THE ECONOMICS OF GASOLINE REGULATION: PRICE IMPACTS AND CONSUMER COSTS OF ENVIRONMENTAL AIR QUALITY PROGRAMS

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Master of Science

by

Michael Henry Gadsden

August 2011

ABSTRACT

This research examines economic impacts of two gasoline regulations designed to combat tropospheric ozone pollution. I construct several fixed effects econometric models to assess impacts of reformulated gasoline and low volatility gasoline on retail gasoline prices and consumer costs. I estimate that reformulated gasoline has had a positive and statistically significant impact on real fuel prices of approximately 3.4 to 6.0 cents per gallon. I estimate that federal low volatility gasoline has had an insignificant price impact of 0.0 to 0.8 cents per gallon, but find that state-level controls more stringent than federal standards may have increased prices by over 8.0 cents per gallon. I also find that both reformulated gasoline and low volatility gasoline price effects likely vary substantially between cities. I present a framework for examining changes in welfare and estimate that over 15 years the reformulated gasoline program has cost consumers between $15.1 billion and $39.0 billion.

BIOGRAPHICAL SKETCH

The author, eldest of three children, was born to devoted parents and raised outside of Philadelphia, PA. He first developed a love of learning while a student at the Gladwyne Elementary School and later at the Episcopal Academy.

His first foray into economics was in the third grade in Mrs. Stockdale's challenge class. There, the class developed its own monetary system (known as "Busy Bucks") and established a market for consumer products. However, Michael quickly squandered his phony currency on such essential luxury goods as a rubber band ball and a hula hoop. While in elementary school, the author also established a "company" called Extermos which sold homemade "insecticide" produced from his friend Philip's mother's kitchen supplies. Upon the well-intentioned advice of his father, Michael hatched an ill-conceived plan to raise equity in his new venture by selling shares of "stock" to his uncle. Although his IPO was vastly successful and raised a whopping $7.50, stock sales quickly eclipsed product sales as his main (i.e. only) revenue stream. Additionally, dividends payable accrued rapidly and to this day have not been paid. Being a private business, Extermos was never audited by the SEC and Michael's Uncle Chris (a philanthropic family man) never filed investor fraud charges regarding this shameless Ponzi scheme. Nevertheless, after his initial economic and financial catastrophes, the author did not pursue the dismal science as a course of academic study until graduate school.

In the meantime, Michael spent many youthful summers in Wyoming and developed a great passion for the outdoors. This led him to Dartmouth College, where he earned a bachelor's degree in Environmental Studies and worked on a volunteer ski patrol. He also spent semesters roaming the outback of Western Australia with the National Outdoor Leadership School and traveling around southern Africa on a Big Green foreign study program. After a brief stint in DC as a hydrogeologist, Michael moved to Victor, Idaho to pursue his dream of skiing in the Tetons. Knowing he was destined for bigger and better things than cashiering and stocking shelves at a local grocery market, he spent two summers leading wilderness trips for high school students in

Alaska and Wyoming. He became intrigued by the concepts of ecological economics as well as alternative energy and decided to pursue a graduate degree.

Attracted magnetically to Ithaca by the brutal, Hanover-like winters and the fact that his favorite Grateful Dead recording had taken place in Barton Hall, Michael fortunately ended up at Cornell in the Department (soon to become "School") of Applied Economics and Management. There, he had the great honor to work as a teaching assistant for Greg Poe, David Lee and Dave Taylor. He also had the amazing opportunity to work on energy and climate change policies as an intern at the White House Council on Environmental Quality during the spring semester of his second year. Michael had a wonderful time in Ithaca and is sad to be leaving his friends and colleagues. However, he is excited to pursue a career in the energy sector where he hopes to focus on renewable electricity.

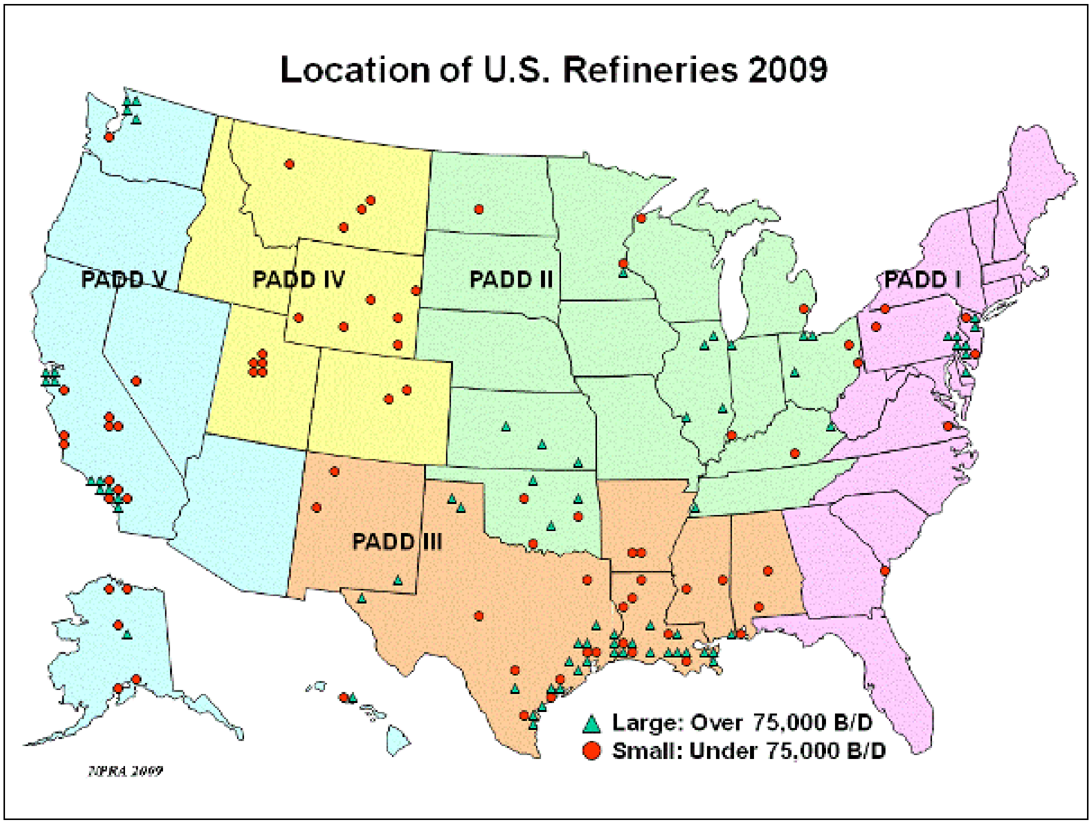
ACKNOWLEDGMENTS

First and foremost, I would like to thank my thesis advisors, Antonio Bento and Dick Boisvert, without whose generous and patient assistance the production of this document would not have been possible. Thanks also to Greg Poe for his personal support, friendship and advice. I would additionally like to thank Linda Morehouse for all of her help navigating the waters of Caldwell Hall. Thanks also to all of my other friends and colleagues in the Dyson School who have supported me in this effort – you know who you are. Finally, thanks to my loving parents, brother and sister for always supporting me and providing companionship throughout the adventure of life.

TABLE OF CONTENTS

LIST OF FIGURES

Figure 1



Source: National Petrochemical & Refiners Association

Figure 2

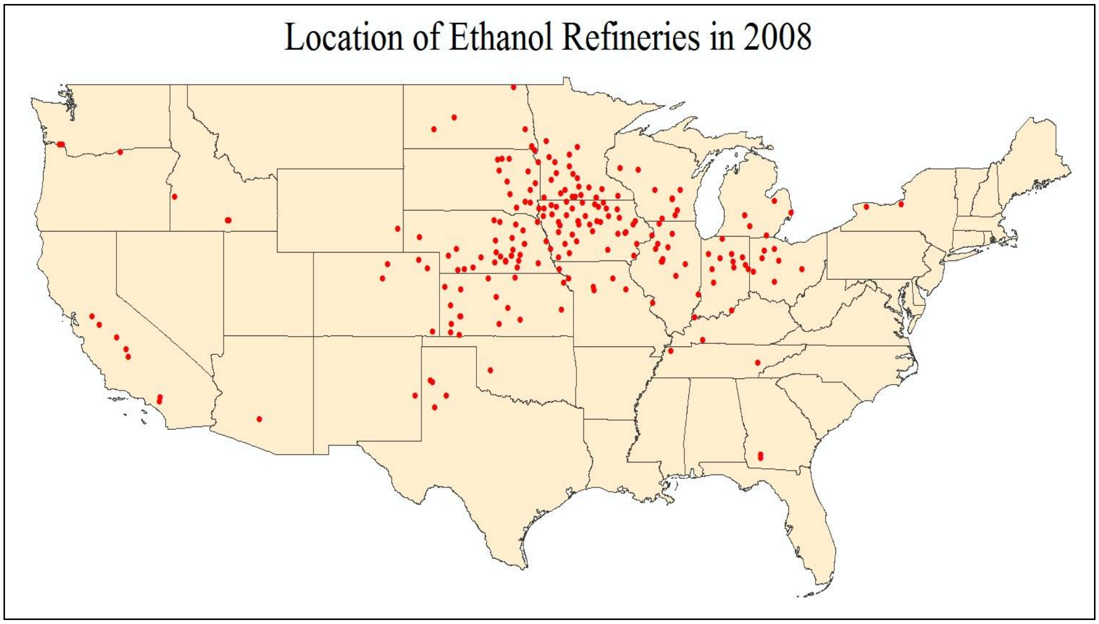


Figure 3

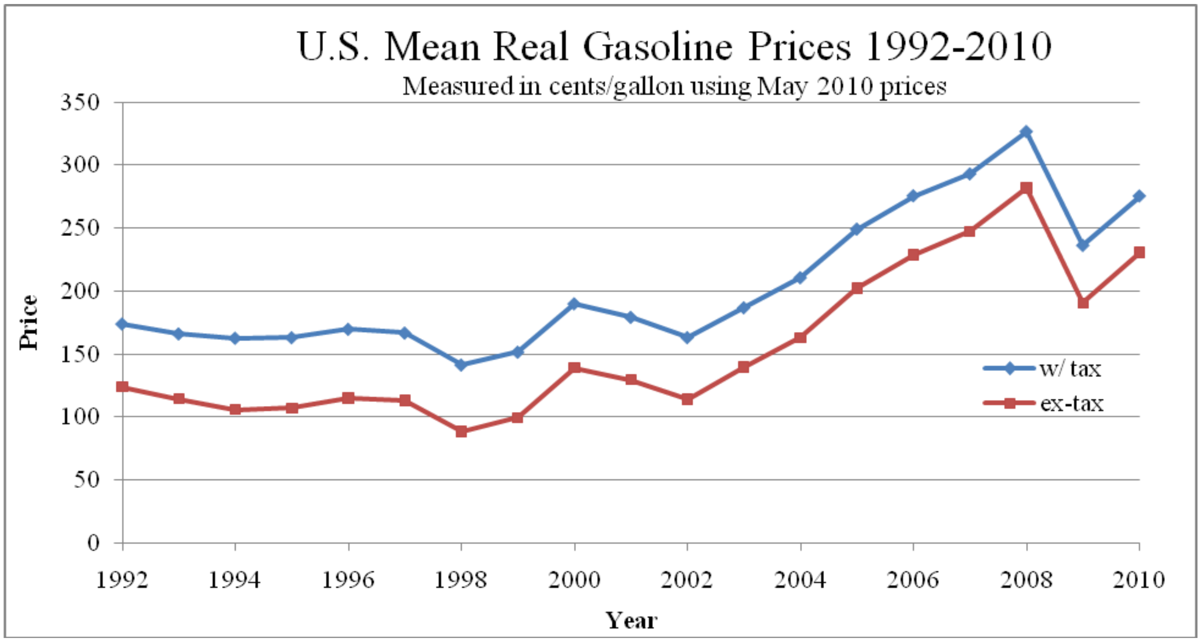


Figure 4

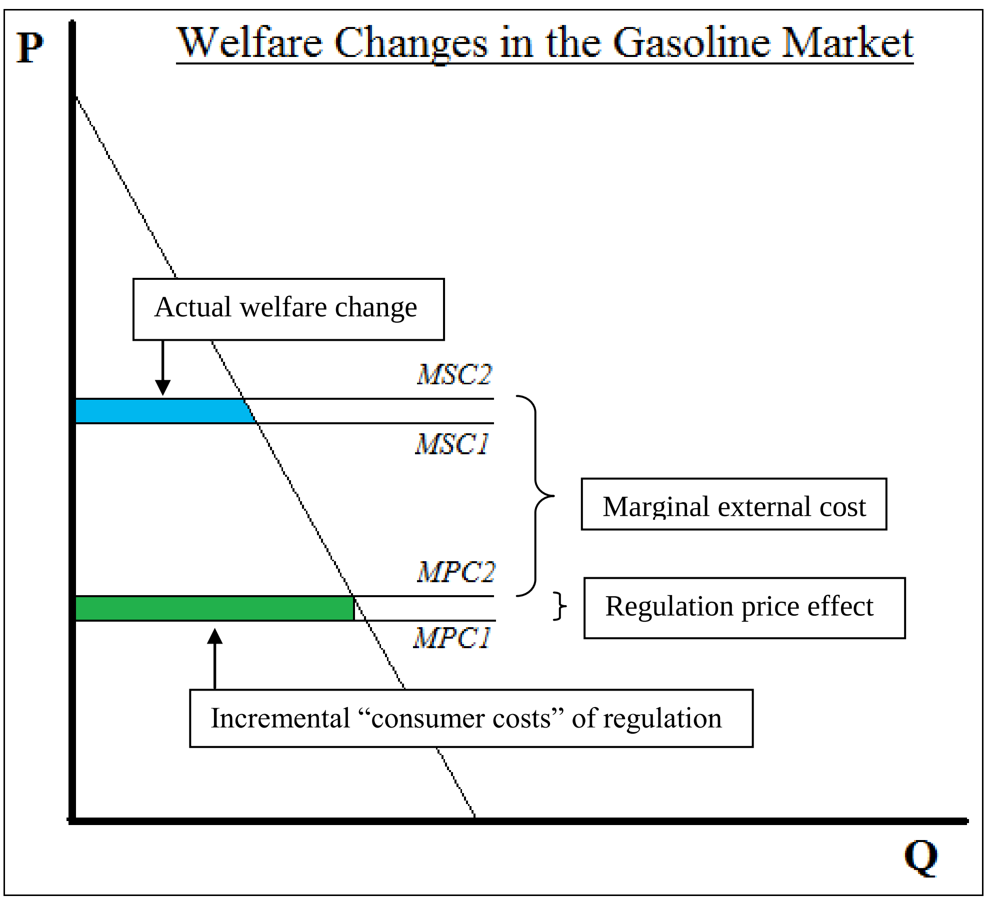
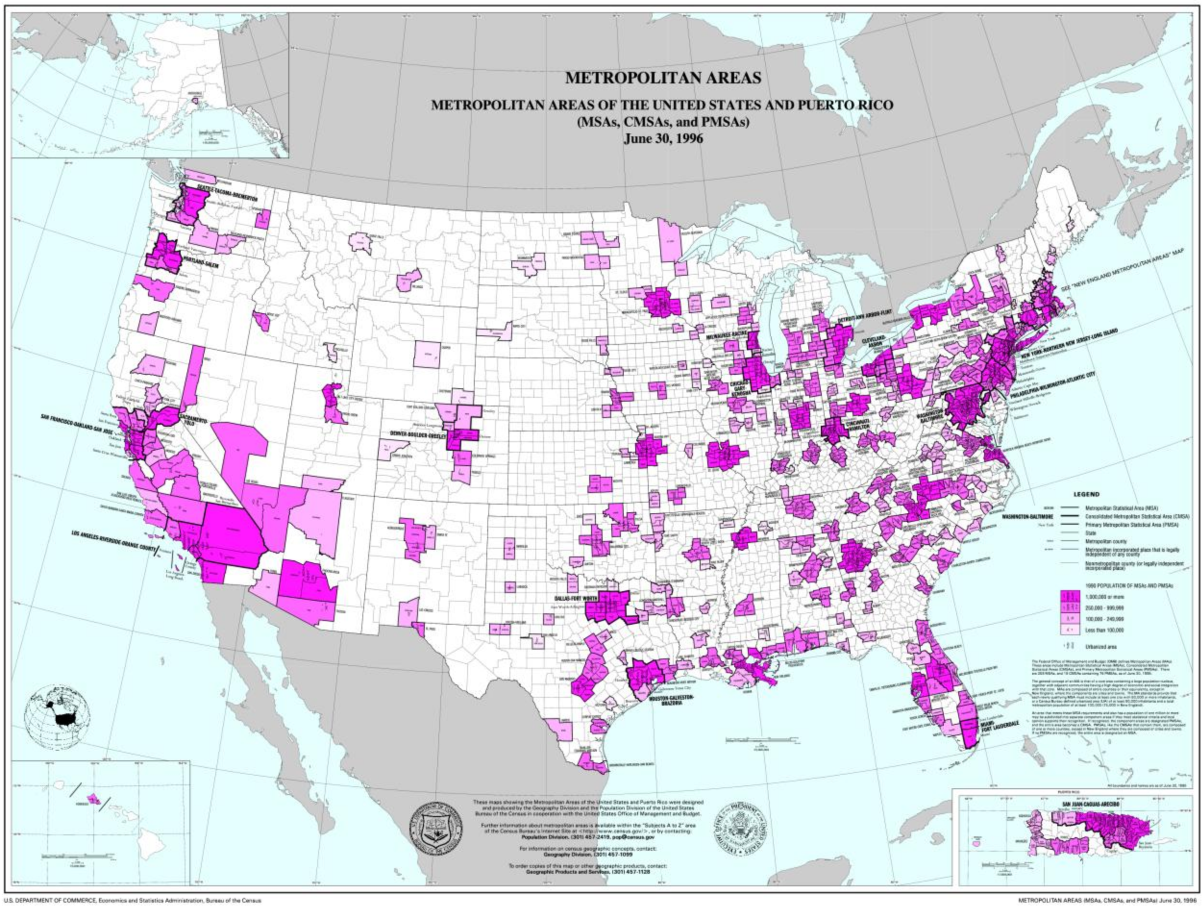


