of education exceeding the national average.

**Table 1 | Summary statistics**

Variable	Overall	Faculty and staff	Students
Kroon Hall	0.60 (0.03)	0.34 (0.04)	0.84 (0.03)
Faculty & staff	0.48 (0.03)	1 -	0 -
Kroon*Faculty & staff	0.17 (0.02)	0.34 (0.04)	0 -
Office	0.45 (0.03)	0.90 (0.03)	0.02 (0.01)
Kroon Hall*Office	0.15 (0.02)	0.29 (0.04)	0.01 (0.01)
Age	36.34 (0.80)	45.30 (1.14)	27.97 (0.44)
Female	0.53 (0.03)	0.57 (0.04)	0.49 (0.04)

Survey weighted statistics with standard errors in parentheses. There are 323 responses in the survey, suggesting a 53.7-percent response rate. However, only 259 observations are complete to include age and gender indicators, a 43.0-percent effective response.

### Survey Design

The survey was offered throughout April 2015 and queried respondent usage and satisfaction with F&ES facilities on campus, basic demographics, and a few questions of less general interest. The core survey was a set of nine questions on the satisfaction with, and impact on productivity from building characteristics categorized as acoustics, aesthetics, air quality, sustainability features, furniture, lighting, functionality, thermal comfort, and other (with an option to write in text). For each category, respondents were asked about the importance of the category and satisfaction with the F&ES building they most use, impact on their productivity in that building, and impact on amount of time spent in the building. Respondents ranked from response=1 for very unimportant, very dissatisfied, greatly interfere, or a lot less time, to response=5 for very important, very satisfied, greatly enhance, or a lot more time as applicable in discrete increments. This data offers a substantial picture of respondent experiences with green Kroon Hall and traditional buildings. In total, nine built environment characteristics are analyzed for their impact on four satisfaction and importance measures. This offers 54 data points per respondent, measured at a resolution of a five-point scale. Respondents were also queried on how they adjust the building environment with a dichotomous choice for ten adaptation options: open and close windows, doors, raise and lower window blinds, adjust building thermostats, air vents, bring in portable heaters, fans, wear different clothing, do nothing, and other (with another write-in option). The analysis to follow focuses on thermal comfort while extended results are included in the appendix.

### Econometric model

The econometric model attempts to identify whether there is an impact on occupant satisfaction and productivity from LEED certified Kroon Hall. It also attempts to identify whether adaptive behavior differs. An ordered probit model is estimated for each experience and impact category to capture to the fullest extent the influence of the green structure in the form:

$$Cat_{ij} = \beta_0 + \beta_1 KroonPrimary + \beta_2 Kroon * Office + \beta_3 Office + \beta_4 Age + \beta_5 Gender + \varepsilon \quad (1)$$

where  $i$  indicates the four measures (importance, satisfaction, work impact, time impact),  $j$  indicates the nine building characteristics (thermal impact, acoustics, aesthetics, etc.), and subscripts for individual observations are suppressed for clarity.  $Cat_{ij}$  is a five-point ordinal response subcategory. The independent variables are  $KroonPrimary=1$  if Kroon Hall is the respondent's self-reported primary F&ES building,  $Office=1$  if they have an office at F&ES,  $Kroon*Office$  as interaction term,  $Age$ , and  $Female=1$  as expected. In selecting the independent variables, Frontczak & Wargocki (2011) and Kingma & Lichtenbelt (2015) emphasize age and gender as important factors influencing indoor comfort. A second version using  $FacStaffOther=1$  if the respondent is faculty, staff, or has indicated a role such as visiting research fellow or postdoc rather than using  $Office$  results in qualitatively same results. The correlation between being faculty or staff and having an office is expectedly high- only students in special research roles and doctoral students generally receive an office assignment. This assignment is similar to that of faculty and staff for these researchers- exogenously determined for the individual and thus the assignment characteristic of office is retained for office-using students. Equation (1) is estimated for each of our 54  $Cat_{ij}$  ordinal response categories. However, the category with the greatest energy impact potential, thermal comfort, is the focus of this analysis while the breadth of results occupies the appendix. The coefficients on the usage of Kroon Hall versus the rest of the F&ES inventory, and interaction of *Kroon Hall* and *Office* are of primary interest.

