The Effect of Energy Efficiency Measures on K12 Educational Performance

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Abstract

This is early work. Still much to do.

History of Current Work

- Noticed this when we made SB 1149 improvements on our schools.
- Gave topics to John Bauer, Timothy Hulseman, Virgina Saraswati in Winter 2017 as a topic in Energy Economics
- They learned enough econometrics and did a good enough job to present at an engineering conference.
- This takes a different approach to the same topic.

Background

- Cost effectiveness evaluation requires an evaluation of *all* costs and *all* benefits.
- Not all jurisdictions use "participant benefits" in evaluation of cost effectiveness because they are not enjoyed by the rate payer.
- The "National Efficiency Screening Project" only gives guidance on including non-energy benefits as it explains the symmetry principal, "If you include participant benefits, include participant costs".
- Some jurisdictions, e.g., The Energy Trust of Oregon, are reducing the technical complexity of evaluations to *reduce evaluation costs*

“Reduced Technical Complexity”

- Free ridership/drivership by survey, “Would you have done this without ETO incentives?”
  - Assume people tell the truth.
  - Economists don’t believe that.
- Simpler econometrics
  - No accounting for self-selection bias.
  - No accounting for sampling bias.
  - Stops ‘futzing’

In short, the opposite of what economics is doing with program evaluation, but more inline with engineering approach.

Why the Effect of Energy Efficency on Education is Interesting

- Decisions to improve structures is a financial decision – money saved on energy.
- No financial gain, not allowed to participate.

Improvements in student/staff health and the lifetime effects of academic performance dwarf the value of energy savings.

Daylighting (Sampling)

- D. A. Kleiber and others. "Environmental Illumination and Human Behavior: The Effects of Spectrum of Light Source on Human Performance in a University Setting." (1973)
  - 3 schools
  - Movement to portables.
  - 17% drop
- L. Heschong. "Daylighting in Schools: An Investigation into the Relationship between Daylighting and Human Performance. Detailed Report." (1999).
  - "Data indicate students with the most classroom daylighting progressed 20 percent faster on math tests and 26 percent on reading tests in one year than those with the least."
  - No control for self-selection
  - ~20,000 schools

- L. Heschong, R. L. Wright and S. Okura. "Daylighting impacts on human performance in school". In: *Journal of the Illuminating Engineering Society* 31.2 (2002), pp. 101-114.
  - Positive effect. Scale is dubious.
  - Multiple school districts with various quality of daylighting.
- M. H. Nicklas and G. B. Bailey. "Analysis of the Performance of Students in Daylit Schools." (1996).
  - "... [daylit] schools outperformed students attending artificially lighted schools by 5 to 14 percent."

Indoor Air Quality (Sampling)

- M. J. Mendell and G. A. Heath. "Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature". In: *Indoor air* 15.1 (2005), pp. 27-52.
  - Not all that critical(Three studies of students, x2 from 70s)
  - Summary, something is there but we don't know what it is.
- S. Moonie, D. A. Sterling, L. W. Figgs, et al. "The relationship between school absence, academic performance, and asthma status". In: *Journal of School Health* 78.3 (2008), pp. 140-148.
  - 3K students
  - More absences, lower test scores.
  - Asthma kids have more absences but not lower scores with same absences.

- U. Haverinen-Shaughnessy, D. Moschandreas and R. Shaughnessy. "Association between substandard classroom ventilation rates and students' academic achievement". In: *Indoor air* 21.2 (2011), pp. 121-131.
    - Schools with less than 7.1 l/s/person, i.e., less than ASHRAE Standard 62 in 2004.
    - "... [1 l/s per person] increase in the ventilation rate within that range, the proportion of students passing standardized test (i.e., scoring satisfactory or above) is expected to increase by 2.9% (95%CI 0.9–4.8%) for math and 2.7% (0.5–4.9%) for reading."

In Short

- Students got stuck in the 60s-70s air conditioning daylighting vs air conditioning battle.
- Air quality is important but we don't know exactly what part
    - Keep in mind that allergenic mold concentrations, colony forming bodies per liter, can change by factor of 10 in a few hours.
    - Hard to measure.

Why Oregon Schools?