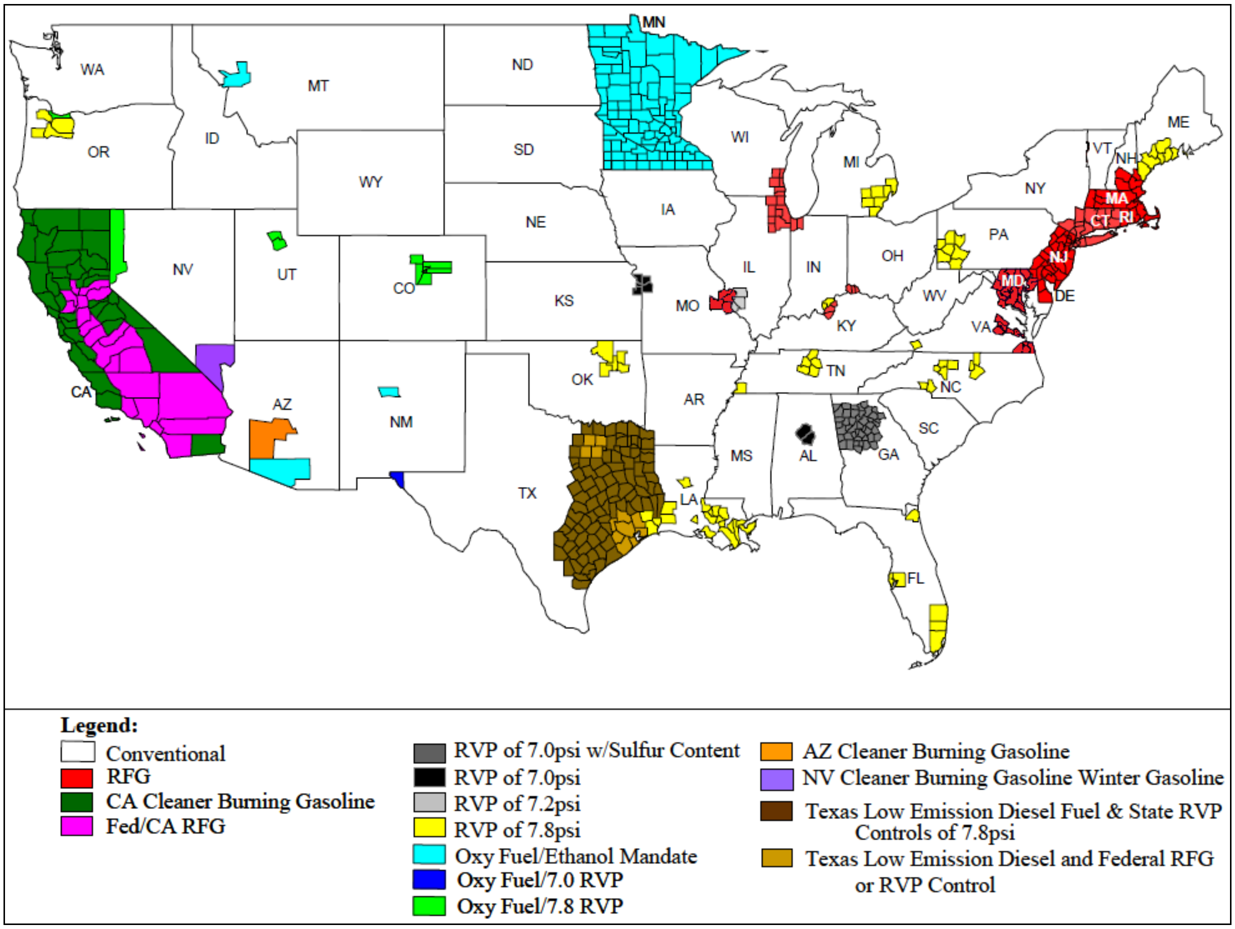
Figure 5



Source: U.S. Census Bureau

Figure 6

Selected Gasoline Regulations as of December 2006



Adapted from: "EPAct Section 1541(c) Boutique Fuels Report to Congress" (U.S. Environmental Protection Agency and U.S. Department of Energy)

LIST OF TABLES

Table 1

City Mean Real Gasoline Prices 1992-2010

Measured in cents/gallon; Prices in May 2010 terms

City	*Price (w/tax)*	*City*	*Price (ex-tax)*
Chicago	228.88	Chicago	171.17
Seattle	221.39	Portland	168.30
Portland	220.79	Seattle	165.68
New York	220.42	Washington, D.C.	162.31
Buffalo	213.01	New York	159.05
Washington, D.C.	209.70	Newark	158.65
Miami	207.95	Boston	156.53
Milwaukee	206.96	Denver	155.33
Boston	206.61	Louisville	154.54
Denver	205.33	Albuquerque	154.51
Philadelphia	205.25	Cheyenne	154.11
Salt Lake City	202.99	Miami	153.97
Pittsburgh	201.87	Salt Lake City	152.23
Cleveland	201.68	Buffalo	151.71
Minneapolis – St. Paul	201.31	Minneapolis – St. Paul	151.41
Baltimore	200.73	Philadelphia	150.49
Omaha	200.68	Cleveland	149.82
Albuquerque	199.90	Baltimore	149.05
Detroit	198.83	Milwaukee	148.96
Louisville	198.72	Norfolk	148.73
Newark	198.68	Atlanta	148.48
New Orleans	195.98	St. Louis	148.46
Indianapolis	195.66	New Orleans	148.43
Dallas – Fort Worth	195.59	Dallas – Fort Worth	148.09
Des Moines	194.59	Pittsburgh	147.13
Norfolk	194.36	Birmingham	146.78
Birmingham	193.93	Omaha	146.75
Memphis	193.51	Des Moines	145.67
Little Rock	192.37	Indianapolis	145.20
Houston	192.02	Little Rock	145.09
Cheyenne	191.35	Kansas City	144.86
Wichita	191.34	Houston	144.52
St. Louis	191.17	Memphis	144.27
San Antonio	190.68	Detroit	144.17
Kansas City	188.93	San Antonio	143.19
Atlanta	188.20	Wichita	142.67
Oklahoma City	184.74	Oklahoma City	141.17
Tulsa	183.28	Tulsa	139.70

Table 2

Independent Variable	I	II	III	IV	V	VI	VII	VIII	IX	X
RFG	5.96	6.49	6.31	6.01	6.57	(dropped)	3.41	4.38	(dropped)	7.38
	(2.26)	(2.46)	(0.00)	(0.57)	(0.55)		(0.28)	(0.26)		(2.16)
RVP ≤ 7.8 psi	0.67	1.12	-4.00	0.75	1.35	-4.00	0.00	0.13	-0.27	
	(1.69)	(2.90)	(1.26)	(0.49)	(0.69)	(1.96)	(0.22)	(0.26)	(0.35)	
RVP = 7.8 psi										0.55
										(1.59)
RVP ≤ 7.2 psi										8.02
										(2.39)
Constant	117.49	103.47	216.71	115.81	115.59	138.22	222.78	137.28	117.54	117.23
City Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	No	No	No	No	No	No	Yes
Monthly Time Trend	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Summer Subset	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
Error Term Clustering	State	State	State	City	City	City	City	City	City	State
Observations	10373	5129	5244	10373	5129	5244	36700	17859	18841	10373
R-Squared	0.97	0.79	0.95	0.97	0.68	0.97	0.96	0.70	0.96	0.97
Date Range of Data	1992-2010	1992-2000	2001-2010	1992-2010	1992-2000	2001-2010	1992-2010	1992-2000	2001-2010	1992-2010

Notes

1. Numbers in parentheses are standard errors calculated by clustering at the state or city level.
2. Columns I, II, III present results from the Basic Model, which used city and year fixed effects with summer-subetted data.
3. Columns IV, V, VI present results from the Monthly Time Trend Model using summer-subsetted data.
4. Columns VII, VIII, IX present results from the Monthly Time Trend Model using full-year data.
5. Column X presents results from the Multiple RVP Regulations Model, which contained separate independent variables for RVP=7.8 and RVP≤7.2.
6. The RFG variable was dropped by the computer in regressions VI and IX due to multicolinearity between the regulation and the fixed effects.

Table 3

Basic Model: City Fixed Effects Estimates

Measured in cents/gallon; Prices in May 2010 terms

	1992-2000	*2001-2010*
Albuquerque	16.38	10.58
Atlanta	3.70	12.07
Baltimore	3.75	1.61
Birmingham	6.46	6.63
Boston	14.21	7.13
Buffalo	18.44	3.27
Cheyenne	20.19	10.66
Chicago	30.16	26.02
Cleveland	11.88	5.58
Dallas – Fort Worth	5.09	1.99
Denver	15.96	19.83
Des Moines	7.93	3.49
Detroit	6.62	8.02
Houston	(dropped)	(dropped)
Indianapolis	8.31	1.26
Kansas City	8.30	6.84
Little Rock	6.85	1.47
Louisville	13.95	6.89
Memphis	6.24	3.38
Miami	18.72	11.24
Milwaukee	7.15	-1.30
Minneapolis – St. Paul	13.90	4.55
New Orleans	10.05	6.52
New York	24.20	3.11
Newark	15.94	7.41
Norfolk	7.04	-1.42
Oklahoma City	3.40	-1.72
Omaha	12.34	0.79
Philadelphia	6.86	1.97
Pittsburgh	10.39	5.21
Portland	30.68	26.72
Salt Lake City	16.19	13.64
San Antonio	5.66	3.16
Seattle	27.90	24.39
St. Louis	8.53	-0.56
Tulsa	3.52	(dropped)
Washington, D.C.	14.34	15.46
Wichita	7.59	-2.95

Table 4

City-Specific Regulatory Price Effect Estimates Measured in cents/gallon; Prices in May 2010 terms			
RFG interacted with	Baltimore	10.70	(1.35)
	Boston	8.76	(1.35)
	Chicago	19.32	(1.35)
	Dallas-Ft. Worth	4.67	(1.35)
	Houston	9.21	(1.35)
	Louisville	11.16	(1.35)
	Milwaukee	0.67	(1.35)
	New York	-11.45	(1.35)
	Newark	-0.62	(1.35)
	Norfolk	6.00	(1.35)
	Philadelphia	5.44	(1.35)
	St. Louis	2.10	(0.94)
	Wash., D.C.	16.29	(1.35)
RVP interacted with	Atlanta	4.22	(0.00)
	Birmingham	2.82	(0.00)
	Dallas-Ft. Worth	1.22	(1.12)
	Denver	4.44	(1.06)
	Detroit	9.74	(1.19)
	Houston	-6.10	(1.12)
	Kansas	3.83	(0.00)
	Memphis	1.06	(0.00)
	Miami	11.20	(0.00)
	New York	4.53	(0.00)
	Pittsburgh	-2.23	(0.95)
	Portland	24.94	(0.00)
	Salt Lake City	11.17	(0.00)
	San Antonio	0.73	(0.85)
	Tulsa	-0.28	(0.85)
Constant		79.59	(0.73)
City Fixed Effects		Yes	
Year Fixed Effects		Yes	
Monthly Time Trend		No	
Summer Subset		Yes	
Error Term Clustering		City	
Observations		10373	
R-Squared		0.97	
Date Range of Data		1992-2010	

Table 5

MTBE Bans		
Sample City	*State*	*Date of State MTBE Ban*
Omaha	NE	July 13, 2000
Denver	CO	April 30, 2002
Detroit	MI	June 1, 2003
Buffalo	NY	January 1, 2004
New York	NY	January 1, 2004
Seattle	WA	January 1, 2004
Wichita	KS	July 1, 2004
Chicago	IL	July 24, 2004
Indianapolis	IN	July 24, 2004
Milwaukee	WI	August 1, 2004
Cleveland	OH	July 1, 2005
Minneapolis – St. Paul	MN	July 2, 2005
Kansas City	MO	July 31, 2005
St. Louis	MO	July 31, 2005
Louisville	KY	January 1, 2006
Newark*	NJ	January 1, 2009

* Not included in specification test because date of MTBE ban was outside date range

Table 6

Welfare Analysis Results: RFG Program All numbers are cumulative values for years 1995-2010; Prices in May 2010 terms		
	Lower Bound	*Upper Bound*
Direct Change in Consumer Welfare (million $)	15,149	39,030
Change in Gasoline Consumption (million gallons)		
Elasticity (η) = -0.23	2,381	6,155
Elasticity (η) = -0.43	4,451	11,506

Table 7

CMSA / MSA	Modeled RFG Gasoline Consumption (billion gallons)																Sample Cities	Mean RFG Price Effect (¢/gal)	Consumer Costs (million $)
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Total			
Boston–Worcester–Lawrence, MA–NH–ME–CT	1.62	1.59	1.57	1.53	1.54	1.49	1.48	1.49	1.51	1.53	1.54	1.60	1.62	1.63	1.64	23.38	Boston	8.76	2,048.26
Chicago–Gary–Kenosha, IL–IN–WI	2.55	2.45	2.36	2.24	2.19	2.07	1.99	1.97	1.97	1.95	1.94	1.98	1.97	1.96	1.93	31.53	Chicago	19.32	6,090.51
Dallas–Fort Worth, TX	1.99	1.99	1.98	1.98	1.95	1.99	1.96	1.95	1.92	1.91	1.88	1.86	1.88	1.86	1.82	28.94	Dallas - Ft. Worth	4.67	1,350.68
Houston–Galveston–Brazoria, TX	1.56	1.53	1.50	1.46	1.46	1.42	1.40	1.37	1.36	1.33	1.31	1.29	1.30	1.27	1.24	20.79	Houston	9.21	1,915.24
Louisville, KY–IN	N/A	N/A	N/A	N/A	N/A	N/A	0.26	0.25	0.25	0.24	0.23	0.22	0.21	0.21	0.20	2.07	Louisville	11.16	230.76
Milwaukee–Racine, WI	0.35	0.37	0.39	0.41	0.43	0.45	0.47	0.45	0.43	0.42	0.40	0.38	0.37	0.35	0.34	6.02	Milwaukee	0.67	40.43
New York–Northern New Jersey–Long Island,NY–NJ–CT–PA	2.98	3.08	3.18	3.24	3.40	3.45	3.56	3.67	3.73	3.84	3.91	3.99	4.16	4.23	4.29	54.71	New York; Newark	(6.04)	(3,301.96)
Norfolk–Virginia Beach–Newport News, VA–NC	0.43	0.44	0.45	0.46	0.46	0.47	0.49	0.47	0.46	0.44	0.43	0.42	0.41	0.40	0.39	6.61	Norfolk	6.00	396.52
Philadelphia–Wilmington–Atlantic City,PA–NJ–DE–MD	1.92	1.81	1.70	1.58	1.50	1.40	1.27	1.30	1.32	1.35	1.37	1.39	1.44	1.46	1.49	22.30	Philadelphia	5.44	1,212.39
St. Louis, MO–IL	0.00	0.00	0.00	0.00	0.87	0.81	0.73	0.79	0.84	0.91	0.96	1.02	1.09	1.15	1.19	10.35	Saint Louis	2.10	217.61
Washington–Baltimore, DC–MD–VA–WV	2.92	2.83	2.74	2.62	2.58	2.45	2.37	2.36	2.32	2.30	2.27	2.24	2.26	2.22	2.18	36.67	Baltimore; Washington, D.C.	13.49	4,948.09
Total	16.32	16.10	15.88	15.51	16.39	16.00	15.97	16.06	16.09	16.21	16.25	16.39	16.73	16.75	16.72	243.37	**"Lower Bound" Consumer Costs (million $)**		**15,149**
Actual RFG Consumption (from EIA)	30.88	36.73	39.13	40.71	42.34	42.46	42.93	44.85	45.92	47.17	47.57	47.57	47.41	47.58	47.24	650.49	**"Upper Bound" Consumer Costs (million $) **Assuming $0.06/gallon RFG price effect****		**39,030**

CHAPTER 1

INTRODUCTION AND MOTIVATION

To comply with national air quality legislation, federal and state regulators have enacted various controls on the content and attributes of liquid fuels. Since the combustion of motor gasoline is a large contributor to the emissions and formation of both criteria and hazardous air pollutants,[1] the characteristics of this prized and ubiquitous[2] commodity are highly controlled in many localities. Two regulations designed to address the problem of tropospheric ozone pollution have had a particularly widespread and longstanding influence on fuel markets and the greater national economy: low volatility gasoline and reformulated gasoline. The former regulation places an upper limit to the reid vapor pressure of affected motor gasoline during summer months to limit the evaporation of volatile organic compounds – precursor pollutants to ozone formation. Reformulated gasoline is more stringent fuel regulation that limits the vehicular emissions of nitrogen oxides and air toxics, as well as volatile organic compounds.

Since the late 1980s, hundreds of counties in dozens of states have adopted the use of low volatility gasoline during the summer months. Since 1995, over 15 large metropolitan areas have required the year-round use of federal reformulated gasoline. In 2009, reformulated gasoline represented over one third of all motor gasoline supplied to U.S. markets (U.S. Energy Information Administration).

---

[1] "Criteria" air pollutants are the six pollutants (including ozone) for which the United States Environmental Protection Agency has determined National Ambient Air Quality Standards. According to EPA: "Hazardous air pollutants, also known as toxic air pollutants or air toxics, are those pollutants that cause or may cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental and ecological effects" <http://www.epa.gov/ttnatw01/pollsour.html>.

[2] In 2009 alone, U.S. consumers used over 137 billion gallons of motor gasoline (U.S. Energy Information Administration).

Given these command-and-control air quality regulations, it is important to understand their marginal costs, benefits and distributive impacts in order to achieve equitable and economically efficient pollution abatement at least cost. While a few studies have attempted to quantify the costs and benefits of the Clean Air Act as a whole, little work has focused specifically on individual fuel-based regulations. Research which has examined low volatility and reformulated gasoline programs has often exhibited a shortage of price and regulatory data (including limited frequency of observations, coarse spatial granularity, and short timeframes of observation) and overly complicated and subjective statistical models. Most research which has estimated cent per gallon price impacts of fuel regulations provides no welfare or cost-benefit calculations.

This thesis is an attempt to address a few of these failures. My work draws heavily from past economic analyses focused on the impacts of gasoline regulations on fuel prices. It both corroborates earlier findings using straightforward methodology and builds upon previous work by using enhanced data and by analyzing a few measures of costs and benefits. By strengthening the analysis and discussion of motor fuel controls, I hope to inform better policy making and encourage more comprehensive analysis of environmental regulatory programs.

A main focus of this study is to determine more accurately the effect that low volatility and reformulated gasoline regulations have had on retail gasoline prices in the United States from 1992 until the present. First and foremost, this research attempts to answer the question of whether these regulations have had any impacts at all on real retail gasoline prices. If so, are these impacts measurable at credible level of statistical significance? The paper also estimates the magnitude and direction of these impacts and whether they vary across time and space. It also attempts to answer the question of whether or not ethanol blending has had a significant impact on gasoline prices. While other literature has focused on distinguishing the precise underlying causes of price changes due to regulation, this research takes a broader view by measuring the average price impacts of regulation with less regard to the potential economic mechanisms (such as market power and geographic segmentation) driving these changes. The secondary emphasis of this study is to conduct a basic analysis of changes in consumer costs and to qualitatively assess the cost-effectiveness of fuel-based regulatory programs.

My work primarily consists of several multivariate statistical models which are used to determine both average and localized price effects of fuel regulations. These models utilize a fixed effects panel structure with over 18 years of regulatory data and weekly retail gasoline prices. They find that the reformulated gasoline program has raised real consumer prices in regulated areas by an average of 3.4 to 6.0 cents per gallon. The models find an insignificant price impact of average low volatility gasoline of between 0.0 and 0.8 cents per gallon, but suggest that state-level controls more stringent than federal standards may increase prices by over 8.0 cents per gallon.