The next measure is whether use of the green building results in a difference in effort to modify the indoor climate by occupants. To explore this, a dependent variable indicating whether the respondent adjusts thermostats, vents, and seven other adaptive behaviors as well as a do-nothing response option are estimated in the form:

$$AdaptiveBehavior_i = \beta X + \varepsilon \quad (2)$$

where  $X$  is the vector of right hand side variables from equation (1), and  $AdaptiveBehavior_i$  is a dichotomous choice measure of whether the respondent engages in the stated behavior. This specification is estimated by two methods. First, each behavior is taken separately using a survey weighted probit model. This indicates which sorts of behavior have the highest probability of occurring, but not about

how many behaviors are engaged in by individuals on average. Second, the individual behaviors are transformed into a count dependent variable of how many behaviors are engaged in. This has the disadvantage of implicitly weighing each behavior equally while some are costlier to the building's bottom line. The advantage is it suggests the severity of the environmental mismatch through how many adaptive behaviors are undertaken. As a final exploration, the marginal effects of the Kroon hall treatment on level of thermal comfort satisfaction are explored. This is more relevant for the F&ES administration than general audience.

Key to the novelty of the results, the population under study is composed of two groups which are materially different in both purpose at the university and the methodological implication. One group, non-office students, can select into and out of Kroon Hall and any other F&ES building. They choose which building to spend time in and designate as their primary. This self-selection implies the coefficient on Kroon Hall cannot be interpreted in the strict context of a quasi-random experiment. It is likely that students who select Kroon Hall do so because they prefer it over the baseline options. One way to check for evidence of this is through the coefficient on Kroon Hall estimated on the *importance* dependent variable as in column 1 of Table 2. In a true random experiment or setting that mimics it, the importance of any attribute should not differ between treatment and control groups yet it is statistically significant for the Kroon Hall student group. An exception to this occurs when the treatment results in the treated developing an affinity for the category being tested- the attribute becomes important after exposure. This exception cannot be tested with the survey, unfortunately.

Estimates on the second group in the study, those with an office at F&ES, adheres to a more rigorous interpretation. Assignment to an office in Kroon Hall or elsewhere, whether faculty and staff or the few students placed through research roles, is effectively assigned irrespective of preferences. In other words, whether the office is in Kroon Hall or the baseline building group is entirely independent of the person. Rather, office assignment has to do with the F&ES administrative division's location or the research center. Importantly, there is no reason to believe that most personnel select into or are hired by these divisions or research projects because of an interest in being seated in Kroon Hall or not. Because of this independence of assignment, the treatment of Kroon Hall can be taken as more rigorous for the office subgroup. This adds to the validity of the coefficients discovered- they represent the treatment of Kroon Hall on the treated, unaffected by self-selection. The estimation could still indicate a statistically significant coefficient on importance of attributes under the circumstance that an affinity has developed from treatment. This is generally not found in the results to follow, however.

## Results

Equation (1) is estimated by ordered probit regression to match the literature. This selection makes less restrictive assumptions about the structure of the data, specifically the error term, than the logistic alternative. Unfortunately, while more appropriate for this sort of analysis, ordered probit coefficients are difficult to interpret as they represent a change in z-scores. Calculated marginal effects are at a specific point as well, holding all else at means or other significant value. This is further complicated in an ordered probit model. The probabilities are calculated of moving between each dependent variable respondent score, from one through five, for each independent variable- a large set of results which are mostly not particularly useful outside F&ES. Simpler and to the point of the research, significance and sign indicate which groups, if any, are impacted by the Kroon Hall green building treatment.

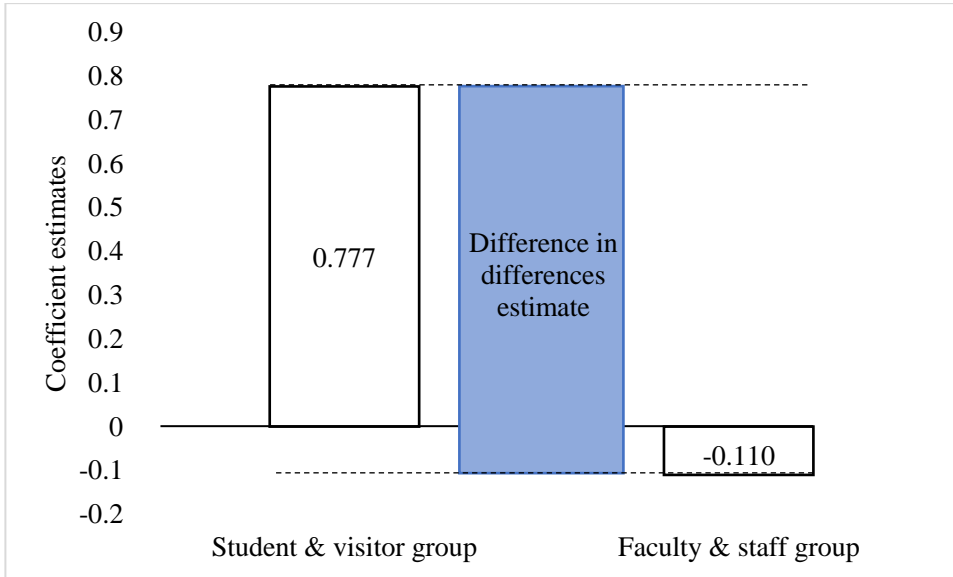
The results on thermal comfort importance, satisfaction, work impact, and time impact are presented in Table 2. From the model specification, the base category are primarily F&ES master's students, not based in Kroon Hall, do not have an office, and male. This base category may self-select into Kroon Hall versus other F&ES buildings in the survey and are more generally transient in nature without assigned office space. The coefficient on Kroon Hall identifies the effect of Kroon Hall on this population. The more rigorously interpretable effect of Kroon Hall on the F&ES group with an office is found by linear combination of *Kroon Hall* and *Kroon\*Office*. This is provided at the bottom of Table 2 for each factor.