- Nice features that remove many, but not all, self-selection problems.
- Decision making cutoffs are based on energy savings, not educational outcomes.
- Still problems
  - Data shortcoming ... as we go along.
  - Standardized tests are not standard from year-to-year.
  - Building data is not so important to departments of education.

Now, on to the data ...

SB 1149

- SB 1149 (1999) was Oregon's deregulation bill.
  - It was part of the implementation of FERC 888.
  - Established a public purpose charge that funds thing like The Energy Trust of Oregon.
- The 3% Public Purpose Charge was collected by *almost* all the IOUs.
  - Pacificorp and PGE collect, but Idaho Power in Eastern Oregon does not.
  - Used for Energy Efficiency
  - 10% must be used in schools.

Schools Program

Schools using SB 1149 public purpose funds:

- Complete energy audits of *buildings*, not districts, served by Pacificorp or PGE (with limitations);
- Audits must be completed by an approved audit company;
- Implement the approved Energy Efficiency Measures identified in the audits;
- Report Energy Use Index data in the Schools Interactive Database each year;

Key Points

- Not all districts are eligible.
- Not all schools within districts are eligible.

Makes it easier to establish a natural control group for any treated school by using others in the district.

Educational Funding in Oregon

Oregon Educational Funding has key provisions that makes using schools in other district more attractive than other states.

- 1991 Oregon establishes an Equalization Formula:
  - The legislature establishes a biennial K12 State School Fund Budget
  - The State School Fund budget is distributed equally by student across the state, but adjusted for property tax collections.
  - $1 increase in property tax collected results in $1 less in State School Fund support.
  - Measure 5 and 50 property tax limitations put most of the power with the legislature.
- Result, equal, per-student, funding across the state with a few exceptions:
  - Short-term, 3 year, property tax operating levies.
  - Capital bonds
  - A few, depends on year, school districts with few students but

School District Size

- Oregon has 197 school districts for ∼500K students.
    - Washington has 296 for ∼1M students
- The three largest school districts, Portland Public, Salem-Keizer, and Beaverton are about 40K each.
    - Washington has 9 over 20K
- The remainder are small.

Less opportunity for intra-district funding differences but need to watch the big three.

Key Points

- Management and salary levels may be different across districts
- There are fewer haves and have nots within and between districts than other states.

We can feel more comfortable using schools out of district for controls given equal funding.

The Energy Efficiency Measures (EEMs)

Mostly what you would expect

- Building Envelope, including windows and insulation.
- HVAC Components
- HVAC Controls
- Pumps, Motors and Drives
- Domestic Hot Water
- Lighting
- Kitchen Equipment
- Other (Pool Covers . . .)

What Should Strike you About the List

- Most of the items you would never notice unless you were an expert looking or listening for them.
- There are a few that could have an impact on the educational environment.
  - Double or Triple Glazed Windows (Sound, Moisture Control)
  - Cavity Insulation (Sound, Moisture Control)
  - Lighting Quality Improvements (Daylighting)

Key Points

- Treated schools may or may not have educationally impactful EEMs.
- Treated schools could have a mix.

The non-impactful EEMs can provide a placebo effect robustness check on the effects of the impactful EEMs on educational performance.

How to Measure Educational Impact

- Some of the measures produce environmental improvements, less moisture, mold, we can look at the effect on attendance.
  - Recorded annually for each school.
  - Intermediate indicator. The more often you go to school the better you do.
- Environmental Improvements can reduce teacher absenteeism.
  - Must be acquired district-by-district and year-by-year.
- Some produce better learning environments, less distraction. We can use the annual standardized testing results.
  - Everyone in the same grade takes the same test, but the test, and the levels can be different from year-to-year.

Key Points

- Test scores are the main indicator but for some EEMs, absenteeism and attendance may be good predictors.
- We have some candidates for instruments if we wish to take that route.

Data Details

Schools Program Audit Requirements

- Non-educational buildings and those that are rented or will close in 5 years are ineligible.
- Energy Audits are required
  - Whole Building audits, similar to ASHRAE Level 2. Identify EEMs with 50 year payback or less.
  - Multi-component payback is allowed
  - Targeted Audits are acceptable for limited scope.
  - Target is 47/48 kBTU/SF/Year for elementary and 61/62 kBTU/SF/Year for High Schools
- Multi-competent payback calculations are allowed.