Additionally, in the Discussion chapter, I present a conceptual welfare framework for evaluating aggregate economic impacts of these fuel regulations. I develop a simple model which uses my estimated price effects as parameters to calculate changes in consumer costs – one important component of the welfare framework. This allows for some basic insights concerning the overall economic cost-effectiveness of the reformulated gasoline program. I find that reformulated gasoline regulations have cumulatively raised consumer costs by anywhere from $15.1 billion to $39.0 billion over the more than 15 years of program implementation. Based on EPA's value of a statistical life and non-monetized health benefits data, I tentatively conclude that the reformulated gasoline program has increased the nation's net economic welfare.

While I do not explicitly model or assess low volatility gasoline for cost and welfare impacts, I suggest that this program could potentially have neutral or even negative welfare implications. A recent study has suggested that most low volatility gasoline is ineffective at reducing ambient ozone concentrations in regulated areas (Auffhammer and Kellogg). If this finding is accurate, traditional volatility regulation as a means to control ozone may impose high costs to society with few economic benefits. If the Environmental Protection Agency finalizes its proposed rulemaking (U.S. Environmental Protection Agency "NAAQS *2010*" 2938-3052) to reduce the National Ambient Air Quality Standard for 8-hour ozone from 0.075 ppm to a level between 0.06 and 0.07 ppm, many additional counties will fall into non-attainment designation. Since volatility and other fuel-based controls are relatively simple, politically favorable, and perceivably inexpensive to implement (compared to costly stationary source retrofits), state and federal regulators may vastly expand the range of these regulations in attempt to reduce ozone in newly non-compliant counties. The concern that this action may increase costs without conferring benefits adds to the existing imperative for solid research regarding the economic impacts of specific fuel-based regulations.

CHAPTER 2

BACKGROUND

This chapter presents an introduction to the problem of ozone pollution and the means by which policymakers have attempted to reduce its ambient concentration through the regulation of motor fuels. After a discussion of the science and problem of tropospheric ozone, I briefly discuss the production and supply chain of motor gasoline. The bulk of the chapter discusses the history of air quality controls, with a particular emphasis on the mitigation of vehicle-originated ozone pollution through the use of regulated gasoline.

Ozone Pollution

Tropospheric "ground-level" ozone – also known as "smog" – is a federally regulated air pollutant that is created by the sunlight-driven chemical reaction of nitrogen oxides (NO_x) and volatile organic compounds (VOCs). Although chemically identical to the higher-altitude stratospheric ozone that defends the earth from ultra-violet radiation, ozone at ground-level has effects that are far from protective. Numerous scientific studies have linked ozone exposure to human health and environmental problems, including permanent lung damage and the reduction of forest growth and crop yields (U.S. Environmental Protection Agency "Ground-Level Ozone"). Ozone precursor pollutants are largely generated by industrial emissions, chemical solvents, natural biological sources and motor vehicle exhaust. The Environmental Protection Agency (EPA) estimated that on-road vehicle use contributed to over 35% of NO_x and 25% of VOC emissions nationwide in 2005, making automobiles the #1 and #2 sources of these respective ozone precursors (U.S. Environmental Protection Agency "Air Emission Sources"). Classified by EPA as a criteria pollutant under the Clean Air Act (CAA), ozone has a long history of regulation by EPA and the states. While multiple regulations apply to both stationary and mobile emission sources of ozone precursors, some of the most important, ubiquitous and potentially costly regulations apply directly to the motor fuel gasoline.

Gasoline: An Overview

By far the most common motor fuel used by the American vehicle fleet is gasoline. In 2009, Americans consumed over 137 billion gallons of the fuel (U.S. Energy Information Administration). Gasoline is not a homogenous substance, such as water or ethanol, but is rather "a complex mixture of hundreds of hydrocarbons" (Gibbs et al. 31). Almost all modern gasoline is composed primarily of petroleum compounds produced from the crude oil refining process, however it is technically (although not currently economically) feasible to produce gasoline from "coal, shale oil, tar sands and exotic sources like recycled plastics and rubber tires" (Gibbs et al. 31).

Modern gasoline production is the result of many interconnected chemical and physical refining processes, usually including crude oil distillation, cracking, reforming and alkylation.[3] The content and characteristics of the end product are determined largely by fuel specification demands of motor vehicles and by regulatory requirements. Air quality regulations have affected gasoline volatility as well as the fuel's contents of oxygen, benzene, heavy metals and sulfur. Most changes to the characteristics of gasoline occur at the refinery level. For example, volatility reductions are achieved during distillation by removal of the lightest molecular elements (particularly butanes) of gasoline (Lidderdale "Environmental"). However, gasoline oxygenation – which occurs through fuel blending – can happen either at the refinery or at the wholesaler.

[3] For a technical discussion of the gasoline production process, refer to Lew Gibbs, et al, *Motor Gasolines Technical Review* Chevron Corporation, 2009).

The gasoline supply chain begins upstream at the petroleum refinery and ends downstream at the retail supplier, or "gas station." To describe the political and physical geographies of gasoline markets, it is sometimes helpful to use the concept of PADD regions. During World War II, the then Petroleum Administration for War divided the United States into five regional zones, known as Petroleum Administration for Defense Districts (or PADDs) to better facilitate the allocation of oil. A map of domestic petroleum refineries, along with PADDs, is provided in Figure 1 (National Petrochemical & Refiners Association). Most American petroleum refineries are located in coastal areas where shipping tankers can easily supply consistent and large supplies of crude oil. Areas of high refinery concentration include southern Texas and Louisiana in the Gulf Coast region; Puget Sound, greater Los Angeles and the Bay Area in the West Coast region; and the Delaware River and New York Harbor in the Mid-Atlantic region. Additionally, there exist inland refineries in the Mid-West and Mountain West which receive crude oil via pipeline from coastal regions, Canada or inland domestic sources. A rapidly growing supply of crude is shipped from the Alberta oil sands, as well as from North Dakota, via pipeline to the Mid-West and Gulf Coast regions. Refineries typically convert crude oil inputs into gasoline, jet fuel, and petroleum distillates (e.g. diesel fuel, heating oil, industrial lubricants, etc.). Gasoline is typically transported from refiners via pipeline, barge or train, to wholesale fuel terminals (known as "racks") that sell the fuel to numerous smaller retail sellers. As of 2008, there were 1,495 rack locations in the United States (Peterson, Chin and Das 1-94). The final transportation link from rack to retail gas station occurs by truck.

History of Air Quality and Motor Fuel Regulations

The legislative basis for the majority of gasoline content controls in the United States resides with the Clean Air Act of 1970 and its subsequent amendments. While federal air quality legislation had existed in some form since the 1950s, the 1970 CAA granted the newly-established Environmental Protection Agency the powers to define harmful air pollutants, set limits to their ambient concentrations, guide state implementation of emission reductions, and enforce controls of motor vehicle emissions. Tropospheric ozone pollution has been regulated since shortly after passage of the 1970 CAA; however emission reduction programs targeting the properties of motor fuels were first implemented only in the late 1980s. Motor fuel regulations were greatly expanded with passage of the 1990 Clean Air Act Amendments (CAAA) and implementation of the federal reformulated gasoline program in 1995. Throughout the 2000s, state and federal legislation pertaining to renewable energy and oxygenate additives led to additional fuel content regulations.

Before the Clean Air Act of 1970 established the basis for a system of enforceable national air quality regulations, the "federal government's role was almost entirely devoted to conducting scientific and technical investigations and providing information to the states" (Martineau and Novello). The United States Congress first recognized the national importance of air quality through passage of the Air Pollution Control Act of 1955, which allocated federal funds for research into the scope and sources of pollution (U.S. Environmental Protection Agency "History"). Additional money for the study of air pollution abatement and the development of a national air quality program was provided by the Clean Air Act of 1963. The Air Quality Act of 1967 also expanded research activities and established enforcement procedures for interstate air pollution transport.

Early on, the federal government identified motor vehicles as a major contributing source of air pollution. While Congress did not pass comprehensive air quality legislation until 1970, the Motor Vehicle Air Pollution Control Act of 1965 authorized the establishment of the first vehicle emission standards. Standards were codified by the Department of Health, Education, and Welfare (a predecessor to EPA) in 1966 and went into effect for vehicle model year 1968 (Martineau and Novello). Recognizing that the proliferation of many different and state-specific vehicle standards could impose unnecessary regulatory burdens to automakers and higher prices to consumers, Congress included a federal preemption of law in the 1967 Air Quality Act. Any state that had not established its own air quality regulation before March 30, 1966 was prohibited from implementing standards different than the federal law.[4] This early concern about the added costs of heterogeneous regulation of vehicles is echoed by concern forty years later over the heterogeneous regulation of fuels and the proliferation of so-called "boutique fuels" or "special gasoline blends."[5]

The Clean Air Act of 1970 and its amendments, through establishment of the first comprehensive and enforceable national air pollution policy, had major impacts on the regulation of both ozone and motor vehicles.

The 1970 CAA charged the new Environmental Protection Agency to develop a list of air pollutants emitted by "numerous or diverse" sources whose atmospheric presence "may reasonably be anticipated to endanger public health or welfare" (Martineau and Novello). After

[4] California – the sole state having established air quality control prior to 3/30/66 – successfully petitioned the Department of Health, Education, and Welfare to retain its more stringent standards.

[5] Heterogeneous regulation may play a large role in the fuel price increases measured by this thesis research. Yacobucci ("Boutique Fuels") discusses the broad economic impacts of boutique fuel proliferation and recent legislative and regulatory measures to "harmonize" fuel types; Brown et al. (pp. 1-19) delves more deeply into the relationship between RVP and RFG regulation, market power, geographic segmentation and fuel prices.

selection of these “criteria” pollutants, EPA was required to develop both health-based “primary” standards and welfare-based “secondary” standards that defined the maximum allowable ambient atmospheric concentrations of each pollutant. These “National Ambient Air Quality Standards” (NAAQS) provide the basis for most Clean Air Act regulatory programs.[6] EPA identified both ozone and its precursor NO_x (along with particulate matter, sulfur dioxide and carbon monoxide) as criteria pollutants, and the Agency developed NAAQS for each through 1971 rulemakings.

EPA initially set the ozone standard at an hourly-averaged atmospheric concentration of 0.08 ppm total photochemical oxidants (of which ozone is just one) not to be exceeded more than once per year. Any monitoring district found in violation of this criterion would be deemed in non-attainment status according to a six-category[7] classification structure based upon the magnitude of the ozone exceedance. EPA revised the primary and secondary ozone NAAQS to 0.12 ppm in February 1979 and subsequently revised the standards to 8-hour-averaged concentrations of 0.08 ppm in 1997.[8] The 0.08 ppm standards (along with EPA’s power to set NAAQS) were initially struck down by the D.C. Circuit Court of Appeals but were later upheld by the Supreme Court in 2001. These litigations delayed until April 2004 the effective implementation of the revised air quality standards and the required state revisions of county attainment levels. In 2008, EPA further reduced the ozone NAAQS to 0.075 ppm (U.S. Environmental Protection Agency “NAAQS” 16435-16514); in January 2010 the Agency issued a proposed rulemaking that would reduce the primary 8-hour standard to a level between 0.06

[6] A notable exception is the Air Toxics program.

[7] In increasing order of severity: Marginal, Moderate, Serious, Severe I, Severe II, Extreme.

[8] The 1997 rulemaking also eliminated the requirement for annual ozone NAAQS compliance and replaced it with the confusing and less-stringent requirement that the three-year average of the fourth highest daily maximum 8-hour average concentration not exceed the NAAQS standard.

ppm and 0.07 ppm. These NAAQS changes may eventually have large impacts on the proliferation of fuel-based ozone regulations; however, almost all current fuel programs have been predicated upon non-compliance with the 0.12 ppm 1-hour ozone standard.

The 1970 Clean Air Act gave EPA the power to define ozone as a criteria pollutant and to set its primary and secondary NAAQS; however Congress delegated most of the implementation and enforcement of the standards to the states. Under the CAA, states must define which counties are in non-attainment and explain how they plan to achieve attainment for the various NAAQS through submission of State Implementation Plans (SIPs). EPA must approve the SIPs for each state.

Federal regulation of motor fuels began when the 1967 Air Quality Act granted the Secretary of the Department of Health, Education, and Welfare the power to designate fuel types for registration (Martineau and Novello). The 1970 CAA gave EPA the additional authority to require health-effects testing prior to fuel registration. Section 211(f) of the CAA required EPA to regulate new fuels and fuel additives. The Act prohibits the introduction to commerce of fuels and additives which are not "substantially similar" to those used in vehicle certification; however, it allows EPA to waive this requirement if a petitioner can show that a new fuel "will not cause or contribute to a failure of any emission control device or system…" In the 1970s, EPA denied acceptance of certain fuel additives (such as the octane-enhancer “MMT” which damaged catalytic converters in automobiles and thus interfered with other pollution control programs). However, during this time period EPA allowed the introduction into commerce of gasoline blended with up to ten percent ethanol (“E10” fuel). The Agency also initiated a major phase down in the amount of lead in gasoline.

EPA first used fuel regulation as a means to achieve ozone NAAQS in 1989 with the initial implementation of the federal volatility control program (hereafter referred to as the "RVP" program). In this two-phased initiative, EPA mandated the sale of gasoline with reduced evaporability (measured by reid vapor pressure – hence "RVP") during summer months. Because evaporating gasoline releases high levels of VOCs (which are precursor compounds to ozone formation), reduction of gasoline volatility should in theory reduce the formation of ozone. Since gasoline is more volatile in warmer temperatures and at higher elevations, the standards take effect only during summer months and tend to be more stringent for non-attainment areas in southern states and the Mountain West.

Phase 1 of the RVP program mandated that the 48 contiguous states (or portions of those states) meet specific RVP limits (of 10.5, 9.5 or 9.0 psi) for all gasoline sold by retail outlets between June 1 and September 15 beginning in the summer of 1989 (U.S. Environmental Protection Agency "Volatility Regulations *1989*" 11868-11911). To ease the annual transition to low-RVP fuel and to ensure retail compliance by June 1, the program mandated that upstream suppliers commence production and sales of summertime fuel by May 1. The EPA's federal volatility program allowed a 1.0 psi RVP waiver for gasoline containing approximately 10 percent ethanol.

Phase 2 of the program originally tightened state RVP limits to either 9.0 psi or 7.8 psi beginning in the summer of 1992 (U.S. Environmental Protection Agency "Volatility Regulations *1992*" 23658-23667). However, after passage of the 1990 CAAA and legislative codification of the RVP program, EPA revised the 7.8 psi RVP limit to apply only to counties then in ozone non-attainment (U.S. Environmental Protection Agency "Regulation of Fuels *1991*" 64704-64713). Section 211(c)(4)(C) of the 1990 CAAA allowed states to adopt more stringent controls of fuels or fuel additives than the federal standards, and granted the EPA administrator the power to “approve such provision in an implementation plan, or promulgate an implementation plan containing such a provision, only if he finds that the State control or prohibition is necessary to achieve the national primary or secondary ambient air quality standard which the plan implements.”

Since the beginnings of the RVP program in 1989 and 1992, numerous state implementation plans have adopted more stringent gasoline volatility controls than the federal program mandates. In almost all cases, EPA has deemed fuel volatility controls “necessary” and has approved the SIPs. For a county-level table of current state and federal summertime volatility limits see EPA’s “Guide on Federal and State Summer RVP Standards for Conventional Gasoline Only” (U.S. Environmental Protection Agency).

Taking an especially prescriptive stance towards policy implementation at EPA, in the 1990 Clean Air Act Amendments Congress legislated the federal reformulated gasoline (RFG) program. RFG legislation, which contained “substantially more statutory text than the entire fuels program previously filled” (Martineau and Novello), created one of the most stringent fuel content regulations in the world. “Reformulated” gasoline is designed to reduce vehicular emissions of air toxics and ozone-forming pollutants. The RFG program does not mandate any specific composition or formulation of gasoline, but it requires that certified fuel meet certain vehicle emission standards when fuel characteristics are tested by an EPA predictive model. Volatility controls are required for RFG only during the summer season as defined by the preexisting RVP fuels program (June 1 – September 15 for retailers; May 1 – September 15 for upstream, suppliers). Additionally, RFG fuel cannot increase NO_x emissions, cannot contain heavy metals (unless EPA deems that the metals do not increase toxic emissions), cannot contain more than 1.0% benzene by volume, and must contain at least 2.0% oxygen by weight. The 2005 Energy Policy Act (EPAct) repealed this final oxygenate blending provision amidst concerns over groundwater contamination from fuel oxygenate MTBE and the predicted rapid expansion of ethanol blending due to federal renewable fuel mandates (*Energy Policy Act of 2005*).

The 1990 CAAA prescribed that nine of the worst ozone-polluted metropolitan areas in the United States implement RFG fuel year-round beginning on January 1, 1995. The amendments also allowed state governors to opt-into the RFG program any areas that desired to join. The RFG program was implemented in two stages, with stricter Phase 2 emission regulations for VOCs, toxics and NO_x taking effect in year 2000. Since 1995, over 70 counties and municipalities have joined the RFG program. A list of the original counties, current opt-in counties and opt-out counties can be found on EPA's "Reformulated Gas: Where You Live" webpage (U.S. Environmental Protection Agency). As of 2010, RFG gasoline accounted for approximately 30% of the nation's gasoline consumption (Renewable Fuels Association).

To achieve NAAQS in carbon monoxide non-attainment areas, EPA established a winter season oxygenated fuels program (OXY) in 1992. This program is implemented entirely by the states and requires gasoline sold typically between November and February to contain a specified oxygen content by weight. Added oxygen helps gasoline burn more efficiently to reduce the formation of carbon monoxide caused by incomplete combustion. During the winter of 1994-1995, thirty one areas across the country implemented OXY regulations; however as of 2008 there were only eight areas still implementing the program (U.S. Environmental Protection "State Winter Oxy" Agency 1-4).

Other motor fuel regulations established by EPA include a detergent additive requirement for all gasoline sold after 1995 (to prevent the accumulation of harmful deposits in engines and fuel systems), and a sulfur phase-down program to protect vehicle emission systems. Beginning in 2004, most gasoline refiners were required to produce gasoline that met a corporate average standard of 120 ppm sulfur and a maximum standard of 300 ppm sulfur. These sulfur standards decreased annually until 2007 when the final standards of 30 ppm average and 80 ppm maximum took effect (Martineau and Novello). EPA anticipated that the final standards would incrementally cost refiners less than two cents per gallon (U.S. Environmental Protection Agency "Tier 2").

During the 2000s throughout much of the country there were major gasoline formulation changes that had little to do with air quality regulation. The first major change was in the form of numerous state bans on fuel blending with methyl tertiary butyl ether (MTBE), which led to the widespread reduction in use of this popular fuel oxygenate. The second major change was the vast growth of ethanol-blended gasoline due to the establishment of federal renewable fuel standards and other government incentives.