**Table 2 | Thermal comfort ordered probit results**

	(1) Importance	(2) Satisfaction	(3) Work impact	(4) Time impact
Kroon Hall	-0.672** (0.336)	0.777*** (0.216)	0.560** (0.217)	0.681*** (0.258)
Kroon*Office	0.631 (0.421)	-0.888*** (0.311)	-0.595* (0.327)	-0.917*** (0.342)
Office	-0.129 (0.351)	0.027 (0.249)	-0.112 (0.239)	0.230 (0.261)
Age	-0.006 (0.006)	0.004 (0.007)	0.008 (0.007)	0.0118* (0.007)
Female	0.388** (0.155)	-0.009 (0.140)	-0.0405 (0.133)	0.0004 (0.140)
Observations	258	255	254	248
Combination: Kroon+Kroon*Office	-0.041 (0.254)	-0.110 (0.225)	-0.036 (0.244)	-0.236 (0.215)
Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1				

Through the model specification, the faculty and staff with a Kroon Hall office are compared to those with an office elsewhere at F&ES and the students in Kroon Hall are compared to students elsewhere.

Then by comparison, a difference-in-differences (DID) approach is reached as illustrated in Figure 1. Comparing the coefficients on Kroon Hall indicating the effect on the student group, to the combination on Kroon+Kroon\*Office for the faculty & staff group arrives at this difference-in-differences result. The data itself does not have an explicit time component as in most DID applications, but rather an implied one from the extended treatment of using F&ES facilities. From the timing of the survey implementation, the time component ranges from at least one academic year for the newest of students, to eight years for some of the faculty (the age of Kroon Hall).



**Figure 1 | Illustration of difference-in-differences identification strategy using green building satisfaction ordered probit estimates.**

It is clear that the non-office student population receives a statistically significant, positive effect of Kroon Hall on general satisfaction, work, and time impact. The linear combination coefficients for office users in Kroon Hall are all statistically insignificant in comparison. These members of F&ES are made no better off statistically than office users throughout F&ES. The comparison of these results suggests an important takeaway- choice is an important driver of satisfaction. Experience with F&ES cautions that I cannot reject an alternative explanation- green ‘vanity architecture’ has primarily improved the public spaces rather than office environment of Kroon Hall relative to the comparison group.

To reinforce reader confidence in the results, equation (1) is also estimated separately by whether respondents have an office and the coefficients presented in Table 2a. This estimation reduces to:

$$Cat_{ijk} = \beta_0 + \beta_1 KroonPrimary + \beta_4 Age + \beta_5 Gender + \varepsilon$$

for the two,  $k$ , separate groups of office and non-office members of F&ES. It is perhaps clearer in this specification that the Kroon Hall coefficient is interpretable as a treatment effect while controlling for age



and gender differences. The coefficients in Table 2a reporting the Kroon hall treatment for non-office and office subgroups separately are qualitatively same to the Table 2 coefficients. The *Non-office* coefficients in Table 2a correspond to the *Kroon Hall* treatment in Table 2 and the *Office* coefficients correspond to the linear combination  $Kroon + Kroon * Office$ . Small coefficient differences occur, however, as estimating the model separately un-constrains the coefficients on age and female.