School Program Implementation

- The maximum amount of PPC funds reimbursed will be capped at the total annual savings multiplied by the Measure Life caped at cost.
- Common for some cost to not be funded.
- Commissioning is required for:
  - All boiler or chiller measures exceeding $100,000
  - All other HVAC measures and all HVAC controls measures exceeding $50,000
  - All lighting control measures exceeding $100,000
  - Other measures in which commissioning is critical for successful implementation and operation of the measure, as deemed appropriate by the auditor.

Required Annual Reporting

- Annual energy expenses by fuel type
- Square footage
- Hours of operation

Summary of Measures

Year	Installations
2010	189
2011	92
2012	119
2013	91
2014	81
2015	33
2016	17

Note spikes in installation.

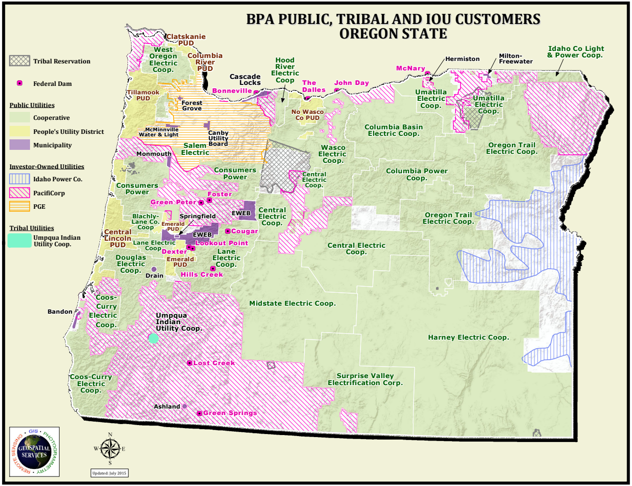
Types of Installed Measures

EEM	Installations
Boiler Equipment	121
Chiller/AC Equipment	3
Controls	44
Distribution System	44
Doors	19
Fixture Modification	100
Flow Issues	2
Heat Recovery Options	3
Insulation	38
Lamp Modification	146
Maintenance	18
Other	47
Windows	37

Comments

- Controls are frequently occupancy sensors and day-lighting controls
- Fixtures are described in detail later as gym, exterior, etc.
- Note that there are large enough numbers of educationally effective and placebo EEMs.

Electric Utilities



BPA 2015

Oregon is a mix

- Most of population is served by IOUs
- Large tracts of COUs
- Only Pacificorp and PGE schools are eligible.

Districts with Eligible Schools

How Many District? Schools? (2016)

- Eligible
  - Districts: 108
  - Schools: 778
- Border (Eligible and ineligible schools in district)
  - Districts: 86
  - With treated schools: 48
- Schools in Border Districts : 934
  - Eligible untreated: 482
  - Eligible treated: 246
  - Ineligible: 206
- Schools in Border Districts with treated schools : 669
  - Eligible untreated: 301
  - Eligible treated: 246
  - Ineligible: 122

Test Scores

There are five tests given over the sample period, school years ending 2010 - 2016.

- English Language Arts 2015-2016
  - Writing 2010 - 2014 (High School Only)
  - Reading 2010 - 2014
- Math
- Science

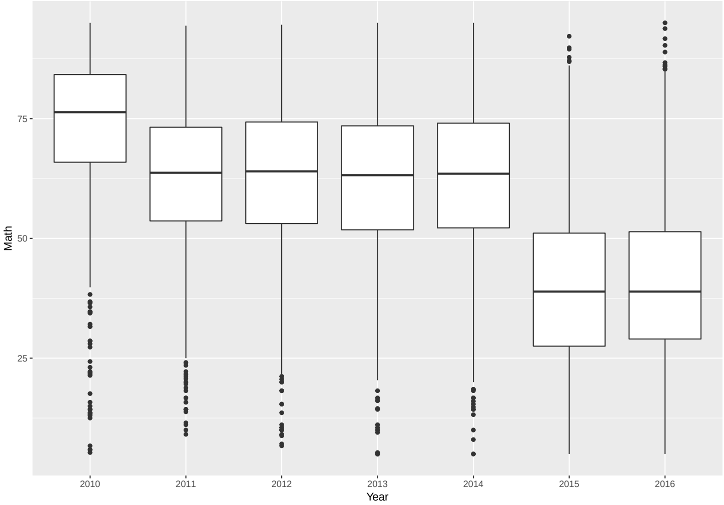
But, some elementary and secondary students will take the high school test.