To comply with RFG and OXY fuel oxygenation requirements, suppliers must add a high-oxygen fuel component to an underlying gasoline blendstock. Due to production costs and product availability constraints of other potential fuel oxygenates, there have been two predominant component fuels used to oxygenate gasoline: MTBE and ethanol.

Ethanol is a fuel-grade alcohol that is distilled from fermented grain. In the United States, ethanol is almost exclusively produced from corn. Due to the economics of transporting corn feedstock, most ethanol refineries are located in the Midwestern states (see Figure 2). Ethanol has hydrophilic and corrosive chemical properties that make it unfit for shipment by most existing petroleum product pipelines. Consequently, more costly trains, trucks and barges currently account for almost all ethanol transport (Peterson, Chin and Das 1-94).

MTBE, on the other hand, is produced from the synthesis of methanol and isobutylene – byproducts of the petroleum refining process. Consequently, production of MTBE typically takes place at petroleum refineries. The chemical properties of MTBE allow it to be transported through standard pipelines either in pure form or as part of blended gasoline. Because of joint production efficiencies and cheaper transportation costs, MTBE has generally been less expensive to produce and ship than ethanol. Additionally, MTBE has a lower volatility than ethanol and MTBE-blended gasoline has a lower volatility than ethanol-blended gasoline, ceteris paribus.

Since a 1.0 psi RVP waiver for ethanol blending does not apply to RFG fuel, a reformulated gasoline blendstock intended for ethanol blending must have a lower baseline vapor pressure than a similar blendstock intended for MTBE blending to comply with summertime volatility restrictions. Production of lower-RVP blendstock for the purpose of ethanol oxygenation incurs higher marginal costs at the refinery level which increases overall cost of the blended fuel, ceteris paribus. For all of these reasons, MTBE became the oxygenate of choice for most gasoline suppliers outside of the Corn Belt states (where lower transportation costs of ethanol and state ethanol blending mandates – specifically in Minnesota – made ethanol blending competitive and prolific). With commencement of the OXY program in 1992 and the RFG program in 1995, MTBE production increased from 83,000 barrels per day in 1990 to 266,000 barrels per day in 1997 (Lidderdale "Motor Gasoline").

Despite the proliferation of MTBE, groundwater contamination concerns eventually heralded the chemical's demise as a fuel oxygenate.[9] In 1999 California became the first state to

[9] The necessity of fuel oxygenation in general was questioned when the state of California, subject to both EPA and California Air Resources Board (CARB) reformulated gasoline standards, effectively demonstrated that it could produce a fuel meeting the RFG program's strict vehicle emissions requirements without the use of oxygenate

pass legislation banning the use of MTBE, and by 2005 twenty four other states had either banned or severely limited its use (U.S. Environmental Protection Agency "State Actions"). In these states, gasoline which was previously oxygenated using MTBE became ethanol-blended. As previously mentioned, the RFG oxygenation requirement was eventually repealed (effective May 5, 2006) by the 2005 Energy Policy Act.

However, the ethanol boom that was fueled by state MTBE bans was not hindered by the Energy Policy Act; on the contrary, the ethanol market was vastly enlarged. In the 2005 legislation, Congress established the first incarnation of the "Renewable Fuel Standards" (RFS) which then mandated that 7.5 billion gallons of renewable (bio)fuels be blended into the domestic gasoline supply by year 2012 (*Energy Policy Act of 2005*). The 2007 Energy Independence and Security Act increased the RFS mandates for total renewable fuel blending to 15.2 billion gallons by 2012 and 36 billion gallons by 2022 (*Energy Independence and Security Act of 2007*). These two pieces of legislation resulted in an enormous increase in the availability and sales of E10 ethanol-blended gasoline at retail outlets as suppliers strove to fulfill the RFS volumetric mandates. In states with a pre-existing ethanol mandate (i.e. Minnesota) or already high market penetration of ethanol-blended fuel (e.g. Iowa), the RFS had little impact on average gasoline formulation. However, in states with no or little previous ethanol blending, the RFS resulted in vast increases of E10. For example, between 2007 and 2009 alone, E10 fuel as a share of total gasoline sales increased from 0% to 60% in Maine and from 2% to 80% in Florida (U.S. Environmental Protection Agency "Regulation to Mitigate" 68066).

---

blending; however, petitions for a state exemption from the oxygenation requirement were rejected twice by the EPA in 2001 and in 2005 (Al Center).

CHAPTER 3

PREVIOUS LITERATURE

Noteworthy economic studies of environmental fuel regulations have only taken place within the previous half decade or so as sizeable time-series of data have become available, allowing researchers to analyze the longer-term effects of these policies. Attempts to quantify the price impacts of federal motor fuel regulations have taken three broad approaches: the simple, the structural, and the reduced-form. In this chapter, I discuss the major previous research efforts from each methodological category. I then discuss how features of my own research build upon and compare against previous efforts.

Simple Approach

The simple approach is the most basic of the three methods because it does not utilize advanced econometrics or mathematical modeling. In its most basic form, arithmetic means of fuel prices are calculated for each sample city or region. Samples are differentiated by fuel type (regulated or unregulated), and are ranked by mean price. These ranked summary statistics may allow a researcher to make very simple inferences based on the observed pattern of average prices and regulations across cities. Standard deviation of prices may also be calculated and compared across regulated and unregulated cities to estimate the effect of regulations on price volatility.

The United States Government Accountability Office (GAO) utilized a similarly simple method in one of the initial attempts to measure the marginal price impacts of different gasoline regulations. In a 2005 report to Congress "Gasoline Markets: Special Gasoline Blends Reduce Emissions and Improve Air Quality, but Complicate Supply and Contribute to Higher Prices," GAO examined weekly wholesale gasoline price data for 100 U.S. cities from December 2000 to October 2004 (U.S. Government Accountability Office). Instead of calculating simple arithmetic means for each city over the given time period, GAO first subtracted the weekly price of West Texas Intermediate crude oil from each price sample. This differencing was intended to remove the component of variation due to fluctuation in oil prices. GAO then ranked the means of these price differentials from highest to lowest and inferred empirical results from these normalized data. The use of price differentials was an important attempt to control for the city-invariant time effects which are correlated with fuel prices. However, underlying this method was the tenuous assumption that the baseline supply of crude for each city's market came from the same source and had the same costs. This model also failed to account for effects which may vary across *city*. In albeit crude fashion, the GAO report recognized that fuel price time trends must be accounted for in order to properly evaluate regulation impacts.

The results of the GAO study provided a good starting point for further research into the impacts of specific regulations. The GAO report examined broad trends in prices related to the incidence of one or more of 11 different "special blends" of fuel, but in general it did not try to isolate the effects of individual regulations. GAO found that "of the 100 cities we examined, most of the 20 cities with the highest prices used special blends of gasoline…[and] among the 20 cities with the lowest prices, 8 used conventional gasoline – the most widely available gasoline blend – and 9 used 7.8 reid vapor pressure" (p. 6). These findings suggest that low-RVP fuel may be correlated with *lower* fuel prices. As acknowledged by the authors, this finding could be indicative of the fact that low vapor pressure fuel is heavily used in Gulf Coast states which have lower average fuel prices due to close proximity to major refineries. Implicitly, this recognition suggests that there exist unobserved city-specific effects which may be related to transportation costs.

The GAO research also examined price patterns related to oxygenate blending and interestingly noted that “average prices for conventional gasoline with ethanol were about 4 cents per gallon higher than conventional without ethanol over the time period we analyzed” and “over the period 2001-2004, the average summer price for federal reformulated gasoline with ethanol was between about 6 and 13 cents per gallon more than for federal reformulated gasoline with MTBE.” These apparently significant effects of ethanol blending warrant further consideration when specifying an econometric model of the price effects of regulation. If the presence of ethanol blending is not perfectly correlated with time or place, annual and city fixed effects will not be effective in removing this variation.

Structural Approach

Structural econometric modeling[10] has also been employed to ascertain the price effects of certain motor fuel regulations. Structural studies of gasoline markets typically examine price changes by modeling the behavior of profit-maximizing petroleum refiners and using spatial or temporal variation within the data to estimate marginal impacts by comparison of simulated results to counterfactuals.

For example, Erich Muehlegger created a model to determine the degree to which price spikes in three states could be attributable to regulatory differentiation (Muehlegger). Using monthly wholesale price and quantity data at the state-level, along with refinery capacity and

---

[10] “In structural econometric models, economic theory is used to develop mathematical statements about how a set of observable ‘endogenous’ variables, y, are related to another set of observable ‘explanatory’ variables, x… economic and statistical assumptions define an empirical model that is capable of rationalizing all possible observable outcomes” (Reiss and Wolak 4282).

outage data, he constructed a three-step game in which refiners maximize expected profits by changing production of different regulated fuels subject to changing information about refinery outages.[11] Muehlegger used this model to estimate the marginal price impacts of using California Air Resource Board gasoline (CARB) and ethanol-blended RFG as opposed to using federal RFG blended with MTBE. He found price increases due to CARB and ethanol-blended RFG of 4.5 and approximately 3 cents per gallon, respectively. These estimates were contingent upon normal refinery operation and represented the increased production costs of these regulated fuels. Muehlegger also estimated price increases when local refineries were not operational: these he interpreted to be the effects of regulation due to fuel incompatibilities between regulated and unregulated areas.[12]

The structural approach was suitable for Muehlegger because sufficient price and quantity data existed at the appropriate spatial and temporal scale of the fuel regulations he examined. However, this approach is effectively limited to the study of certain regulations. The city-specific nature of RVP and RFG regulations is better suited to data with a finer spatial granularity than the state-level. The seasonality of RVP lends itself to data at the daily or weekly level, as opposed to the monthly level. A significant drawback of the structural approach is the necessity of obtaining fuel quantity data. Publicly available data on gasoline quantity exists only at the state-month level, making it ineffective for the study of many fuel regulations, and thereby limiting the usefulness of structural modeling. While I am unaware of other structural economic

[11] "In the first step, refineries commit to quantities of light petroleum products without knowing outages. In the second step, outages are realized and observed by all refineries. In the final step, refineries allocate production across different geographic areas in response to the outage" (p. 11).

[12] The separation of price effects by different causes is an important theme that recurs in the Brown et al. (pp. 1-19) reduced-form study. While my own research does not explicitly attempt to measure the individual causes of observed price differentiation due to regulation, the policy implications of such an approach may be quite powerful.

models which have estimated price effects of fuel regulations, it is not unlikely that other researchers have attempted to use these methodologies to similar ends. Nevertheless, since many more studies (including my own) have utilized reduced-form modeling, I discuss this latter approach at significantly greater detail in the following section.

Reduced-Form Approach

By far the most common method used to evaluate the price effects of regulation has been the reduced-form, or econometric, approach.[13] This is the general method which I use in this paper, and at least four previous studies have utilized similar reduced-form models (Brown et al. 1-19; Chouinard and Perloff 1-26; Walls and Rusco 145-164; Chakravorty, Nauges and Thomas 106-122). Reduced-form models typically have used panel data to regress fuel prices in various regions at different dates against explanatory variables that capture the effects of regulations and other sources of variation. Researchers have used reduced-form models to study the effects of a range of fuel content controls (including RFG, RVP, CARB fuel, ethanol blending and oxygenation requirements). They have employed creative techniques to model these regulations (including dummy variables and population-based proxy variables) and have included explanatory variables ranging from federal taxes, personal income, the risk-free interest rate and population density (Chouinard and Perloff 1-26) to refinery capacity per capita (Chakravorty, Nauges and Thomas 106-122).

[13] "Although the term reduced form is used frequently, the underlying definition has evolved over time. The traditional econometrics textbook definition of reduced form refers to simultaneous equations, where the system of equations is solved to eliminate all endogenous variables. The reduced-form model links the dependent variable solely to exogenous variables, which, by definition, are not influenced through feedback loops of the system… The emphasis is on eliminating endogenous variables, whereas a structural setup would model and estimate the effect of such variables directly. Modeling such endogenous variables usually requires structural assumptions to identify these variables of interest as well as suitable instruments. The goal of a reduced-form model is to avoid as many structural assumptions as possible" (Timmins and Schlenker 365-366).

These econometric papers on motor fuel regulations are primarily differentiated by data source, the modeling of the regulatory variables, the choice of other explanatory variables, and (to a lesser extent) estimation technique. These differences are examined more thoroughly throughout the following discussion of the four reduced-form fuel regulation studies and their relationship to my research.

Chouinard and Perloff specified and estimated a large econometric model to explain gasoline price as a function of numerous market characteristics, including consumer demographics, supply disruptions, taxes, weather and content regulations (Chouinard and Perloff 1-26). Using monthly retail and wholesale prices at the state level for the years 1989 to 1997, the authors found that most of the variance in gasoline prices could be explained by changes in crude oil prices. However, the study also concluded that "areas with federal reformulated requirements may face average [per gallon] prices nearly 1¢ higher than those without the law, and the oxygenated areas have prices nearly 5¢ higher" (p. 21). These estimates must be taken with a dose of skepticism, however, because of the coarse spatial granularity of their data[14] and the increased risk for multicolinearity problems introduced by the inclusion of a large number of related explanatory variables.

Chakravorty, Nauges and Thomas (Chakravorty, Nauges and Thomas 106-122) examined the effects of RFG and OXY fuel using state-level data for the years 1995 to 2002. Similar to the Chouinard and Perloff study (Chouinard and Perloff 1-26), the authors included a large number of explanatory variables comprised of both gasoline market characteristics and state-specific

[14] Except for a few small Mid-Atlantic and New England states, most states with RFG counties also contain areas using conventional gasoline. Aggregation of price data at the state level is inconsistent with the observed pattern of fuel regulations in most states. Use of this spatially coarse price data eliminates the ability to explicitly model the presence of fuel regulations. To compensate for this limitation, the authors (and also Chakravorty, Nauges and Thomas 106-122) had to utilize less-direct population-based proxy variables.

demographics. The authors treated all gasoline market variables (e.g. refinery capacity, average distance to refinery, etc.) as endogenously co-determined with regulation due to the possibility of effective lobbying efforts from regulated fuel suppliers. The authors also included time fixed effects and state fixed effects. Instead of explicitly modeling regulations using dummy variables, the authors constructed proxy variables based upon the percentage of population using special fuels in each state at each time, as well as the relative differences of these measures between adjoining states.

The study concluded that RFG and OXY programs increased fuel prices both by increasing refining costs and by increasing supplier market power through market segmentation. Chakravorty et al. estimated the model using three-stage least squares regression (3SLS) to account for the endogeneity problem, and the authors found regulation price effect estimates that were consistently higher than similar regression using ordinary least squares (OLS). The use of proxy market size variables to account for RFG and OXY regulations was a creative approach to the problems of coarse data granularity. However, this method provided a quite indirect measure of the actual fuel price effects of regulation,[15] and there was a large mismatch in the spatial and temporal scales of the price and regulations data (i.e. RFG and OXY are implemented on a city – not state – basis; the OXY program is implemented only during winter months).

Walls and Rusco (Walls and Rusco 145-164) used data from the simple Government Accountability Office study (U.S. Government Accountability Office) to construct a "panel data regression model to explain fuel prices as a function of fuel attributes, the price of crude oil, and

[15] The authors did not explicitly model the presence of regulations in their research, but instead used population percentages as independent variables. After regressing gasoline prices on these percentage variables, they then estimated fuel prices in states for which with 0% and 100% of the population used regulated fuels. The authors interpreted this difference to be the per-gallon price effect of each respective regulation. Using this methodology, Chakravorty et al. estimated that "the price of gasoline would increase by 16 percent if a state with no regulation would impose either RFG or OXY regulation to the whole population."

seasonal and city-market-specific effects" (p. 146). The researchers analyzed weekly wholesale price data from 99 cities for the time period between December 2000 and October 2004. The study estimated price effect coefficients for RVP, RFG, ethanol blending, low-sulfur requirements, CARB and other fuel regulations. To remove time effects, the study included as explanatory variables both the price of West Texas Intermediate crude oil and seasonal dummies. To remove city effects, Walls and Rusco estimated their model using four different specifications: common intercept, fixed effects, random effects, and AR1 serially auto-correlated fixed effects. They also included a variable measuring the distance to the nearest source of a substitute (regulated) fuel.

In accord with the results of the GAO study, Walls and Rusco found no statistically significant price effect of RVP 7.8 fuel. The authors also found no significant effect of low-sulfur fuel. They did, however, find significant positive price effects of approximately 4.3 cents per gallon for RVP 7.2 fuel and 5.7 cents per gallon for 10% ethanol-blended fuel. Reformulated gasoline blended with MTBE had an insignificant positive price effect of between 1.0 and 1.4 cents per gallon, whereas ethanol-blended RFG had a statistically significant price effect of 6.6 cents per gallon. This large differential between MTBE- and ethanol-blended RFG price effects suggests a large cost of biofuel blending – a subject which warrants further investigation.

Brown, Hastings, Mansur and Villas-Boas (Brown et al. 1-19) further explored the impacts of geographic segmentation and changes in market power due to regulation. Using city-aggregated supplier-level wholesale gasoline price data for the years 1994-1998, the researchers examined the impact of three motor fuel regulations (RVP, RFG w/ethanol, RFG w/o ethanol) by creating dummy variables for each. Recognizing that heterogeneous regulation may cause some suppliers to drop out of the market (thus increasing market power and the prices charged by remaining suppliers), Brown et al. included as an explanatory variable the number of wholesale fuel suppliers in each city at each time. Since the number of suppliers could be endogenous to the price of gasoline, the researchers instrumented[16] for this variable using the number of (consistent) refiners serving the city, the regional PADD, the Hirschman Herfindahl Index (HHI) and the percentage of state-level gasoline consumption that is reformulated. To remove price-correlated time effects and regional effects, Brown et al. used a treatment and control approach whereby the authors included as additional explanatory variables the average conventional gasoline prices in neighboring unregulated cities.

This approach differed significantly from other models, many of which had accounted for time and regional effects using an average (city-inspecific) price of crude oil, a proxy variable representation of fuel regulations, and many explanatory variables including city characteristics (e.g. population, vehicles per capita, average income, etc.) or supplier/market factors (e.g. distance to refinery or substitute supplier, refinery concentration index, relative size of regulated market, etc.). The novel use of a treatment and control method in Brown et al. allowed estimation of the regulation effects without the selection of additional and seemingly contrived explanatory variables. However the selection of which control cites to use remained a matter of researcher discretion, and the treatment and control method risked introduction of high levels of colinearity if fuel prices behaved highly regionally. The authors estimated the model using both fixed and random city effects, after correcting for AR1 serial autocorrelation. To measure the effects of geographic segmentation, they also estimated the model with the inclusion of two additional

[16] An explanatory variable correlated with the error term may bias regression coefficient estimates. To correct this problem and produce unbiased estimates, an “instrumental variable” (IV) that is both uncorrelated with the error term and partially correlated with the endogenous explanatory variable may be used as a proxy variable in place of the endogenous variable. The use of IVs, a common practice in applied econometrics, “provides a general solution to the problem of an endogenous explanatory variable” (Wooldridge “Econometric Analysis” 83-84).

explanatory variables based upon the average distance to (aka "Proximity Measure") and total number of (aka "Potential Partner Count Measure") all other cities with fungible fuel types. As with the distance variable in the Walls and Rusco paper, these variables aimed to capture the specific effect of geographic market segmentation due to fuel regulation.