**Table 2a | Coefficients on Kroon Hall from estimating non-office and office groups separately**

	(1) Importance	(2) Satisfaction	(3) Work impact	(4) Time impact
Non-office	-0.692** (0.339)	0.904*** (0.228)	0.659*** (0.235)	0.627*** (0.240)
Office	-0.051 (0.248)	-0.090 (0.214)	-0.022 (0.233)	-0.285 (0.251)

Only the quasi-treatment coefficient on Kroon Hall is reported while age and gender coefficients are included in the estimation as with the primary results in Table 2. Standard errors in parentheses: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

This study now analyzes how respondents adjust the building atmosphere when it doesn't fit preferences. This question is clearly important in the context of running a building efficiently. If a significant share of residents behave in ways counter to efficient operation, it may require a different set of operating parameters such that marginal savings from reducing counter-efficient behavior meet any corresponding increase in marginal costs from operating the building. In other words, it may be worthwhile to increase the building's temperature such that fewer portable heaters are brought in during the winter. Table 3 presents the results from a set of probit regressions where the dependent variable is equal to one if the adaptive behavior is indicated. Column (7) on operating a portable heater may be of greatest concern from an energy saving perspective. The survey finds that across F&ES facilities, more than one in ten users brings in a space heater. However, this is highly concentrated in the office group of faculty, staff, and researchers as nearly one-quarter admit to bringing a heater into the office. The analysis finds, however, that the Kroon Hall faculty are no different from counterparts residing in other F&ES spaces in this regard. In fact only adjusting thermostats and air vents are statistically different for Kroon Hall office users and these can be explained by building design. Kroon Hall thermostats differ from most structures in that they allow the user to only slightly modify the temperature rather than granting full control. In contrast, Kroon Hall has far more vents to adjust than most buildings- several hundred dispersed across the floor.

A qualitative analysis of the text submitted in conjunction with the Other category (10) also suggests general building atmosphere mismatches. This is not specific to Kroon Hall but for office users in general. The majority of responses discuss strategies to compensate for excessively hot temperatures, either from weather in the summer or from building systems. These are as extreme as leaving on hot

summer days, reducing productivity, and turning on window air conditioners in the winter to offset the building heating system, a surprising waste. Obviously, this is an extremely inefficient method to compensate from a building operation standpoint. It is also likely not preferred by the respondent. A subcategory, Do nothing (9) is also offered in the survey but only 16 respondents indicated this. As such, nearly every user attempts to adjust F&ES building climates in at least some way. Finally, Table 3 includes a row reporting the percent of respondents who reply yes to the adaptive behavior. Despite the discussion of costly adaptation strategies, it is reassuring to note a far larger share of respondents adapt by less costly means for the building operator. The largest adaptation share is found in adjusting clothing which likely has no negative impact on building energy usage.