What is Reported

What is reported is the fraction of students at each school that 'meet standards'.

- That standard changes from year-to-year
- Year is an important control variable, but will be surpressed in later tables

Percent Passing Math By School (State)



Getting at Causality, the Identification Problem

How Different are Treated, Untreated and Ineligible schools?

Ideally, there should be no *observable* difference. As close as you can get to random assignment.

- Dimensions:
  - Current Student Population, free and reduced rate, ethnicity, etc.
  - Prior Test scores (Parallel movement)
  - Facility characteristics
- Problems:
  - Oregon Department of Education discontinued the School Facilities Report in 2002. Only have built and remodel dates before 2001.
  - Current facilities characteristics are *only available for audited buildings in schools*.
    - Schools are collections of buildings, not one, very common to

In short. . .

We can't use building characteristics but we can use student characteristics to model treatment process.

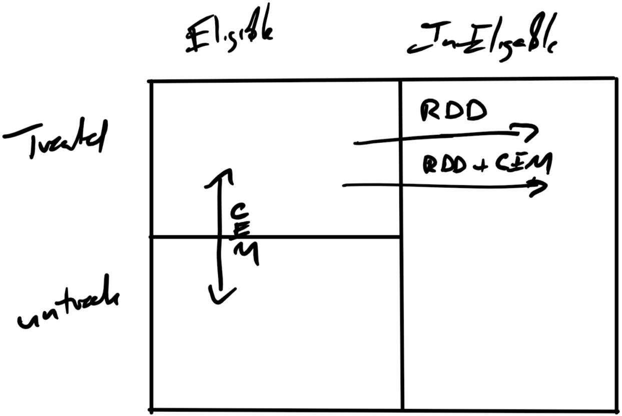
Approaches

- Only looking at schools in districts that have both eligible and ineligible schools
  - Helps control for teacher salaries
  - Other district policies
- Ineligible schools as control
  - *Regession Disontinuity Design* (RDD) with student population controls.
  - Refine with a matching method, *Coarsened Exact Matching* (CEM) and Synthetic Control Method (SCM).
- Eligible but untreated schools as controls
  - CEM
  - SCM

Methods

- Regression Discontinuity Design (RDD)
  - Old. . . 1960
  - Arbitrary line cutting eligible and not.
  - "As good as Randomized Control Design (RCD)" with many caveats.
  - Can be sensitive to specification bias.
- Coarsened exact matching (CEM)
  - Iacus, King, and Porro (2012)
  - Define what you mean by close enough in multiple dimensions
  - Find the close enough match on observable dimensions
  - Reduces sensitivity to specification bias.
- Synthetic control method (SCM)
  - Card, D. and A. Krueger (1994)
  - Mix of differences in differences and matching
  - Weights basket of controls to achieve better results.

Cover Many Different Assumptions about Endogenaity



Simple RDD

- Strong prior that treatment, installing EEMs, is unrelated to student characteristics
- RDD requires at least parallel movement in response, test scores in this case,

Parallel Movement

$$logit(Meet\ Standard) = f(EverTreated, EverTreated * Year; Gender, Race/$$

- Border districts with both treated and untreated eligible schools.
- Only pre-treatement observations of treated schools.
- Simple F-test with and without Eligible

F-Test for Parallel Movement

School Type	Math	Science	ELA	Reading	Writing
High	0.357	0.535	NA	0.258	0.172
Middle	0.862	0.128	NA	0.643	
Elementary	0.878	0.145	0.543	0.825	

- Blanks for non-required tests
- ELA started in 2015, no Middle or High Schools treated.
- Slight concern with Middle and Elementary Science test.

Comments on Demographic Controls

For those that don't work with education data.