After instrumenting for number of suppliers, Brown et al. concluded that RVP regulations increased fuel prices (relative to conventional RVP 9.0 gasoline) by approximately 1.1 cents per gallon, whereas MTBE-blended and ethanol-blended RFG increased prices by 2.7 and 4.1 cents per gallon, respectively. These price estimates varied by approximately 8 cents across different cities. The authors also found a significant coefficient for the number of fuel suppliers (-0.4 cents per gallon per wholesaler), a significant coefficient for the Proximity Measure, but an insignificant coefficient for the Potential Partner Count Measure. These results implied that price increases in regulated cities were due to within-city changes in supplier market power as well as geographic isolation caused by market segmentation.

How Does My Study Compare?

A handful of previous economic studies have estimated the marginal costs to consumers of various gasoline content regulations, including RVP and RFG. However, many of these studies have carried potentially serious data and multicolinearity concerns. Additionally, no study has employed its regulation price effect estimates in a conceptual or analytical discussion of welfare impacts.

My reduced-form regression model is similar to Brown et al. in that it uses an unambiguous dummy variable specification to measure *directly* the price impacts of regulations, instead of using population-based proxy variables (as have Chakravorty et al. and others). This specification is possible because of the availability of city- and week- level price and regulations data.

My research differentiates itself from previous studies through its use of a longer time-series of weekly city-level price and regulation data. Additionally, its use of *retail* price data is almost unprecedented in the existing literature – despite the fact that retail prices may provide more robust and interpretable results. By utilizing retail price data, fewer variables and an explicit dummy variable representation of regulations, my models generate price effect estimates with lower risks of multicolinearity and which may capture more accurately the impact of the regulation on consumers.

My presentation of a conceptual welfare framework is unique in the fuel regulations literature. This research builds upon the existing literature by being the first such study to use price effect estimates to infer aggregate consumer cost changes. While previous research efforts have ended with the estimation of price impacts from regulation, this paper uses these estimates as parameter inputs to the estimation of a welfare analysis model. Consumer cost impacts and other welfare measures, although admittedly subject to greater uncertainty than price estimates, may have far greater relevance for policy evaluation and decision-making.

CHAPTER 4

METHODS

The primary analytical methodology of my research consists of several multivariate statistical models: a “Basic Model” and two variations of a “Monthly Time Trend Model.” These models differ in their specification of unobservable time effects, as well as in the seasonality of their data. To test whether regulation price effects remain constant over time, I estimated *all* models for all years (1992 – 2010) as well as for two subsets of date ranges (1992-2000 and 2001-2010). Additionally, I conducted two specification tests to determine if very-low state RVP standards have had disproportionate marginal price impacts (“Multiple RVP Regulations Model”), and to estimate city-specific price effects (“City-Specific Price Effects Model”). This chapter exhaustively details the methodology of these econometric models.

Basic Model

All regression models presented in this chapter are simply variations of the basic model presented below. Consequently, I describe the basic model in quite some detail. The basic methodology used to estimate the price impacts of RVP and RFG regulation is a panel data[17] fixed effects[18] regression model of the following specification:

[17] Panel data “consist of repeated observations on the same cross section of, say, individuals, households, firms, or cities, over time” (Wooldridge “Econometric Analysis” 6).

[18] Greene (pp. 193-194) writes that “the fixed effects model arises from the assumption that the omitted effects c_i, in the general model, $y_{it} = \boldsymbol{x}'_{it}\boldsymbol{\beta} + c_i + \varepsilon_{it}$, are correlated with the included variables.” If Var[c_i|$\mathbf{X}_i$] is constant, the model may be written as $y_{it} = \boldsymbol{x}'_{it}\boldsymbol{\beta} + \alpha_i + \varepsilon_{it}$, where each α_i is uncorrelated with the error term and “is treated as an unknown parameter to be estimated.”

$$P_{i,t} = RVP_{i,t} + RFG_{i,t} + \alpha_i + \beta_{year} + \varepsilon_{i,t}$$

The dependent variable $P_{i,t}$ is the real ex-tax retail price of gasoline in city *i* measured at time *t*, where *t* is measured by the number of weeks elapsed since January 1, 1992. $RVP_{i,t}$ and $RFG_{i,t}$ are dummy variables indicating respectively the presence (in city *i* and time *t*) of gasoline reid vapor pressure restrictions equal to or less than 7.8 psi, and federal reformulated gasoline regulations. The α_i term is a matrix of time-invariant city fixed effects, and β_{year} is a matrix of city-invariant year fixed effects. The city-and-time-specific error term is denoted by $\varepsilon_{i,t}$. Data were subsetted by summer month only, and models were estimated using ordinary least squares (OLS) regression.

Price Variable

I obtained price data from the Oil and Gas Journal (OGJ) online research center.[19] Because the states of California and Arizona have adopted significantly different and more stringent fuel regulations than the rest of the country, I excluded data from four cities in these states. My final dataset consisted of 38 cities. All nominal prices were converted to real May 2010 dollars using monthly values for the U.S. Bureau of Labor Statistics' Consumer Price Index for All Urban Consumers (CPI-U).

Ex-tax prices were used to eliminate potential bias in the city fixed effects variables that could arise from heterogeneous changes over time of state fuel taxes. The *federal* gasoline tax

[19] Average retail gasoline prices in 42 U.S. cities have been published weekly by OGJ since January 1986 and composite spreadsheets of the entire dataset were downloaded in June 2010. I obtained price series for actual retail prices as well as retail prices less state and federal taxes. OGJ's reported retail price data reflect average prices of 2-3 randomly sampled gas stations in each city at each time period. According to an OGJ representative, these "prices and trends have compared favorably" to the more extensive (and expensive) Lundberg Survey.

impacts could have been removed through the use of time fixed effects alone, but the use of ex-tax pricing also achieved this goal.

If retail gasoline sales margins are correlated with prices – as would maximize profit in a Nash-Bertrand game (Hastings 16) – wholesale prices and retail prices will not move equally with cost changes. Additionally, an extensive body of research (including but by no means limited to: Karrenbrock 19-29; Borenstein, Cameron and Gilbert 305-339; Noel 324-334) has suggested that retail gasoline prices move asymmetrically[20] with changes in wholesale prices. Under either of these possible pricing regimes, the use of *wholesale* price data could bias the estimation of the *retail* price effects actually experienced by consumers. Since retail prices provide a more accurate measure than do wholesale prices of the economic conditions faced by consumers, since consumer price and welfare impacts have greater interpretive value and are more relevant to policymakers, and since the use of wholesale prices could result in inaccurate results, I chose to examine retail prices.

Conversion of nominal price data to real (May 2010) terms sought to eliminate price variation due to inflation.[21]

[20] Asymmetric price movement is the idea that retail prices typically rise faster than they fall for an identical (i.e. "symmetric") rise and fall in wholesale prices.

[21] Use of the Bureau of Labor Statistics' nationally aggregated CPI-U carries the dual assumptions that gasoline price inflation occurred at a similar rate to a representative basket of other economic goods, and that gasoline price inflation was constant across all cities. I believe that these assumptions are appropriate for a few reasons. First, gasoline prices are highly correlated to the price of crude oil, which represents an economically systemic cost underlying the production of many economic goods measured by the CPI-U. Thus, if nominal oil prices are correlated to the nominal prices of these goods, gasoline prices should also be correlated. Second, in large part due to correlation with crude oil prices, gasoline prices across the country have historically trended closely together. While this phenomenon may introduce its own problems of colinearity to the data, it also reduces the possibility of geographic heterogeneity in price inflation. Additionally, if fuel price inflation varied significantly across cities one might expect there to be very different long-term consumption trends of gasoline exhibited in the composition of city vehicular fleets, ceteris paribus; this effect does not seem evident in then data. Fuel price arbitrage opportunities likely eliminate these differences. Finally, the CPI-U is a generally accepted inflation index which is used frequently in most economic literature.

Regulation Variables

A dummy variable representation of the RVP and RFG programs was chosen to provide a simple and unambiguous measure of the presence of regulation in each city at each time period. This methodology was possible because the spatial aggregation and frequency of the price data was consistent with implementation of the two regulations. Unlike the method used for the more granular dataset in Chakravorty et al. (Chakravorty, Nauges and Thomas 106-122), the dummy variable method allowed direct modeling of the regulations. Consequently, the price effects attributable to the regulation dummies should better reflect the direct economic impacts of the regulations themselves, instead of inferring impacts from less-direct population-based proxies.

For every city/date observation, the RVP and RFG[22] variables were assigned a value of "1" if the respective fuel regulation was present and a value of "0" if said fuel regulation was not present. Fuel regulation data were constructed from EPA online sources and published announcements in the Federal Register.[23]

Of the cities in my dataset, nineteen were subject at any point in time to a volatility restriction of RVP 7.8, one (Kansas City) to a limit of RVP 7.2, and five (Atlanta, Birmingham, Detroit, Kansas City, Saint Louis) to a limit of RVP 7.0. I considered the creation of four separate dummy variables to model the presence of the following low volatility regulations: RVP

[22] As with the originally-proposed RVP program, the RFG program technically has separate summertime volatility restrictions for states in the "North" and "South." However, I chose to combine both groups into one overarching RFG variable. Since the program's regional differences are quite small, it is probably safe to ignore this regulatory variation. By combining two potential variables into one, I significantly increased the statistical power of my model without significantly biasing my results.

[23] To construct data on RVP program regulations, I scoured backlogs of the Federal Register for EPA rulemakings pertaining to the approval of State Implementation Plan changes relevant to the cities within my dataset. The effective EPA approval dates of state RVP changes were noted and used to create dummy variables for each level of volatility regulation. Data for the reformulated gasoline program were somewhat simpler to compile. I constructed a single dummy variable for the presence of federal RFG regulation using the EPA's "Reformulated Gas: Where You Live" document (U.S. Environmental Protection Agency).

9.0, RVP 7.8, RVP 7.2 and RVP 7.0. However, due to the limited number of sample cities and time periods in which RVP limits less than 7.8 psi were implemented, I chose to measure the price effect of *average* RVP regulation. Thus, the basic model included just a single, comprehensive low volatility dummy variable that indicated if and when each sample city imposed regulations with RVP limits ≤ 7.8 psi. In a later specification test, I tested for the possibility that lower-than-federal RVP limits had different marginal price effects. This test (in which I created two RVP dummies) is discussed in the upcoming Multiple RVP Regulations Model section of this chapter.

Specification of the RVP dummy variable also required a few carefully considered assumptions about the start dates of the program. Since the EPA-effective date of initial RVP program implementation in many cities did not coincide with the effective date of state implementation,[24] it was unclear which dates to use. I believe that use of the EPA approval date provided the best and most consistent representation of regulatory changes for two reasons. First, changes to SIPs that have not been approved by EPA are not legally binding in federal court. Fuel suppliers thus had no incentive to comply with state RVP regulations until the regulations were approved by EPA. Second, the EPA approval date provided a concrete and definitive compliance deadline. Due to the multitude of state legislative and regulatory requirements, it would have been extremely difficult to determine for each regulatory change when the effective (however not legally binding at the federal level) state regulatory implementation date occured.

A second timing issue arose in modeling the annual start of the summer RVP season since wholesalers and retailers are subject to different start dates for annual regulatory

[24] For instance, a state regulator could approve a lower RVP limit and submit a revised SIP for EPA approval. If EPA delayed ruling on this proposed SIP change for period of time during which the state regulator enforced the (unapproved) change, the EPA approval date may have varied from the actual implementation date of the regulation.

compliance. Because my data consist of *retail* prices, I chose to use the retail supplier regulatory enforcement deadline of June 1 (as opposed to the May 1 deadline for upstream supplier). It is important to note that higher retail prices may have occurred prior to June 1 due to anticipation of volatility restrictions, early transition of fuel types, or the pass-through of costs by vertically-integrated, oligopolistic suppliers. However, the basic regression model eliminated this issue of fuzzy regulatory discontinuity by examining only a subset of the summer months.

A total of 13 cities in my sample had implemented the RFG program, 12 of which joined at the onset of the program in 1995, and one of which (Saint Louis) joined in 1999. Admittedly, since reformulated gasoline regulation takes effect year-round, the RFG variable may suffer slightly from a lack of within-city variation and from the fact that this variation occurred at the same point in time for nearly all sample cities.[25]

An additional challenge of the RFG dummy is that it did not account for the more stringent *volatility* limitations imposed on reformulated gasoline during summer months. However, the basic model eliminated this problem by using a data subset of summer months only. This subset (discussed in-depth in a following section) eliminated within-year variation in RFG, and also generated a price effect estimate that reflected the slightly more stringent summertime (volatility-controlled) formulation. If the RFG price effect was lower during non-summer months, my use of a summer subset may have produced coefficients which overestimated the actual price effect as measured on an annually averaged basis. Because I

[25] Since the RFG program is implemented all year, the only within-city variation present in each city occurred from the one-time initial implementation of the program. Because all but one (i.e. Saint Louis) RFG-implementing city entered the program on January 1, 1995, there was also virtually no variation over time of this start date. Therefore, it is difficult to say with certainty that the RFG coefficient captured the full price effect of the RFG program without accidentally measuring time-correlated price trends or price differentials due to city-specific attributes that are strong indicators of RFG presence (e.g. highly urban demographics or East Coast geography). The use of fixed effects helps to substantially mitigate these concerns but cannot eliminate them entirely.

examined only data from the *summer* months (which may have exhibited larger price increases than other times of the year), my RFG price effect parameters could potentially bias upward my subsequent consumer cost welfare analysis (which is based upon *annual* fuel consumption).

There are two reasons I was not initially concerned about this problem. First, volatility regulations for non-RFG fuels (i.e. the RVP program) were found to be significantly insignificant. Second, compliance with winter-month RFG requirements usually resulted in a lower baseline fuel volatility than conventional fuel, so the marginal costs to the refiner of further (summertime) volatility reductions were likely smaller than for the RVP program. Nevertheless, I estimated an additional model (using full-year data) as a specification test to check for possible seasonal variations in the RFG effect. This model is described in the Monthly Time Trend Model section.[26]

As mentioned previously, until 2006 RFG fuel was oxygenate-blended with either MTBE or ethanol. While the constraints of my data do not allow direct precise determination of the oxygenate used in each city during each time period, I attempted an empirical test determine the marginal impacts of ethanol blending. This specification test is explained in depth in Ethanol Blending and State MTBE Bans section of the Results chapter.

[26] An additional form of unaccounted-for variation in the RFG variable occurred temporally with the commencement of “Phase 2” regulations in year 2000. According to EPA, the second phase of the RFG program was designed to cut VOC, NOx, and toxic pollutant emissions to respectively 27%, 7%, and 22% below levels produced by conventional gasoline (U.S. Environmental Protection Agency). These requirements appear significantly more stringent than the 17%, 2%, 17% reductions under Phase 1, and it is very likely that fuel prices reflect these differences. EPA predicted that the second phase regulations could increase fuel refining costs by one to two cents per gallon (U.S. Environmental Protection Agency “Phase II”). Inclusion of a “millennial” dummy variable interacted with RFG could be one possible way to indicate this change and measure the incremental effects of Phase 2 requirements.

The modeling of RFG impacts was somewhat complicated by the fact that the regulatory program generally does not set specific fuel content mandates.[27] However, regional variations in price due to different RFG composition or production methodologies should have been captured by city fixed effects.

Finally, the exclusion of oxygenated fuel regulations from the price effects model was a very intentional decision. There are a few reasons why I did not attempt to model this variable. First, because states are solely responsible for implementing winter oxygenated fuels programs, enforcement of these programs is likely to vary significantly. If enforcement is incomplete, observed fuel prices may not actually represent regulated fuels; here, regulation dummy variables would inaccurately identify the fuel type. This is a potential problem with estimates of any fuel regulation when price data are not specifically attached to a fuel-type.[28] However, it can be reasonably assumed that enforcement at the federal (EPA) level – even if imperfect – will be at least more consistent than enforcement by various separately-administered and separately-funded state environmental agencies. Second, implementation of oxygenated fuel requirements differ significantly between locations, with some state (or local) regulators mandating that gasoline contain 3.5% oxygen by weight while others require only 1.5%. Although 2% may not seem like a large difference, it is equivalent to an increase in total fuel ethanol content of 5.7% or an increase in MTBE content of approximately 11%.[29] This large variation between local and

---

[27] Since RFG fuel is certified by a predictive model which forecasts typical vehicular outputs (i.e. emissions of VOCs, NOx, and air toxics), the inputs (i.e. fuel contents) are allowed to vary so long as regulatory requirements are met. As exemplified by the state of California's demonstration that RFG-certified fuel can be produced without oxygenation, the refining processes (and chemical composition) of RFG may vary widely.

[28] See the section A Data Limitation in the Results chapter for further discussion about this problem.

[29] "Ethanol…contains 35 percent oxygen by weight, twice the oxygen content of MTBE." MTBE & Ethanol, 11/17 2010 <http://www.seco.cpa.state.tx.us/re_ethanol_mtbe.htm>.

state requirements for fuel oxygenation, in addition to discrepancies in state enforcement practices, makes estimation of winter OXY effects unsuitable for the basic dummy variable model. Finally, my use of a summer-subsetted basic model actually precluded the modeling of most oxygenation regulations, since the majority of affected cities only required fuel oxygenation during winter months.

Summer Subset and Fuel Baselines

The data were subsetted to include only summer months and dates after 1992 so that RVP 9.0 gasoline could be used as a baseline.[30] The widespread use of this fuel type made it an appropriate baseline against which to test more stringent fuel regulations. Since there is no baseline fuel volatility regulation for non-summer months, inclusion of prices from other seasons would have resulted in a less easily interpretable measure of marginal regulatory impacts.

Because of the huge amount of RVP 9.0 fuel supplied and consumed each year, any good estimate of the overall economic impacts of the volatility program should account for the price effects of RVP 9.0 above and beyond a baseline of no fuel regulation at all. Previous studies have found negligible impacts of RVP 9.0 on the per-gallon price of gasoline. Since my basic model selects RVP 9.0 as a *baseline* fuel, all measured price effects are relative to the price of this volatility-controlled gasoline. If implementation of RVP 9.0 indeed increased prices relative to unregulated fuel, my estimates for RVP and RFG variables may have underestimated the actual impacts of these regulations.

[30] Phase 2 of the federal RVP fuel program required that summer gasoline in all 48 contiguous states meet RVP 9.0 restrictions.

Fixed Effects

The specification of fixed effects variables was crucial to the design of my price effect models, and use of these variables required certain assumptions. Theory predicts that retail fuel prices should differ across cities due to factors including, but not limited to: petroleum supply market factors such as transportation-related costs, demographic factors such as real household income, and gasoline demand factors such as vehicular fleet composition and per-capita vehicle miles travelled. Indeed, summary statistics of my dataset show a wide variation in mean fuel prices between different cities (see Table 1). While some previous studies have attempted to include many or all of the above variables in complex regression models, I modeled most as unobservable city fixed effects. This specification relied upon the assumption that the *average* effects of these unobserved variables varied across cities, but were consistent over time in any given city.