**Table 3 | Adaptive behavior probit models**

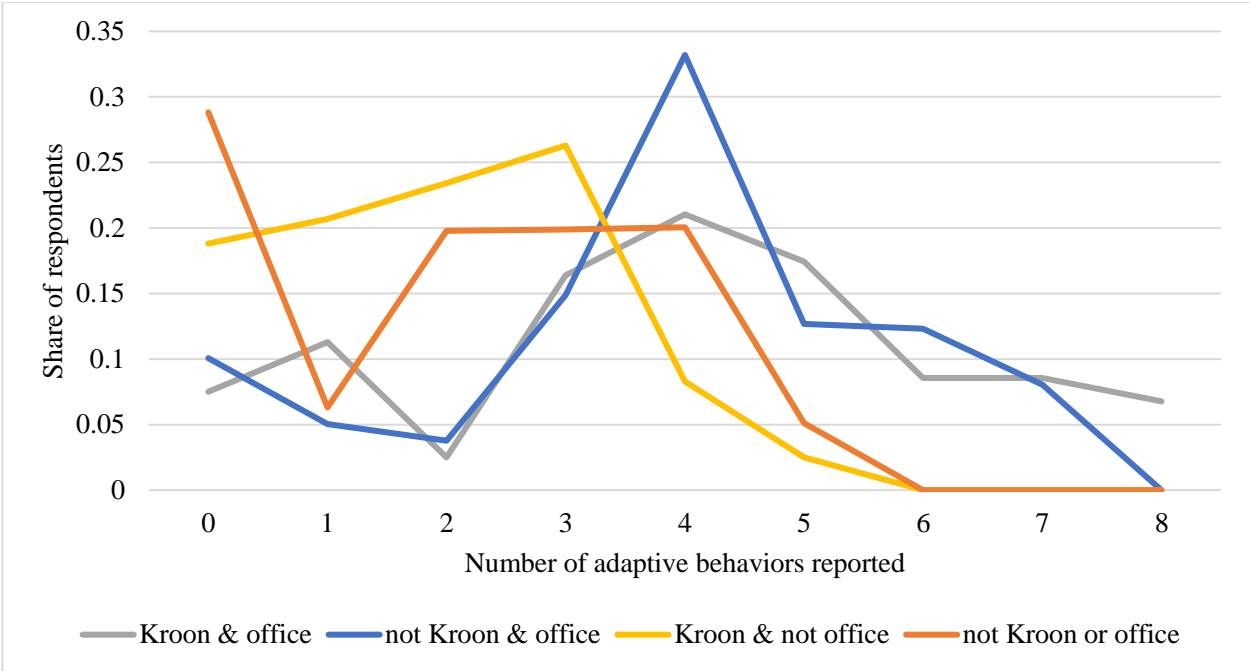
	(1) Adjust air vents	(2) Adjust thermostat	(3) Different clothing	(4) Open/close doors	(5) Open/close windows	(6) Portable fan	(7) Portable heater	(8) Raise/lower blinds	(9) Do nothing	(10) Other
Kroon hall	4.044*** (0.244)	-0.520 (0.336)	0.119 (0.312)	-0.505* (0.285)	-0.451 (0.289)	-3.985*** (0.509)	-3.988*** (0.403)	0.215 (0.286)	-0.511 (0.398)	3.656*** (0.263)
Kroon*Office	-2.690*** (0.376)	-0.190 (0.429)	0.179 (0.419)	0.225 (0.383)	0.336 (0.405)	3.455*** (0.569)	4.010*** (0.489)	0.004 (0.386)	-3.463*** (0.484)	-4.230*** (0.440)
Office	3.991*** (0.210)	1.057*** (0.334)	0.202 (0.337)	0.234 (0.298)	0.321 (0.320)	1.141** (0.458)	1.102** (0.500)	0.251 (0.300)	-0.383 (0.453)	4.431*** (0.204)
Age	0.018* (0.010)	-0.002 (0.008)	0.001 (0.008)	0.005 (0.008)	-0.001 (0.008)	0.024** (0.010)	0.002 (0.011)	0.004 (0.007)	-0.022 (0.019)	0.005 (0.011)
Female	0.393* (0.223)	-0.0244 (0.185)	0.592*** (0.184)	0.361*** (0.168)	0.061 (0.169)	0.421 (0.261)	0.344 (0.245)	0.045 (0.162)	-0.704** (0.291)	-0.079 (0.266)
Constant	6.313*** (0.515)	0.801* (0.416)	-0.456 (0.407)	0.463 (0.382)	-0.487 (0.399)	3.022*** (0.510)	2.092*** (0.472)	0.426 (0.384)	0.173 (0.700)	5.657*** (0.446)
Percent 'Yes'	13.7	24.7	71.4	36.8	57.0	11.0	11.2	44.0	5.2	6.0
Combination:	1.354***	-0.710***	0.298	-0.280	-0.116	-0.530	0.022	0.219	-0.511	-0.574
Kroon+Kroon*Office	(0.294)	(0.263)	(0.287)	(0.253)	(0.281)	(0.307)	(0.277)	(0.256)	(0.398)	(0.374)

259 observations each. Standard errors in parentheses: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Another perspective on adaptive behaviors is offered in Table 4. Here the dependent variable is a count of the adaptive behavior categories from Table 3. This implicitly assumes equal importance which is not accurate from an energy usage perspective. The advantage is to account for the number of potential adaptive behaviors engaged in by a representative individual. The model from equation (2) is estimated with a negative binomial regression as appropriate for survey non-ordinal, count dependent variables. Note again the significance of *Office* and *Female* but not *Kroon Hall* or interaction term *Kroon\*Office*. Both office users in general and women are more likely to engage in a greater variety of adaptive behaviors. The results are also presented as incidence-rate ratios. This is an alternative method to display results rather than separate estimation.

<b>Table 4   Count of adaptive behavior</b>		
Variable	nbreg	IRR
Kroon Hall	-0.127 (0.124)	0.881 (0.109)
Kroon*Office	0.103 (0.153)	1.109 (0.170)
Office	0.401*** (0.124)	1.493*** (0.186)
Age	0.004 (0.003)	1.004 (0.003)
Female	0.165*** (0.061)	1.180*** (0.072)
Constant	0.738*** (0.158)	2.091*** (0.330)
Combination:	-0.021	-
Kroon+Kroon*Office	(0.087)	-
259 observations. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. F-statistic of 19.88.		