- Male: Correlated with lower pass rates.
- Free Reduced: Correlated with lower pass rates.
- Surpressed in later tables

RDD Model Results (Math)

	MathLogit Elementary	Middle	High
FixtureMod	0.110*** (0.039)	0.023 (0.046)	
Lamp	0.029 (0.032)	0.076* (0.045)	0.679 (0.505)
Controls	−0.139 (0.109)	−0.065 (0.116)	0.026 (0.944)
Insulation	−0.049 (0.062)	0.081 (0.085)	
Windows	0.013 (0.054)	0.416*** (0.144)	−0.711 (1.198)
Doors	−0.237*** (0.080)	−0.070 (0.169)	
Boiler	0.051 (0.037)	−0.134*** (0.046)	0.250 (1.228)
Distribution	0.046 (0.058)	0.067 (0.085)	0.352 (0.554)
Chiller	0.050 (0.179)	0.039 (0.231)	
HeatRecovery	0.297** (0.146)		
Flow	−0.481** (0.189)	0.826*** (0.310)	
Other	0.044 (0.053)	0.044 (0.077)	−0.214 (1.002)
Maintenance	0.032 (0.096)	−0.030 (0.078)	
Observations	1,686	896	203
R^2	0.721	0.692	0.545
Adjusted R^2	0.716	0.683	0.497
Residual Std. Error	0.493 (df = 1659)	0.489 (df = 870)	0.853 (df = 183)
F Statistic	164.604*** (df = 26; 1659)	78.066*** (df = 25; 870)	11.526*** (df = 19; 183)

Notes: ***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

RDD Model Results (Science)

	ScienceLogit		
	Elementary	Middle	High
FixtureMod	0.020 (0.052)	0.040 (0.053)	
Lamp	−0.069 (0.042)	0.085 (0.052)	0.378 (0.357)
Controls	−0.207 (0.150)	−0.105 (0.134)	0.771 (0.667)
Insulation	0.080 (0.081)	0.046 (0.098)	
Windows	0.125* (0.071)	0.207 (0.164)	−0.563 (0.847)
Doors	−0.092 (0.104)	0.414** (0.192)	
Boiler	0.051 (0.050)	−0.192*** (0.054)	−0.162 (0.868)
Distribution	−0.063 (0.076)	0.060 (0.097)	0.104 (0.392)
Chiller	0.328 (0.235)	0.499 (0.346)	
HeatRecovery	0.209 (0.191)		
Flow	0.724*** (0.248)	0.805** (0.351)	
Other	0.128* (0.070)	0.002 (0.088)	0.035 (0.708)
Maintenance	0.261** (0.126)	0.047 (0.091)	
Observations	1,590	866	203
R^2	0.540	0.548	0.421
Adjusted R^2	0.533	0.535	0.361
Residual Std. Error	0.646 (df = 1563)	0.554 (df = 840)	0.603 (df = 183)
F Statistic	70.646*** (df = 26; 1563)	40.756*** (df = 25; 840)	7.014*** (df = 19; 183)

Notes: ***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

RDD Model Results (ELA)

	ELALogit		
	Elementary	Middle	High
FixtureMod	0.033 (0.057)	−0.027 (0.070)	
Lamp	0.038 (0.053)	−0.002 (0.072)	0.135 (0.870)
Controls	−0.300 (0.435)	−0.379 (0.404)	
Insulation	−0.042 (0.074)	0.101 (0.106)	
Windows	0.100 (0.073)	0.205 (0.190)	0.007 (1.249)
Doors	−0.071 (0.088)	−0.092 (0.201)	
Boiler	0.063 (0.053)	−0.164** (0.064)	
Distribution	0.023 (0.073)	0.090 (0.106)	
Chiller	0.131 (0.219)	−0.110 (0.216)	
HeatRecovery	0.465** (0.192)		
Flow	−0.310 (0.302)	0.773** (0.339)	
Other	−0.022 (0.067)	−0.110 (0.099)	
Maintenance	0.046 (0.132)	0.117 (0.111)	
Observations	480	260	58
R^2	0.676	0.662	0.426
Adjusted R^2	0.661	0.633	0.304
Residual Std. Error	0.418 (df = 458)	0.397 (df = 239)	0.864 (df = 47)
F Statistic	45.505*** (df = 21; 458)	23.368*** (df = 20; 239)	3.486*** (df = 10; 47)

Notes: ***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

RDD Model Results (Reading)