Time-invariant city effects may be viewed as a bold and dangerous assumption; however, I believe it is not an unreasonable one. First, the physical infrastructure of the petroleum supply chain has changed little in the past 18 years. As of late 2007, no new petroleum refineries had been built in the United States in almost 30 years (Shurtleff and Burnett). Additionally, since 1992 there have been few major alterations to the interstate highway system or the petroleum pipeline system that could have led to large and differential supply cost changes between cities.[31] Second, while changes in U.S. city demographics and gasoline demand attributes could theoretically have affected fuel prices, the magnitudes of any actual differences between cities have likely been small – and their effects small – relative to swings in the price of crude oil. In

[31] The vast shipments of Albertan and North Dakotan crudes via recently constructed pipelines are beginning to change this.

short, I believe it is safe to assume that unobservable city-level variables have remained generally constant during the timeframe of my dataset.

The city-level variables which of course have changed over time are gasoline fuel regulations. As Brown et al. determined, the imposition of these regulations may have impacted some unobserved variables related to wholesaler market power and the average distance to fuel suppliers. While these endogenous variables have the potential to bias estimation results, any price effect due to them is a direct impact of RVP and RFG programs and should rightly be included in the price effect estimate of the respective regulatory variable.

To account for observed time trends in the national average real price of gasoline (see Figure 3), I included a city-invariant year effects term β_{year}. I chose to model time effects at the annual level because monthly or seasonal time effects might introduce problems of multicolinearity with the summer-only RVP regulation. Also, year effects seemed to appropriately balance the tradeoff between model flexibility and statistical significance (as considered by the number of explanatory variables). Modeling time effects as city-invariant also reduced the required number of power-depleting dummy variables. However, this specification required the assumption that all unobserved time-correlated variables were constant across cities. This assumption certainly did not hold when refinery outages or natural disasters (such as hurricanes along the Gulf Coast) caused regional or city price shocks. However, most regional or city price shocks occurred temporarily (for a period of days or weeks) and thus are not likely to have significantly affected the mean annual price of gasoline in a given location. The use of annual time effects obviates the potential problem of short-term price shocks. Annual time effects also eliminate the need to explicitly model fuel regulations which were phased in nationally and which affected all cities equally – such as the detergent additive regulations.[32]

Error Term and Estimation

Recognizing that some cities may have correlated residuals, I clustered[33] the error terms by state. This choice attempted to account for both political and geographical unobservables. Metropolitan areas may be defined both by locally-specific regulatory, demographic and market factors as well as by state-specific factors. The regulatory dummies and city fixed effects should remove most variation in local factors, but several time-correlated state-level unobservables could still remain. Variables that are likely to be constant across cities within a given state (but vary between states and over time) may include political and governmental characteristics (e.g. state taxes on income and consumption, state business taxes and investment) and any other state-level consumer demographics correlated with fuel prices (e.g. household income, average vehicle fleet, etc.). One could argue that the impacts of state government on fuel prices are small compared to demographic or market effects and that it would be more appropriate to cluster error

[32] Low-sulfur and ethanol-blended (E10) gasolines were decidedly not phased in equally across cities, however. This fact presents a potential problem for my model. Both low-sulfur and renewable fuel standard regulations set fuel content mandates at the producer level. Refiners were assigned a minimum production quota for regulated fuels but could otherwise choose in which market(s) to sell and/or distribute said fuels. Thus, the distribution of E10 and low-sulfur fuels (during the regulation phase-in years) might not have occurred equally at the retail level across cities. If this was so, annual fixed effects would not remove the price impacts of these regulations and RVP and RFG variables could be biased if the effects of low-sulfur and ethanol-blended fuels are significant. At least one previous study (Walls and Rusco 145-164) found no significant price effect related to low-sulfur gasoline. However, a few previous studies have found relatively large and statistically significant impacts of ethanol blending on RFG fuel (Brown et al. 1-19; U.S. Government Accountability Office ; Muehlegger ; Walls and Rusco 145-164). For this reason, I conducted the additional specification test discussed in the Ethanol Blending and State MTBE Bans section.

[33] See Wooldridge ("Cluster Sample Methods" 133-138) for a concise yet analytically thorough explanation of clustering theory.

terms by geographic region. I do not refute the presumption that in some cases this specification may be appropriate and perhaps preferable to state-level clustering (e.g. certainly, geographic residuals should be more highly correlated between Baltimore and Washington, DC than between Buffalo and New York City). However, geographic clustering alone neglects the effect of all non-gasoline[34] state taxes and political factors. Moreover, geographic or regional error-clustering is subject to a large amount of researcher discretion when defining the boundaries of each cluster.[35] State-clustering, while imperfect, utilizes clearly-defined boundaries and rests upon a solid theoretical underpinning. Relative to no clustering, state-clustering of residuals will not alter estimated variable coefficients using OLS regression; however, clustering will result in larger – but more believable – standard errors.

Monthly Time Trend Model

Because RVP regulation is almost perfectly correlated with the summer season, any seasonal price effects are indistinguishable from regulatory price effects. Additionally, summertime volatility controls *of RFG* are difficult to quantify using the basic model. I considered the use of city-invariant month dummy variables (i.e. *January*, *February*, *March,* etc.) as a means to correct these problems but rejected this idea for use in the basic model because of the aforementioned multicolinearity concerns. Instead, I opted for a model which included monthly time trends. Using sample cities as groups, this model estimated separate time fixed effects for each month/year combination. By treating each city individually and by utilizing within-year regulatory and price variation, this model specification better differentiates RVP

[34] Recall, gasoline tax was previously subtracted from the data; here I am referring to other state taxes.

[35] For example, if Baltimore and Washington, DC are clustered, should Philadelphia be included also? What about Newark, NJ or Norfolk, VA?

effects from seasonal time effects than does the basic model. However, use of month effects increased flexibility at the expense of statistical power. Error terms were clustered by *city* because there were insufficient observations to cluster by state. I estimated two versions of the monthly time trend model: one using only summertime data, and the other using full-year data.

The summer-subsetted version of the monthly time trend model is quite similar to the basic model, since it did not utilize any additional seasonal variation. This model provided a useful specification test for my use of *year* fixed effects in the basic model. A large difference in price effect estimates between the basic model and the summer-subsetted monthly time trend model could indicate the presence of unobserved within-*summer* price variations due to regulations. While not predicted by any theory, such a phenomenon could have rendered the basic model's use of year fixed effects inappropriate. Fortunately, the results of the summer-subsetted monthly time trend model appear consistent with the basic model estimates, reaffirming the appropriateness of the latter's specification.

A primary purpose of the monthly time trend model was to take advantage of additional seasonal (within-year) variation in the data. By using twelve months of data, rather than three, the full-year version of this model might better remove the effects of naturally-occurring seasonal price fluctuations[36] and provide more accurate annual average estimates of the marginal impacts of reformulated gasoline regulation.[37] Perversely, however, the full-year model could

[36] Due to demand increases (e.g., increased driving due to vacation travel), supply shocks (e.g., increased prevalence of hurricanes), and other factors, motor fuel prices tend to rise during the summer months. If prices of unregulated gasoline and low volatility gasoline rise by the same cent per gallon amounts, then the basic model's price effect estimates should be unbiased by seasonal price fluctuations. However, if regulated and unregulated fuel prices change separately (or if a price differential already exists between fuels, and summer prices rise by a constant percentage), then the basic model could produce biased results.

[37] As discussed previously in the Regulation Variables section, the use of full-year data can reduce potential bias in RFG price effect estimates. This is because RFG may actually cost more during the summer (when it is subject to

also lead to a downward bias in RVP coefficient estimates.[38] The lesson of this is that there is no one perfect model for estimating the price effects of motor fuel regulations – each specification has its own advantages and limitations. While the results of different models might not be directly comparable from a purely theoretical perspective, reasonable consistency of their estimates would reinforce my Basic Model methodology and conclusions.

Multiple RVP Regulations Model

Some states have chosen to enact summertime low volatility gasoline standards more stringent than the federal standards. As mentioned earlier, several sample cities were subject to gasoline RVP limits of 7.2 psi and 7.0 psi. Since lowering fuel volatility requires additional refining processes (to remove very light hydrocarbon molecules from gasoline), economic theory predicts that these processes incur marginal costs to producers, who then pass along some of the costs to consumers. These marginal refining costs (along with additional marginal price effects from changes in market power, geographic isolation, etc.) should be reflected in higher retail fuel prices. These marginal price effects could likely differ between different stringencies of volatility limits. While my small sample size of "very low" RVP cities prohibited inclusion of multiple RVP variables in the basic model, I did however conduct a specification test which separated summertime low volatility regulations into two categories: RVP = 7.8 and RVP ≤ 7.2. This

---

stricter volatility controls), and because the basic model's use of a summer subset may lead to an overestimate of the annual-average RFG price effect.

[38] While not an issue for summer-subsetted data, the fact that low RVP fuel supplies are likely phased in gradually throughout the month of May creates a problem when using full-year data. Because the dummy variable method can only model a discrete regulatory change, and because the summertime RVP transition is not discrete but occurs throughout the month of May, my regressions which used full-year data may have underestimated the real magnitude of RVP regulation impacts.

model was identical to the basic model, except that there were two separate RVP variables to reflect the two regulatory categories. This model is shown below in equation form:

$$P_{i,t} = RVP78_{i,t} + RVP72_{i,t} + RFG_{i,t} + \alpha_i + \beta_{year} + \varepsilon_{i,t}$$

City-Specific Price Effects Model

My price effect model provided single-value RFG and RVP coefficients under the assumption that regulatory price impacts stayed the same over each year and in each city. These calculated coefficient estimates represented only average values for all cities and time periods and ignored the possibility that fuel regulations could have differential impacts across cities and throughout time. Perhaps some cities experienced larger price impacts due to fuel regulations than others. Perhaps average price effects declined over time due to improved production efficiencies or economies of scale as regulations became more widespread. One publication found that RFG price effects varied by up to eight cents between sample cities (Brown et al. 1-19). The same study also observed a slight decrease in the average RFG price effect when using data that included a more recent date range.

To test by what extent RFG and RVP price effects varied *across cities*, I estimated an additional model which interacted each regulation with the cities implementing that regulation. This model took the following form:

$$P_{i,t} = (RVP)_{i,t}\, x(city)_{i,t} + (RFG)_{i,t}\, x(city)_{i,t} + \alpha_i + \beta_{year} + \varepsilon_{i,t}$$

This specification produced *city-specific* price effect estimates which I used in some of the welfare analysis calculations explained in the Discussion section. As discussed earlier, to test for changes in price effects *over time*, the main regression models each utilized three different date ranges.

CHAPTER 5

RESULTS

This chapter begins by explaining the results from the three regressions estimated using the Basic Model. It then discusses the six regressions from the Monthly Time Trend Model and the one regression from the Multiple RVP Regulations Model. All of these regression estimates are summarized in Table 2 and are displayed completely in the Appendix. The results from the City-Specific Price Effects Model (presented in Table 4 and the Appendix) are also presented here. I explain an additional specification test to assess the impacts of ethanol blending, and I also discuss an important feature of my data which constrained my ability to estimate certain price effects.

Basic Model

Statistical results from the basic model and full date range are shown in column (I) of Table 2. Based on data for the entire sample (1992-2010) for the summer months, I found that the presence of RFG regulation was associated with a 5.96 cent per gallon (cpg) increase in the average retail price of gasoline in affected cities. Similarly, gasoline volatility regulations more stringent than the nationwide summer-month RVP 9.0 baseline increased fuel prices by 0.67 cpg. Clustering standard errors at the state level, the RFG estimate was significant at the $\alpha = 0.05$ significance level, while the RVP estimate was insignificant. These findings are consistent with the results of previous literature: Walls and Rusco found a significant price increase of 6.6 cpg for ethanol-blended RFG fuel and an insignificant price increase of 0.48 cpg for RVP 7.8 fuel (Walls and Rusco 145-164). Brown et al. found a slightly lower effect for ethanol-blended RFG of 4.1 cpg and a slightly higher – yet insignificant – effect of 1.1 cpg for low-RVP gasoline.

The basic model results from years 1992-2000 and 2001-2010 are presented, respectively, in columns (II) and (III) of Table 2. On the surface, these results indicate that the average costs to the consumer of RFG regulation remained fairly consistent (slightly less than six and one half cents per gallon) between the first six years and latter nine and a half years of the fuel program. However, it is important to note that there is absolutely no within-city variation in reformulated gasoline regulation during the latter time period, so the RFG dummy may accidentally capture some city-specific effects unrelated to fuel content. If this is the case, the estimated RFG price effect may be an overestimate.

The RVP estimates are more perplexing. For the first half of the years since Phase 2 of the program was first implemented, RVP regulations less than or equal to 7.8 psi appear to have had a positive but statistically insignificant price effect of over one cent per gallon. However, for the latter range of years RVP regulation appears associated with a highly significant 4.00 cpg *decrease* in fuel prices. This unexpected result disagrees with theoretical predictions that volatility restrictions should increase consumer prices, and may indicate a problem of multicolinearity.

Additionally, the fixed effects estimated from regression model (II) appear to decrease in magnitude for most cities when the later date range of regression model (III) is used (see Table 3). At the same time, the estimated intercept (error) term is nearly twice as large in the model which used the later date range. This may imply that during later years (i.e. the 2000s) omitted variables accounted for a greater proportion of overall variation. The low-sulfur gasoline program and ethanol blending (due to both state MTBE bans and the 2005 EPAct / 2007 EISA renewable fuel standards) are two possible omitted variables which could have influenced these results.

Monthly Time Trend Model

Price effect estimates using the summer-subsetted monthly time trend model are shown in columns (IV), (V) and (VI) of Table 2, for the entire dataset, the years 1992-2000 and the years 2001-2010, respectively. The results of the former two regressions appear quite consistent with the original model results, however the RVP estimate for years 1992-2000 is now statistically significant at the $\alpha = 0.05$ level. Unfortunately, regression (VI) did not produce a valid estimate of the RFG effect because the variable was dropped by the computer due to multicolinearity issues. Additionally, the RVP estimate from regression (VI) remained a perplexing and statistically significant negative 4.00 cpg.

The results from the full-year monthly time trend model are shown in columns (VII), (VIII) and (IX) of Table 2. RFG variable estimates decreased in magnitude by over 2.0 cpg in all cases. This suggests that reformulated gasoline price effects may have been significantly greater during the summer (volatility-controlled) season and that use of summer-subsetted data may have resulted in an overestimate of price effects. RVP estimates also decreased in magnitude and were statistically insignificant. The unusual negative RVP estimate for years 2001-2010 decreased in magnitude to negative 0.27 cpg and became statistically insignificant from zero.

Multiple RVP Regulations Model

When the original model was specified with two RVP variables to account for the observed differences in city summertime gasoline volatility limits, the more stringent of the fuel regulations had large and significant price effects. As shown in column (X) of Table 2, RVP fuel restricted to 7.8 psi was associated with an insignificant price effect of only 0.55 cpg; however, gasoline with an RVP limit equal to or less than 7.2 psi had an average price increase of 8.02 cpg

– larger even than the RFG estimate of 7.38 cpg. This result was significant at the $\alpha = 0.01$ level. The large magnitude and high level of significance for this estimate suggests that state volatility restrictions which are more stringent than the federal (RVP 7.8) low vapor pressure requirements may impose very high costs on consumers (even though the federal regulations may not).

City-Specific Price Effects Model

As discussed in the Methods section, I interacted regulation and city dummies to test whether the effects of RVP and RFG programs varied across cities. Regression results from this separate model are displayed in Table 4. These results indicated the presence of a wide range of different price effects across regulated cities. While the national mean RVP effect was close to zero and insignificant, RVP effects in individual cities varied from approximately negative 6 cpg in Houston to positive 25 cpg in Portland.

This wide range in price effects may be explained by the absence of within-city regulatory variation in many sample cities. Since Portland implemented RVP 7.8 every year from 1992 onwards, and since the data is subsetted to include summer months only, there are no baseline gasoline price data for *non*-regulated fuel in Portland. The lack of within-city variation produces RVP regulatory dummies that exhibit perfect within-city correlation with the city-specific fixed effect dummies. This results in city-specific price effect estimates which may accidentally capture much of the unobserved city-specific effects. Unfortunately, this is a problem for multiple cities in the dataset.

City-specific reformulated gasoline price estimates also displayed a wide range of values: in New York, RFG had a negative 11 cpg effect while in Chicago the regulation had a positive

19 cpg effect. In all RFG locations, there exists some within-city regulatory variation simply due to the fact that RFG did not exist before 1995 while the dataset begins in 1992.

Ethanol Blending and State MTBE Bans

Although previous studies have found large and statistically significant differential price effects due to ethanol blending, my primary models did not account for ethanol. This omission was due to data constraints that made it impossible to precisely determine whether oxygenated fuel contained MTBE or ethanol. Nevertheless, it was important to try to measure the marginal impacts of ethanol blending, so I conducted an additional, rather crude, specification test utilizing state-level MTBE bans as a source of variation. Recognizing that an MTBE ban could indicate a transition from MTBE blending to ethanol blending, I ran a regression of the following specification:

$$P_{i,t} = RVP_{i,t} + RFG_{i,t} + MTBE_{i,t} + \alpha_i + \beta_{year} + \varepsilon_{i,t}$$

Here, the variable $MTBE_{i,t}$ is a dummy that indicated the presence of a state-wide MTBE ban in city *i* at time *t*. For all dates prior to the effective implementation of the ban, this variable assumed the value of "0" and for all dates after the ban it equaled "1". To minimize variation due to complicating non-MTBE factors, I subsetted the data to include only the dates between January 1, 2000 and May 5, 2006. During this timeframe, the majority of state MTBE bans took effect and the federal renewable fuel standards had yet to achieve large-scale implementation. To avoid the complicating effects of the 2005 EPAct regulatory changes, I chose the latter date to coincide with the end of the federal requirement that RFG fuel be oxygenated. Because of the relatively short timeframe of data and because RVP estimates[39] were not the goal of this specification test, I utilized full-year data.

To elicit the marginal price effect of ethanol relative to MTBE, the MTBE ban date would ideally represent a discrete change in fuel type from MTBE to ethanol; however, this did not necessarily occur. If a city used ethanol prior to an MTBE ban there would be no real effect of the ban and inclusion of such a city would bias downward the marginal price effect of ethanol blending. As opposed to the Midwestern states, many of which predominately blended ethanol prior to enactment of MTBE bans, the East Coast states had historically oxygenated gasoline using MTBE. I planned to further subset the data to include only PADD 1 (East Coast) cities so as to reduce the possibility of downward bias due to previous ethanol blending.