Figure 2 displays the identifying variation used in the negative binomial regression model, or lack of, graphically. The two-by-two matrix of office and Kroon Hall statuses are graphed separately. The share of respondents indicating each count of adaptive behavior is compared. Generally, shares of office workers select the same count of adaptive behaviors, and similarly so for non-office members of F&ES regardless of building.



**Figure 2 | Respondent engagement in adaptive behavior**

The remaining results are relevant to Yale F&ES rather than the general population. First, what are the probabilities of selecting each satisfaction level for groups within Kroon Hall? Margins on satisfaction with thermal comfort are calculated for the Kroon Hall subgroup both combined and by subcategory. Students without offices are more likely to select higher satisfaction levels for thermal comfort. However, both students and faculty of Kroon Hall select a satisfaction level of four, labeled in the survey as somewhat satisfied, most often.

**Table 5 | Ordered probit margins on satisfaction with thermal comfort**

Response scale	(1) Pr(Overall Sat_level)	(2) Pr(Sat_level  Kroon Students)	(3) Pr(Sat_level  Kroon office)
1	0.081	0.037	0.092
2	0.242	0.174	0.273
3	0.137	0.124	0.148
4	0.366	0.411	0.356
5	0.174	0.254	0.131

Scale of 1 being the lowest to 5 being the highest satisfaction; Standard errors not shown- all significant at the 1% level. The potential responses are: 1=Very dissatisfied, 2=Somewhat dissatisfied, 3=Neutral, 4=Somewhat satisfied, 5=Very satisfied

I then ask, how is the experience different for the non-office users in Kroon Hall versus other F&ES buildings? And how is it different for faculty and staff in Kroon Hall versus elsewhere? Table 6 presents the changes in the margins from the Kroon Hall treatment for each group. A student in Kroon Hall is 11-percent less likely to be very dissatisfied and 25-percent more likely to be very satisfied than students reporting other F&ES buildings, at a one-percent or better level of statistical significance. Unfortunately,

within Kroon we also see that having an office decreases the probability of being very satisfied and increases the probability of being dissatisfied relative to other office users, however, this is not though statistically significant at any acceptable level.

**Table 6 | Changes in margins on satisfaction with thermal comfort**

Response scale	(1) Effect of Kroon Hall on students	(2) Effect of Kroon Hall on office holders
1	-0.116	0.088
2	-0.196	0.062
3	-0.046	-0.009
4	0.109	-0.090
5	0.25	-0.052

Scale of 1 being the lowest to 5 being the highest satisfaction. Standard errors not shown- For column (1) all significant at the 1% level and for column (2) none are statistically significant. The potential responses are: 1=Very dissatisfied, 2=Somewhat dissatisfied, 3=Neutral, 4=Somewhat satisfied, 5=Very satisfied

## Discussion & Conclusion

This study provides three results for the general audience. First, carefully defining the population surveyed in green versus conventional building comparisons informs the context of results. A survey that only collects on the stationary, assigned inhabitants of a green building does not inform on the experience of visitors and vice versa. Second, self-selection may play an important role in building satisfaction. Organizations that use buildings of differing character may be best served by letting their users select and trade spaces. And third, green vanity architecture works... for those served by the public spaces where the architect has focused.

By surveying both building users who can self-select and those who are assigned to green versus conventional buildings, this study sheds light on a discrepancy in the green building literature. Prior studies have generally surveyed transient users of green buildings, those assigned to a green versus non-green building, or all users of a space without distinguishing between these. Their results then mirror these differences when examined. This study contributes a unique feature of differentiation and reconciles the results from other studies in the process. It finds one group consistently prefers the green building in the study- the more transient users. In contrast, users who are usually randomly assigned relative to building preference, the permanent users, are indifferent between the green and non-green buildings on average. This is an important contribution on its own.

This study suggests that allowing self-selection may enhance satisfaction. This is particularly relevant in an organization like Yale F&ES that has buildings of differing attributes. A reorganization scheme allowing faculty and staff to trade spaces may enhance satisfaction. The alternative, that green vanity architecture is to blame must be considered. It may be the case instead that Kroon Hall only excels in

public spaces by design. It was no doubt designed to impress and has done so for visitors. It seems to be having less of a positive impact on the faculty and staff, however.

Regardless of cause, a marked discrepancy in the satisfaction effect of green Kroon Hall exists. The Yale F&ES subgroup assigned to offices are made no better off on average by their assignment to Kroon Hall. In comparison, the student body that may self-select into Kroon Hall are markedly more satisfied across measures. LEED Platinum certified Kroon Hall has certainly performed well by certain measures- it is efficient and impresses visitors by demonstrating that a green structure can be elegant. It appears to have missed the mark on improving the office setting, however, and so this study indicates an area that could benefit from greater effort in green building design.