	ReadingLogit		
	Elementary	Middle	High
FixtureMod	0.051 (0.046)	0.027 (0.045)	0.113 (0.112)
Lamp	0.013 (0.035)	0.162*** (0.044)	0.099 (0.076)
Controls	−0.110 (0.106)	−0.059 (0.099)	−0.052 (0.330)
Insulation	−0.150* (0.083)	0.051 (0.097)	−0.241 (0.168)
Windows	−0.052 (0.064)	0.232 (0.156)	0.165 (0.122)
Doors	−0.281** (0.126)	−0.169 (0.208)	−0.273 (0.273)
Boiler	0.075* (0.043)	−0.142*** (0.048)	−0.082 (0.085)
Distribution	−0.016 (0.072)	0.014 (0.093)	−0.318* (0.167)
Chiller	0.019 (0.230)	−0.133 (0.422)	
HeatRecovery	0.336* (0.176)		0.714* (0.367)
Flow	−0.186 (0.204)	0.637 (0.418)	
Other	0.135** (0.066)	0.130 (0.083)	0.270* (0.158)
Maintenance	0.008 (0.113)	0.016 (0.078)	0.011 (0.158)
Observations	1,169	634	361
R^2	0.666	0.627	0.616
Adjusted R^2	0.659	0.613	0.591
Residual Std. Error	0.449 (df = 1144)	0.402 (df = 610)	0.507 (df = 338)
F Statistic	95.194*** (df = 24; 1144)	44.641*** (df = 23; 610)	24.694*** (df = 22; 338)
Notes:	***Significant at the 1 percent level.		
	**Significant at the 5 percent level.		
	*Significant at the 10 percent level.		

RDD Model Results (Writing)

	WritingLogit		
	Elementary	Middle	High
FixtureMod	0.200** (0.098)	−0.060 (0.096)	
Lamp	0.106 (0.069)	0.041 (0.087)	1.210*** (0.345)
Controls	0.037 (0.290)	−0.156 (0.225)	−0.182 (0.611)
Insulation	0.292 (0.289)	−0.150 (0.271)	
Windows	−0.203 (0.166)	0.325 (0.455)	−2.608*** (0.807)
Doors			
Boiler	0.246 (0.150)	−0.119 (0.164)	0.476 (0.772)
Distribution	−0.310 (0.190)	−0.344 (0.233)	0.865** (0.405)
Chiller			
HeatRecovery			
Flow	−0.187 (0.389)		
Other	0.176 (0.183)	−0.316* (0.175)	0.100 (0.770)
Maintenance	−0.094 (0.237)	0.079 (0.160)	
Observations	484	279	142
R^2	0.537	0.556	0.564
Adjusted R^2	0.516	0.522	0.504
Residual Std. Error	0.545 (df = 462)	0.508 (df = 258)	0.536 (df = 124)
F Statistic	25.477*** (df = 21; 462)	16.186*** (df = 20; 258)	9.426*** (df = 17; 124)
Notes:	***Significant at the 1 percent level.		
	**Significant at the 5 percent level.		
	*Significant at the 10 percent level.		

RDD Model Results (Attendance)

	AttendanceLogit		
	Elementary	Middle	High
FixtureMod	−0.007 (0.020)	−0.026 (0.032)	
Lamp	−0.016 (0.017)	−0.001 (0.033)	0.747 (0.550)
Controls	−0.100* (0.060)	−0.098 (0.098)	
Insulation	−0.000 (0.027)	0.006 (0.054)	
Windows	−0.025 (0.026)	0.003 (0.092)	−0.907 (0.845)
Doors	−0.056* (0.033)	0.054 (0.099)	
Boiler	0.011 (0.018)	0.059* (0.031)	
Distribution	−0.022 (0.026)	−0.092* (0.052)	0.731 (0.571)
Chiller	−0.089 (0.081)	−0.102 (0.122)	
HeatRecovery	−0.032 (0.066)		
Flow	0.387*** (0.103)	0.315* (0.187)	
Other	0.021 (0.024)	0.101** (0.050)	0.167 (0.548)
Maintenance	−0.005 (0.049)	−0.104* (0.054)	
Observations	727	391	90
R^2	0.391	0.275	0.447
Adjusted R^2	0.372	0.234	0.352
Residual Std. Error	0.174 (df = 704)	0.229 (df = 369)	0.439 (df = 76)
F Statistic	20.523*** (df = 22; 704)	6.673*** (df = 21; 369)	4.718*** (df = 13; 76)
Notes:	***Significant at the 1 percent level.		
	**Significant at the 5 percent level.		
	*Significant at the 10 percent level.		