Unfortunately only two eastern states within my sample dataset – New York and New Jersey – had actually enacted an MTBE ban (and only the former had done so during my selected date range), so this geographically-subsetted specification was not possible. Instead, I used all 15 sample cities which had implemented an MTBE ban during the given time period (see Table 5 for a complete list of affected sample cities and their MTBE ban implementation dates).[40] Because of the implicit downward bias due to the inclusion of sample cities which likely blended

[39] It is important to note that there currently exists a 1.0 psi waiver granted to low RVP gasoline blended with between 9-10% ethanol (i.e. E10 fuel). In these RVP-regulated areas, E10 fuel is allowed a higher summertime volatility limit of either 8.8 psi or 10.0 psi. This waiver allowance further complicates the measurement of RVP price effects and the elicitation of ethanol blending impacts, and may partially explain why my RVP coefficient estimates decreased during the 2000s. In theory, as more ethanol was blended into gasoline due to the renewable fuel standards, and E10 comprised a larger percentage of total fuel consumption, more fuel was granted a 1.0 psi RVP allowance and average volatility restrictions likely became less stringent. However, this would also imply that average RVP price effects had exceeded average ethanol blending price effects, a situation which does not appear to have been true.

[40] To create this list, I adapted to my sample cities EPA's "State Actions Banning MTBE (Statewide)" document.

some amount of ethanol all along, my estimated *MTBE* coefficient represented a *lower-bound* estimate for the marginal price effect of ethanol blending versus MTBE blending.

The results of this specification test – although still statistically inconclusive – did not soundly reject the hypothesis that ethanol blending impacted fuel prices the same as MTBE blending. The regression yielded a positive MTBE ban price effect that was equal to 5.5 cents per gallon; however this was only significant at the $\alpha = 0.11$ level.

Oddly, at 11.3 and 11.4 cents per gallon respectively, RFG and RVP estimates were much larger in magnitude and more significant than previous regressions had found. While the more than five cent per gallon *MTBE* effect seemed consistent at face value with previous ethanol blending cost estimates (i.e. Brown et al.'s 4.1 cpg estimate or Walls & Rusco's 5.7 cpg estimate), I am cautious to read too much into my result due to the fact that it is statistically insignificant and nominally only half as large as the regression's estimate for RVP effect. If the *MTBE* effect were half as large as the (insignificant) RVP effect determined from the main model specification, then its magnitude would not be much different than zero.

On the other hand, it is important to reiterate that this *MTBE* effect provides a lower-bound estimate for the true ethanol blending effect due to the fact that some included sample cities likely blended ethanol before enactment of state MTBE bans.[41] While it is certainly possible that ethanol blending could have had a significant impact on fuels prices and that exclusion of this variable biased my results (in particular for regressions using the 2001-2010

[41] Additionally, direct comparison of ethanol blending estimates from different studies is complicated by the fact the previous researchers have used different specifications and baseline fuel types. For instance, Brown et al.'s 4.1 cpg estimate appears relative to fuel produced with no oxygenate blending rather than relative to MTBE-blended fuel; consequently, my (nominal) results could imply an ethanol blending price effect that is significantly larger than the Brown et al. estimate.

date range), I am nevertheless hesitant to draw too many conclusions from this rough and imperfect specification test.

A Data Limitation

While it was impossible for me to accurately determine the price impacts of ethanol blending, my ambiguous results were largely due to inadequate data. My raw price data contained only three dimensions: date, city and price. All fuel attributes, connected to a given price data point, were inferred from knowledge of federal and state regulatory requirements. Consequently, where fuel attributes were not determined by city-and-date-specific mandates (as in the case of ethanol-blended, MTBE-blended and low sulfur gasoline), there was no reliable way to determine what fuel attributes were actually reflected in the price data. Even in the cases where city-and-date-specific regulations did exist, imperfect enforcement, the presence of fuel arbitrage between cities, and non-discrete regulatory phase-in periods prevented fuel attributes from being known with 100% certainty. Thus, there was no perfect guarantee that gasoline prices in an RFG or RVP city actually represented RFG or RVP fuel.

It is possible that these problems could be easily (although not inexpensively) solved through the use of price data that differentiates between specific fuel attributes. With accurate knowledge of whether oxygenated fuel was blended with MTBE or ethanol (and to what percentage level), and with confidence that observed prices reflected sales of specific fuel types, it would have been possible to determine much more credible estimates for the price effects of ethanol blending. It is fairly easy to find datasets which differentiate between conventional and reformulated gasoline types (EIA supplies such price data for free at the weekly, city-level; nevertheless, there were too few cities in this dataset for the purposes of my research). However, it is much more difficult to find weekly city-level data which contains RVP, sulfur, MTBE or ethanol attributes. For-profit petroleum data companies – such as the Oil Price Information Service (OPIS) – may differentiate gasoline fuel prices by some of the above-listed attributes; however proprietary, purchase-only datasets can be prohibitively expensive for many researchers and were so for this project. Regardless, future research projects could benefit greatly from knowing exactly what fuel types are represented by their price data.

CHAPTER 6

DISCUSSION

In this chapter, I discuss the significance of my findings regarding both low volatility gasoline and reformulated gasoline. I discuss the implications of a recent study which has assessed the air quality *benefits* of federal RVP, and I present a conceptual welfare framework which I then use to estimate the total consumer costs of the RFG program. I use these cost changes, in conjunction with estimated health benefits of the 1990 Clean Air Act Amendments, to qualitatively assess the cost-effectiveness of this program.

Low Volatility Gasoline

Besides a couple of inconsistent (and likely erroneous) strongly negative coefficient results from the 2001-2010 data regressions, the federal (7.8 psi) RVP program exhibited no significant impacts on retail prices when either the basic model or the monthly time trend model with yearly data was estimated. Because of the RVP program's low price effect coefficient (between 0 and 0.8 cents per gallon) and the high statistical uncertainty surrounding its estimation, I did not model welfare changes for this regulation. Changes in consumer costs and gasoline demand – if existent at all – are likely to be small in magnitude. However, RVP price effects may vary significantly by city. As my regulatory interaction specification test found a range of city-specific price effects from negative 6 cpg up to approximately 25 cpg,[42] it is

[42] This excludes the specification test's finding of a 25 cent per gallon impact of RVP regulation in Portland, Oregon. I disregarded this outlier result because its value seemed unreasonably high – a possible indication that the regulatory coefficient captured some city-specific effects related higher PADD V fuel prices.

possible that while average RVP effects were insignificant, individual RVP counties may have indeed experienced significant price increases.

Perhaps the most meaningful finding regarding the RVP program came from the Multiple RVP Regulations Model. If the results of this regression are believable, then RVP restrictions that are more demanding than the federal limit (i.e. RVP $\leq$ 7.2 psi) increase retail fuel prices by an average of over 8.0 cents per gallon. This result vastly exceeds the analogous Walls and Rusco (Walls and Rusco 145-164) estimate of 4.3 cents per gallon, and it even exceeds my estimated RFG price effect.

The difference with the Walls and Rusco study could be due in part to my use of retail price data. It could also arise from the application of different estimation techniques (for instance, Walls and Rusco corrected their data for serial autocorrelation, whereas I did not). If these were the sole explanations however, large differences should also arise between the two studies' estimates of other regulatory price effects. This is not apparent for RVP 7.8 regulations or for ethanol blending impacts; however, it may be so for RFG (remember, Walls and Rusco found no significant effect of MTBE-blended reformulated gasoline). Regardless of which study is correct, the high costs of more stringent, state-imposed RVP limits cannot be denied.

Determination of exactly *why* very low RVP fuel is so much more expensive is beyond the scope of this paper. However, as Brown et al. (Brown et al. 1-19) has suggested, increased geographic isolation and supplier market power may contribute significant incremental price effects to any already increased producer costs.

As of 2010, five sample cities had ever implemented RVP limitations of 7.2 psi or less.[43] These municipalities were subject to ozone State Implementation Plans which sought to impose

[43] This does not include cities which have implemented effectively even lower volatility limits through RFG program VOC reductions.

stricter limits than the federal standard for nonattainment areas. While the per-gallon price effect of these stricter volatility controls likely exceeds the per-gallon RFG price effect, annual per-capita city-level *consumer costs* are probably lower for consumers of very low RVP (than for RFG consumers) fuel due to the fact that RVP regulations are not implemented year-round. Since far fewer cities require very low volatility gasoline than reformulated gasoline, nationally-aggregated consumer costs should also be lower than RFG consumer costs.

The *benefits* of RVP fuel regulations have been recently challenged by academics. Forthcoming research in the American Economic Review by Auffhammer and Kellogg (Auffhammer and Kellogg) suggests that ozone regulation broadly targeting motor fuel volatility does not substantially reduce ambient ozone concentrations. Their research regressed a panel of daily ozone concentration data from over 720 monitoring locations between years 1989 and 2003 against explanatory variables that controlled for region- and time-specific effects, weather effects, and demographic effects including county-level personal income. After estimating both difference-in-differences and regression discontinuity models, Auffhammer and Kellogg concluded that traditional RVP controls led to statistically insignificant reductions in peak ground-level ozone of little more than 1% in most places.[44] This result, if credible, implies that the prolific summertime RVP fuel controls required by EPA and implemented by many state regulators may not provide substantial direct positive benefits related to ozone reductions.

Fortunately, my findings suggest that most RVP areas have not incurred large incremental costs of regulation. This result might seem to imply that total economic impacts of

[44] The California Air Resources Board's unique volatility program *was* found to reduce ambient ozone concentrations. In suburban locations, reductions averaged around 10% and were statistically significant at the 1% level. The authors attribute this phenomenon to the fact that California specifies which (typically, the most ozone-formative) gasoline components must be removed to achieve low vapor pressure mandates, whereas the federal program does not specify.

RVP regulation have been neutral. However, there may exist unobserved administrative, regulatory compliance, or enforcement costs that are not captured by my price effect estimates. Moreover, the few areas implementing very low (i.e. ≤ 7.2 psi) RVP requirements have likely realized significantly negative total economic impacts due to the high price effects and consumer costs of these volatility regulations. Nevertheless, due to the uncertainty of my estimates, the relative recentness of the Auffhammer and Kellogg article and the lack of additional RVP benefit studies to substantiate their findings, I am hesitant to draw any definitive conclusions about the overall economic cost-effectiveness of gasoline volatility regulations.

Reformulated Gasoline

The finding that RFG regulation significantly increased retail gasoline prices in regulated cities by approximately 3.4 to 6.0 cents per gallon is consistent with multiple previous studies which utilized shorter time series of data. While lack of variation made it difficult to assess whether the price impacts of the RFG program have evolved over time, the fact that my average estimates (based on over 18 years of data) were nearly identical to earlier estimates (based on much shorter sets of data from years closer to the initial implementation date of the program) suggests that reformulated gasoline has had real, lasting effects on consumer pump prices. Future researchers and policymakers should be aware of the potentially large impacts of ethanol blending as well as the possibility of large variations in RFG price effects between cities.

Since a loss of economic welfare due to higher prices from regulation may be partially offset by a decrease in external damages resulting from lower demand for fuel and driving, welfare changes due to regulation are quite complex. Although I cannot estimate the complete welfare impacts of fuel regulations using my reduced-form price effect model, I can still gain valuable and policy-relevant information through some basic calculations. In the following section, I present the conceptual framework and results from a simple, "welfare analysis" model for fuel-based regulations, specifically the RFG program.[45]

Welfare Analysis

This section begins with the presentation of a conceptual welfare framework for motor fuel regulations. I then estimate aggregate incremental consumer costs resulting from reformulated gasoline regulation. This calculation utilizes my estimated city-specific regulation price effect coefficients as parameters. Due to the absence of fine-grained, fuel-specific quantity data, it is impossible to confidently estimate changes in demand or net economic surpluses (i.e. consumer, producer, or total). Nevertheless, under a set of quite restrictive assumptions, I do calculate and present a crude estimate of the change in quantity demanded for gasoline. Given my consumer cost estimates, I back-calculate one estimate of health-related benefits that might be necessary for RFG to be deemed cost-effective.

Conceptual Welfare Framework

The welfare impacts of motor fuel regulations can be simply conceptualized as costs and benefits affecting two different markets. Fuel regulation costs occur within the market for gasoline, whereas the benefits of these regulations occur within a "market"[46] for air quality.

[45] Effects of RVP regulation could be modeled using identical methodology. However, I did not include these calculations because the regression price effect estimates of RVP regulation were insignificant from zero.

[46] Air quality, the "market" equilibrium of which is defined by the intersection of society's marginal benefits of clean air and marginal costs of pollution abatement curves, is a classic example of a non-market good – a core theme of numerous environmental economics textbooks. See (Perman et al.) for examples and the theoretical framework of this concept.

Gasoline market costs may result from increased production costs (including administrative and regulatory compliance costs) at the petroleum refinery or oxygenate blender. In the long-run, the majority of these costs are passed onto consumers. Air quality benefits of fuel-based regulations accrue from the *direct* reductions in health and environmental damages attributable to air pollution. Changes in societal welfare from fuel-based regulations can be regarded as the summation of welfare changes in the market for air quality and the gasoline market.

Welfare changes in the air quality market are difficult to monetize, and it can be equally difficult to attribute causality for these changes to the impacts of specific fuel-based regulations.[47] While I do not attempt to thoroughly quantify or monetize air quality benefits, one could possibly do so using a model that expresses benefits from changes in air quality as the multiplicative combination of various environmental and health parameters (e.g. reduced pollution emission levels or ambient concentrations, human and environmental exposure rates, dose-response rates and mitigation costs). Very similar "regulatory risk assessment models" have been used to conceptualize and study optimal environmental regulation for decades (Crouch and Wilson 47-57; Lichtenberg and Zilberman 167-178). In this paper, I choose to *qualitatively* assess the aggregate air quality benefits of reformulated gasoline using non-monetized EPA health benefits estimates for the 1990 Clean Air Act Amendments in aggregate. This procedure is admittedly incomplete and does not support a true cost-benefit analysis; however, the main focus of my research was to assess the costs of regulation, not the benefits.

[47] The air quality market actually consists of multiple sub-markets and may be disaggregated by individual pollutants (ozone, NOx, air toxics, etc.). This creates a potential problem for reduced-form estimation, as these sub-markets may not be separable into the strictly exogenous variables required for linear regression. The marginal benefits of air quality improvements may be highly uncertain, as they are determined by complex or unobservable human and environmental health variables such as exposure levels and dose-response rates. The marginal costs of air quality improvements may also depend upon proprietary industry abatement cost information, making them difficult to ascertain for policymakers.

Welfare changes in the gasoline market are more easily quantifiable and monetized than are the benefits that accrue in the air quality market. When fuel-based regulations are imposed, these content controls may incur higher production costs to the refiner (or blender, in the case of oxygenation). These marginal costs are reflected in higher prices for wholesalers, retailers and consumers. While a few studies have acknowledged the existence of incomplete (and asymmetric) price pass-through in wholesale and retail markets in the short-term (Karrenbrock 19-29; Borenstein, Cameron and Gilbert 305-339), most of these studies also have found a high-level of pass-through in the long-term.[48]

Since my welfare analysis focuses on the long-term, aggregate impacts of fuel regulations, I assume that any changes in refiner or blender costs are completely passed-through to the retail prices paid by consumers.[49] I also assume that the retail gasoline market is perfectly competitive with a perfectly elastic supply curve. This assumption seems reasonable given the large number of small sellers and the fact that gasoline is a largely homogeneous product. With a downward-sloping demand curve for gasoline and a positive and constant cent-per-gallon price effect for fuel regulation, I define the incremental consumer costs to be the observed quantity of

---

[48] For instance, Karrenbrock found that a 10 cpg increase in the wholesale price for premium gasoline resulted in a 6.4 cpg increase in the retail price during the first month, and a 3.1-3.5 cpg increase during the second month. Borenstein, Cameron and Gilbert found that a 10 cpg increase in the price of crude raised retail prices by 6.7 cpg after four weeks and 8.1 cpg beyond ten weeks.

[49] A caveat to my welfare analysis is that the simple examination of price differentials between regulated and unregulated fuels may not in fact capture the entire costs of regulation. Fuel regulatory programs may very likely incur added administrative costs to regulators as well as industry-wide producer compliance costs that are not specifically reflected in regulated fuel prices. Additionally, any added production costs related to RVP or RFG may be allocated across the costs (and pump prices) of unregulated fuel. If this occurs, relative fuel prices may not appropriately reflect the incremental costs of regulation and my model is likely to underestimate actual economic impacts. Since my price effect model measures only the incremental costs of regulated fuels relative to unregulated fuels, it implicitly assumes that the prices of unregulated fuels are unaffected by regulation. However, if market impacts of the RVP or RFG programs have led to increases in the prices of unregulated fuels, then my price effect estimates and welfare analysis results will understate the true economic impacts of these regulations.

regulated gasoline consumption multiplied by the estimated price effect.[50] This area is shown in Figure 4 as the green-shaded rectangle, where *MPC1* is the pre-regulation marginal private cost curve (i.e. supply curve) of retail gasoline and *MPC2* is the post-regulation marginal private cost curve.

Gasoline consumption incurs external costs related to the climate change impacts of carbon dioxide, the effects of local air pollution (i.e. tropospheric ozone, NO_x, VOCs and air toxics) on human health and environmental quality, and – arguably – vehicular accidents and congestion.[51] Assuming that marginal external costs are constant on a per-gallon basis, the pre- and post-regulation marginal social cost curves for the retail gasoline market are represented in Figure 4 by *MSC1* and *MSC2*, respectively. Because of the presence of these external costs, the measurement of consumer costs alone overstates the magnitude of actual welfare change in the gasoline market. Given the existence of external costs, the actual change in welfare is denoted as the blue-shaded area in Figure 4. This area may be approximated using the parameters of gasoline demand elasticity, marginal external cost, gasoline consumption and the price effect of regulation. However, due to the high levels of uncertainty regarding these parameters, I do not attempt to calculate actual welfare changes in the following section. Instead, I estimate the rectangle of incremental consumer costs.

[50] Because consumer demand is not perfectly inelastic, a rise in price will reduce the quantity of gasoline demanded. Hence, because equilibrium quantity changes, this measurement of incremental "consumer costs" is not exactly equal to the actual change in consumer expenditures on gasoline (which in fact will be somewhat lower).

[51] Economists Ian Parry and Kenneth Small have argued that to internalize external costs (including, to a large extent, congestion costs) the optimal tax for gasoline in the United States should be just over one dollar per gallon (Parry and Small 1276-1289).

Methods

To estimate consumer costs, I first created a model of yearly city-level gasoline consumption. Gasoline quantity data is difficult to obtain at the city-level, so this model relied on the interpretation of various other data, such as average vehicle age, fuel efficiency, and total vehicle miles travelled per year. These data were collected and interpolated from the Federal Highway Administration's 1995, 2001 and 2009 National Household Transportation Surveys. To begin, I created a data matrix, $VMT_{i,year}$, consisting of total vehicle miles travelled in each of the eleven statistical sample area (CMSA or MSA) [52] corresponding to my sample RFG cities for years 1995 through 2009:

$$VMT_{i,year} = \begin{bmatrix} VMT_{1,1995} & \cdots & VMT_{1,2009} \\ \vdots & \ddots & \vdots \\ VMT_{11,1995} & \cdots & VMT_{11,2009} \end{bmatrix}$$

Here, each $VMT_{i,\,year}$ term represents the total annual vehicle miles travelled in CMSA/MSA "*i*" during year "*year*".