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## Appendix

Table A1 presents regression results using responses on ‘importance’ of building characteristics. Unlike in the other tables that follow, no clear pattern across categories emerges. One interesting question to consider, do students self-select into Kroon Hall based on the features important to them? Note in column (2) the large coefficient on aesthetics for *Kroon Hall* relative to all other coefficients in the table and its significance at all levels. Contextually, Kroon Hall is known for aesthetic appeal. For those with Kroon Hall offices, who cannot self-select, the nearly equal, negative coefficient does not refute the student self-selection hypothesis. Although less significant, at the 10% level, it can also be considered whether this is the case with thermal comfort- selecting out of Kroon Hall. Specifically, would this be more significant if we differentiate between Kroon Hall male and female users? Noting the 1% level of significance for *Female*, an auxiliary regression is estimated including an interaction term *Kroon Hall\*Female* which

resulted in both *Female* and *Kroon Hall\*Female* becoming insignificant while remaining jointly significant (F-test) at the 5% level suggesting over-specification. Unfortunately, this auxiliary regression neither supports nor refutes a self-selection hypothesis then. Finally, since aesthetics, air quality, and sustainability features are statistically significant for female respondents and acoustics positively related with age, these may suggest a greater need to focus on their preferences in these areas when planning and operating facilities.

Moving from ex post importance to satisfaction analysis, table A2 presents ordered probit regressions on satisfaction with F&ES facilities. Students who primarily use Kroon Hall consistently claim a higher level of satisfaction across subcategories at the 1% level of significance. This would be a significant architectural achievement for a LEED certified structure as the literature cites dissatisfaction in many of these categories for many green buildings across the nation. However, this may not be as momentous when the competition is considered- the baseline category is a set of aging but relatively familiar office settings. The building satisfaction picture is not as rosy for Faculty, Staff, and resident researchers of Kroon Hall. Across all columns (with five of eight significantly) the coefficients on *Kroon\*Office* carry a negative sign and partially or fully offset *Kroon Hall*. This suggests if resources are used to improve the operation of Kroon Hall, the question of what is behind these lower levels of building satisfaction for office space users should be understood first. Tables A3 and A4 on the work and time impacts of building spaces tells the same story- students are more satisfied, receive a work benefit, and prefer to spend more time in Kroon Hall due to its environment while the faculty receive less of a benefit or even a penalty from placement in Kroon Hall.

**Table A1 | Ordered probit regressions on importance responses**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Acoustics	Aesthetics	Air quality	Functionality	Furniture	Lighting	Sustainability	Thermal comfort	Other
Kroon hall	0.178 (0.231)	0.923*** (0.234)	0.0648 (0.241)	-0.0768 (0.293)	0.206 (0.292)	-0.495* (0.293)	-0.239 (0.228)	-0.672** (0.336)	0.0842 (0.698)
Kroon*Office	0.399 (0.339)	-0.812*** (0.309)	-0.303 (0.354)	0.446 (0.407)	-0.664** (0.336)	0.526 (0.383)	0.381 (0.307)	0.631 (0.421)	-1.544 (1.493)
Office	-0.387 (0.242)	0.151 (0.230)	0.632** (0.282)	0.0345 (0.316)	-0.121 (0.287)	-0.504 (0.315)	-0.408* (0.245)	-0.129 (0.351)	0.357 (0.832)
Age	0.0332*** (0.00667)	0.00735 (0.00635)	0.00385 (0.00721)	-0.00441 (0.00705)	0.00334 (0.00520)	-0.00552 (0.00672)	0.00842 (0.00638)	-0.00628 (0.00586)	0.0353 (0.0239)
Female	0.00290 (0.143)	0.298** (0.143)	0.284* (0.158)	0.0635 (0.172)	0.113 (0.143)	-0.0573 (0.158)	0.367** (0.144)	0.388** (0.155)	0.468 (0.743)
Observations	254	257	258	256	257	258	257	258	31

Standard errors in parentheses: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1



**Table A2 | Ordered probit regressions on satisfaction responses**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Acoustics	Aesthetics	Air quality	Functionality	Furniture	Lighting	Sustainability	Thermal comfort	Other
Kroon hall	0.779*** (0.223)	1.500*** (0.272)	1.232*** (0.205)	0.836*** (0.246)	0.914*** (0.235)	1.175*** (0.214)	2.254*** (0.289)	0.777*** (0.216)	1.054* (0.612)
Kroon*Office	-1.026*** (0.333)	-0.405 (0.353)	-0.286 (0.316)	-0.512 (0.312)	0.137 (0.330)	-0.852*** (0.307)	-0.659* (0.335)	-0.888*** (0.311)	-6.154*** (1.115)
Office	0.163 (0.237)	-0.156 (0.266)	-0.0620 (0.208)	0.0331 (0.260)	-0.0812 (0.260)	0.177 (0.225)	0.202 (0.267)	0.0272 (0.249)	-0.597 (0.667)
Age	0.00152 (0.00688)	0.00587 (0.00671)	0.00628 (0.00686)	0.0121* (0.00622)	-0.00254 (0.00654)	-0.00590 (0.00637)	0.000516 (0.00649)	0.00411 (0.00709)	-0.00927 (0.0180)
Female	-0.0613 (0.139)	0.121 (0.157)	-0.229 (0.146)	0.150 (0.140)	0.224 (0.144)	0.0851 (0.144)	0.224 (0.153)	-0.00856 (0.140)	-0.547 (0.606)
Observations	254	255	257	255	257	255	257	255	28

Standard errors in parentheses: \*\*\* p&lt;0.01, \*\* p&lt;0.05, \* p&lt;0.1

**Table A3 | Ordered probit regressions on work impact responses**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Acoustics	Aesthetics	Air quality	Functionality	Furniture	Lighting	Sustainability	Thermal comfort	Other
KroonPrimary	0.469** (0.186)	1.721*** (0.248)	0.622*** (0.191)	0.852*** (0.249)	0.883*** (0.253)	1.037*** (0.204)	1.093*** (0.222)	0.560** (0.217)	0.936 (0.669)
KroonOffice	-0.739** (0.300)	-1.025*** (0.340)	0.0152 (0.315)	-0.398 (0.333)	-0.244 (0.324)	-0.725** (0.312)	-0.719** (0.355)	-0.595* (0.327)	-6.772*** (1.019)
Office	-0.278 (0.199)	0.427* (0.258)	-0.282 (0.203)	0.205 (0.243)	0.122 (0.263)	0.0506 (0.205)	0.0589 (0.239)	-0.112 (0.239)	-1.215 (0.757)
Age	0.0146** (0.00620)	0.00842 (0.00766)	0.00615 (0.00653)	0.00469 (0.00599)	0.00638 (0.00611)	0.00359 (0.00664)	0.00548 (0.00831)	0.00751 (0.00655)	0.00985 (0.0197)
Female	-0.0319 (0.132)	0.135 (0.148)	-0.125 (0.136)	0.175 (0.137)	0.216 (0.137)	0.0485 (0.135)	0.227 (0.152)	-0.0405 (0.133)	-0.226 (0.514)
Observations	253	253	252	251	252	252	251	254	27

Standard errors in parentheses: \*\*\* p&lt;0.01, \*\* p&lt;0.05, \* p&lt;0.1

**Table A4 | Ordered probit regressions on time impact responses**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Acoustics	Aesthetics	Air quality	Functionality	Furniture	Lighting	Sustainability	Thermal comfort	Other
KroonPrimary	0.388 (0.247)	1.852*** (0.338)	0.759*** (0.236)	0.737*** (0.270)	0.952*** (0.298)	1.038*** (0.273)	1.408*** (0.310)	0.681*** (0.258)	0.951* (0.475)
KroonOffice	-0.838** (0.333)	-0.621 (0.420)	-0.307 (0.346)	-0.542 (0.344)	-0.699* (0.365)	-0.612* (0.330)	-0.841** (0.425)	-0.917*** (0.342)	-1.483** (0.696)
Office	0.00449 (0.245)	0.0653 (0.362)	-0.0331 (0.254)	0.272 (0.261)	0.479* (0.290)	0.321 (0.250)	0.295 (0.318)	0.230 (0.261)	0.299 (0.498)
Age	0.00570 (0.00640)	-0.00251 (0.00898)	0.00108 (0.00756)	-0.00191 (0.00635)	0.00201 (0.00667)	-0.0101 (0.00688)	-0.00940 (0.00980)	0.0118* (0.00670)	0.0183 (0.0129)
Female	-0.0314 (0.147)	0.0683 (0.158)	0.0203 (0.150)	0.177 (0.142)	0.194 (0.151)	0.165 (0.146)	0.225 (0.173)	0.000384 (0.140)	-0.00859 (0.366)
Observations	246	247	246	247	245	247	242	248	43

Standard errors in parentheses: \*\*\* p&lt;0.01, \*\* p&lt;0.05, \* p&lt;0.1