I estimated the average vehicular fuel efficiency (in each area at each year) by relating a similar matrix of the average age of new vehicles in each area and year, $AGE_{i,year}$, to a matrix of nationally-averaged new vehicle fuel efficiencies in each year, MPG_{year}. Mathematically, these matrices are denoted as follows:

[52] Metropolitan Statistical Areas (MSAs) and Consolidated Metropolitan Statistical Areas (CMSAs) are "geographic entit[ies] defined by the federal Office of Management and Budget for use by federal statistical agencies" (U.S. Census Bureau).

See Figure 4 for a map of MSAs and CMSAs, as of 1996.

$$AGE_{i,year} = \begin{bmatrix} AGE_{1,1995} & \cdots & AGE_{1,2009} \\ \vdots & \ddots & \vdots \\ AGE_{11,1995} & \cdots & AGE_{11,2009} \end{bmatrix}$$

$$MPG_{year} = [MPG_{1980} \quad \ldots \quad MPG_{2009}]$$

The MPG_{year} matrix represents a weighted average of car and light truck miles-per-gallon estimates for each year from 1980 through 2009.[53] I transformed the vehicle age matrix, by subtracting the age value from the sample year, to display the year that the average vehicle in each area was new. This transformed age matrix, $DATENEW_{i,year}$, is shown below:

$$DATENEW_{i,year} = year - AGE_{i,year} = \begin{bmatrix} 1995 - AGE_{1,1995} & \cdots & 2009 - AGE_{1,2009} \\ \vdots & \ddots & \vdots \\ 1995 - AGE_{11,1995} & \cdots & 2009 - AGE_{11,2009} \end{bmatrix}$$

After rounding to the nearest whole year, I combined the values of the $DATENEW_{i,year}$ matrix with the vehicle fuel efficiency matrix to produce an area- and year-specific fuel efficiency matrix, $MILEAGE_{i,year}$:

$$MILEAGE_{i,year} = \begin{bmatrix} MPG_{(DATENEW_{1,1995})} & \cdots & MPG_{(DATENEW_{1,2009})} \\ \vdots & \ddots & \vdots \\ MPG_{(DATENEW_{11,1995})} & \cdots & MPG_{(DATENEW_{11,2009})} \end{bmatrix}$$

[53] The ratio of cars to light trucks is assumed to remain constant across cities and time, and this ratio is modeled as a variable for all welfare analyses. If the variable takes a value of "0" this implies that all vehicles are light trucks (which have lower average efficiencies); a value of "1" implies that all vehicles are cars. Because there is likely larger variance in fuel efficiency between cars and light trucks than there is variance in the car/light truck ratio over time or between cities, I believe that the use of a time and city-invariant ratio can be justified as long as it is supported by sensitivity analysis performed using the extreme ratio values.

Dividing each term of the vehicle miles travelled matrix, $VMT_{i,year}$, by the corresponding term of the area- and year-specific fuel efficiency matrix, $MILEAGE_{i,year}$, I generated a matrix of estimated fuel consumed in each area during each year, $Q_{i,year}$:

$$Q_{i,year} = \frac{VMT_{i,year}}{MILEAGE_{i,year}} = \begin{bmatrix} \frac{VMT_{1,1995}}{MILEAGE_{1,1995}} & \cdots & \frac{VMT_{1,2009}}{MILEAGE_{1,2009}} \\ \vdots & \ddots & \vdots \\ \frac{VMT_{11,1995}}{MILEAGE_{11,1995}} & \cdots & \frac{VMT_{11,2009}}{MILEAGE_{11,2009}} \end{bmatrix}$$

The quantity estimates generated above were for the CMSA and MSA spatial areas sampled in the National Household Transportation Survey; however, these areas did not always perfectly coincide with my city sample locations or with the spatial boundaries of RFG fuel regulations (see Figures 5 and 6). This presented a potential complication to the determination of national welfare impacts. To account for this source of error, as well as uncertainty related to my price effect estimates, I specified and estimated two different models to provide a range of likely consumer cost changes.

To calculate a lower-bound estimate for total consumer costs due to RFG regulation, I aggregated each CMSA/MSA's fuel consumption data (as given in the $Q_{i,year}$ matrix) over the years of its RFG implementation, then multiplied the resultant fuel quantities by the corresponding city-specific RFG price effects determined from my price effect regression model. The resultant *city-specific* consumer costs are given by the following equation:

$$(\Delta Cost)_i = (\Delta P)_i \sum_{year} (Q_{i,year})$$

Here, $Q_{i,year}$ denotes elements of the fuel consumption matrix by city and year, and $(\Delta P)_i$ denotes terms of a city-specific RFG price effects vector. The $(\Delta Cost)_i$ term denotes the calculated city-specific consumer costs due to regulation. Summing these elements over all cities provides a nationally-aggregated estimate of total changes in consumer costs:

$$(\Delta Cost)_{TOTAL} = \sum_i (\Delta Cost)_i$$

This lower-bound model included only sample cities for which price estimates were available from my price effect regression. Since my price effect model excluded the entire state of California (which is an enormous consumer of federal RFG fuel and its more stringent California Air Resources Board formulation) as well as a few other locations with regulated gasoline requirements, this model under-represents national RFG consumption. To further promote conservativeness in my final estimates, I deemphasized gasoline demand by modeling each city's fleet as if it were composed of 100% cars and 0% trucks. I ran the lower-bound model using city-specific price effects determined by interacting cities with the presence of RFG fuel regulation.[54] Where two sample cities fell within the same CMSA/MSA area (i.e. Baltimore & Washington DC, and Newark & New York City), I omitted one city (lest I double-count fuel consumption data) and used the unweighted average price effect estimate of the two cities.

The upper-bound consumer cost model utilized a similar specification but required simpler data inputs. Instead of using city-specific RFG consumption and price-effect data, I used nationally-aggregated RFG quantity data (from EIA's "Petroleum Supply Annual") and my national average price effect estimate. Since I used aggregated national-level data and did not

[54] Specification and estimation of the City-Specific Price Effects Model is presented in the Methods chapter. The estimated coefficient s are displayed in Table 4 and are discussed in the Results chapter.

model city-level gasoline consumption for this upper-bound estimate, the car/truck ratio was irrelevant.

In addition to direct changes in consumer costs, I also roughly estimated the changes in gasoline consumption that resulted from imposition of fuel regulations. These calculations utilized the basic economic relationship between demand elasticity and changes in price and quantity:

$$\eta = \frac{\frac{\Delta Q}{Q}}{\frac{\Delta P}{P}}$$

Rearranging this equation to solve for ΔQ allowed me to estimate the changes in gasoline consumption in each city during each year:

$$\Delta Q_{i,year} = \frac{\eta(Q_{i,year})(\Delta P)_i}{P_{i,year}}$$

Here, the $P_{i,year}$ values are annual average prices for each sample RFG city, calculated from my Oil and Gas Journal price dataset. The $Q_{i,year}$ values are taken from my estimated fuel consumption matrix. The elasticity parameter η is a city- and time-invariant scalar value from Molly Espey's meta-analysis study (Espey 273-296).[55] After analyzing hundreds of different economic studies, Espey found that short-term and long-term gasoline price elasticities of demand averaged -0.23 and -0.43, respectively.

[55] For another good meta-analysis of gasoline demand elasticities, see Dahl and Sterner (Dahl and Sterner 203-210).

The above equation requires a few qualifications, and it likely would be unacceptable for any serious calculation of welfare impacts. First, it presumes that gasoline elasticity η is constant over time and space – an assumption which does not likely hold in reality. To be theoretically accurate, the equation also requires the overly-restrictive assumptions of a perfectly elastic supply curve and a constant elasticity demand curve. While my methodology for calculating demand changes may not be too accurate in a real-world scenario, I believe it is still instructional for demonstrating changes in demand for regulated fuel.

Summing the values of $\Delta Q_{i,year}$ over all cities and years provides a lower-bound aggregate change in consumption resulting from RFG regulation. I ran the same model using a national-average RFG price effect estimate of 6.00 cpg with annual unweighted average fuel prices from across the RFG cities in my OGJ price dataset. This model specification provided an upper-bound estimate of the change in gasoline consumption, and it is given below in equation form:

$$\Delta Q_{year} = \frac{\eta(Q_{year})(\Delta P)}{P_{year}}$$

<u>Results</u>

Summary results from the welfare analysis model are displayed in Table 6. I present lower and upper bound model results for both consumer cost changes and changes in gasoline consumption. Because the choice of gasoline demand elasticity can strongly influence results, and because elasticity tends to differ widely with the time frame of interest,[56] I have presented

[56] Gasoline demand elasticity is larger in magnitude in the long-term than the short-term. This is because, in the short-term, consumers can only effectively reduce demand by driving less. However, in the long-term, consumers can also purchase more fuel-efficient vehicles and reduce fuel demand by a much larger amount.

demand change estimates for both Espey's short-term (-0.23) and long-term (-0.43) median elasticity values. Detailed estimates for city-specific and aggregate consumer costs, as well as actual and modeled RFG consumption, are presented in Table 7.

As is evident in the tables, there exists a wide range of results between the lower and upper bound estimates for consumer costs and changes in quantity demanded. Reformulated gasoline regulations have cost consumers anywhere between $15.1 billion and $39.0 billion since initial implementation of the program in 1995. These numbers are calculated in real May 2010 dollars. The higher fuel prices directly attributable to the RFG program may have reduced domestic fuel consumption by between 2.3 billion gallons and 11.5 billion gallons. This latter number represents more than eight percent of *all* gasoline motor fuel consumed by the United States in year 2009; however, it must be taken with a grain of salt given the previous methodological concerns with my calculated demand changes.

Using the mean regulatory consumer cost value of $27.1 billion, the RFG program has incurred annualized incremental retail costs of over $1.7 billion during its approximately fifteen-and-a-half-year existence. Put another way, a 6.00 cpg increase in gasoline prices costs a hypothetical consumer, driving 12,500 miles per year in a 25 mpg vehicle, approximately $30 annually. This is no small amount.

It is important to recognize that these numbers only indicate direct changes in consumer costs. They do not represent total changes in either consumer surplus or net economic surplus, nor should the results be construed in any way as an indictment of the reformulated gasoline program. My price effect estimates and welfare calculations are based upon changes in the observed retail pump prices of gasoline, and these changes are only one effect of the RFG program. Most importantly, however, these numbers ignore the health and environmental *benefits* of the program.

Discussion

Unfortunately, the direct benefits of individual air quality compliance regulations are exceedingly difficult to measure and quantify with much certainty. Consequently, I am not aware of any benefit analyses that provide estimates for RFG specifically. However, I can conduct a simple break-even analysis to determine what benefits would be necessary for RFG to be economically advantageous from a cost-benefit perspective. Using EPA's recent estimate of $7.9 million per statistical life (Borenstein) and my annualized *consumer cost* estimate of $1.7 billion, the RFG program would need to prevent the equivalent of 215 deaths per year to be deemed worthwhile.

A recent EPA report (U.S. Environmental Protection Agency "The Benefits and Costs…Summary" 13) estimated that in aggregate the 1990 Clean Air Act Amendments prevented 1,400 ozone-related deaths in the year 2000 and approximately 4,300 deaths in 2010. Additionally, the report estimated that in 2010 these ozone reductions prevented 3.2 million lost school days and contributed (along with particulate matter reductions) towards 86,000 fewer emergency room visits and 41,000 fewer hospital visits for respiratory-related problems. While the EPA report counted aggregate ozone benefits (which are attributable to a combination of regulatory programs and not only RFG), it seems not unreasonable that the RFG program could be the mechanism behind a significant fraction of these benefits. If just ten percent of the annual ozone reductions attributable to the 1990 Clean Air Act Amendments were due to the RFG program, then the program would be economically beneficial. Because this estimate does not account for any *environmental* benefits from ozone mitigation, or human health benefits from the RFG program's reductions in air toxics, reformulated gasoline may be substantially more cost effective than these results imply.

Of course, the previous conclusions only hold true if use of RFG fuel actually results in reductions of air toxics and ozone. The former is clearly true since heavy metals and other hazardous pollutants are physically removed from the fuel during the refining process, and resultant tailpipe emissions show measurable decreases in these toxic species (U.S. Environmental Protection Agency "Phase II"). However, since vehicles emit only precursor pollutants (and not ozone itself), it is difficult say for certain that reduced emission levels of VOCs and NO_x precursors will automatically reduce the production (and consequently, ambient concentration) of ozone. Factors such as sunlight and temperature play a large role in driving the chemical reaction behind ozone formation, and other determinants such as time of day, location and weather patterns can affect the resultant concentrations of this capricious and short-lived criteria pollutant.

CHAPTER 7

CONCLUSIONS

This study has examined the economic impacts of gasoline content regulations designed to improve air quality. Using an innovative fixed effects econometric model with a lengthy panel of weekly retail data from 38 cities and over 18 years, I estimated the effects that both low volatility gasoline and federal reformulated gasoline programs have had on retail fuel prices.

Having concluded (as a few previous researchers have) that RFG regulation significantly increased consumer prices whereas average RVP regulation did not, I ran additional tests to evaluate both the price effects of different low volatility regulations as well as city-specific regulatory price effects. The latter test discovered a potentially large variability in the impacts of fuel regulations across cities. The former test found that states which have implemented gasoline volatility limits more stringent than the federal standard may incur very high incremental consumer costs. This second finding is broadly consistent with the results of previous studies, but is far greater in magnitude than most. This significant result warrants researchers and policymakers to carefully reevaluate many “boutique” RVP regulations.

Having estimated the effects of RVP and RFG programs on fuel prices, I then defined a fuel regulation welfare framework and attempted to estimate a few components of it. Modeling annual fuel consumption in sample metropolitan areas, I was able to estimate the total incremental consumer costs attributable to the RFG program. While information about the economic benefits of both fuel regulatory programs was somewhat uncertain, I was able to conduct a simple qualitative analysis to assess the cost-effectiveness of the RFG program.

Due to the low magnitude and insignificance of RVP regulation price effect estimates, I did not explicitly model the welfare implications of low volatility gasoline restrictions. However, I was able to draw a few simple conclusions about the cost-effectiveness of low volatility gasoline controls, based on the findings of a recent peer-reviewed study of the program's air quality benefits.

My conclusions reinforce the need for additional research on the benefits of fuel regulatory programs, the economic impacts of ethanol blending, and the spatial heterogeneity of fuel regulation price effects. In these efforts, future econometric studies should be mindful of (and attempt to avoid) the modeling problems created by the near-perfect correlation between the presence of volatility regulation (in affected cities) and the summer season. They should also be aware of the influences of seasonal price fluctuations and the limitations associated with the use of dummy variables to represent fuel regulations.

Policymakers in states which have imposed volatility limitations more stringent than the federal (7.8 psi) standard should carefully weigh the costs and purported benefits of these programs, consider transitioning to alternative fuel types (RVP 7.8, component-specific RVP akin to California's low volatility fuel requirements, RFG, or conventional gasoline). They should also consider the use of more cost-effective methods of mitigating tropospheric ozone formation from both mobile and stationary sources. EPA should allow for and incentivize the adoption of alternative ozone mitigation measures in State Implementation Plans.

While any model by definition is an imperfect representation of reality, the general agreement of my estimates with those from the existing literature hopefully adds credence to my price effect results. While it is true that high levels of uncertainty surround the calculation of the total costs and benefits of individual fuel programs, it is crucial to consider the societal and economic implications related to various implementations of the Clean Air Act and other environmental administrative actions. I am optimistic that my humble attempt to broaden the existing scope of air quality regulatory analysis will draw greater attention to this important area of environmental policy and will contribute towards more informed and increasingly beneficial decision-making.

APPENDIX

EXPANDED REGRESSION RESULTS

Basic Model, 1992-2010 (Table 2, Column I)

Linear regression

Number of obs	=	10373
F(19, 31)	=	.
Prob > F	=	.
R-squared	=	0.9659
Root MSE	=	12.86

(Std. Err. adjusted for 32 clusters in state)

value_EXT~10	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
rfg	5.964229	2.260375	2.64	0.013	1.354163	10.5743
_78	.6691421	1.689832	0.40	0.695	-2.777294	4.115578
place_dum_1	15.24339	2.979447	5.12	0.000	9.166766	21.32001
place_dum_2	7.601198	1.887168	4.03	0.000	3.752294	11.4501
place_dum_3	4.880941	1.411289	3.46	0.002	2.002599	7.759283
place_dum_4	6.199492	1.887786	3.28	0.003	2.349327	10.04966
place_dum_5	12.77352	1.689832	7.56	0.000	9.327085	16.21996
place_dum_6	12.55947	2.979447	4.22	0.000	6.482846	18.63609
place_dum_7	17.16634	2.979447	5.76	0.000	11.08971	23.24296
place_dum_8	30.20767	1.689832	17.88	0.000	26.76123	33.6541
place_dum_9	10.48455	2.979447	3.52	0.001	4.407931	16.56118
place_dum_10	3.524158	2.07e-10	.	0.000	3.524158	3.524158
place_dum_11	18.11834	2.534891	7.15	0.000	12.9484	23.28829
place_dum_12	7.477151	2.979447	2.51	0.018	1.400528	13.55377
place_dum_13	6.873708	2.072889	3.32	0.002	2.646024	11.10139
place_dum_14	(dropped)					
place_dum_15	6.536439	2.979447	2.19	0.036	.4598157	12.61306
place_dum_16	7.212912	1.887786	3.82	0.001	3.362747	11.06308
place_dum_17	5.925688	2.979447	1.99	0.056	-.1509353	12.00231
place_dum_18	(dropped)					
place_dum_19	12.524	1.689832	7.41	0.000	9.077561	15.97043
place_dum_20	4.445643	1.887786	2.35	0.025	.5954776	8.295808
place_dum_21	14.58673	1.887786	7.73	0.000	10.73656	18.43689
place_dum_22	5.016911	1.689832	2.97	0.006	1.570475	8.463347
place_dum_23	10.96624	2.979447	3.68	0.001	4.889621	17.04287
place_dum_24	7.917943	1.887786	4.19	0.000	4.067778	11.76811
place_dum_25	15.6771	1.689832	9.28	0.000	12.23067	19.12354
place_dum_26	13.76645	1.689832	8.15	0.000	10.32001	17.21289
place_dum_27	4.976155	1.411289	3.53	0.001	2.097813	7.854497
place_dum_28	2.605824	2.979447	0.87	0.389	-3.470799	8.682447
place_dum_29	8.291075	2.979447	2.78	0.009	2.214452	14.3677
place_dum_30	6.529522	1.689832	3.86	0.001	3.083086	9.975958
place_dum_31	(dropped)					
place_dum_32	7.266588	2.190327	3.32	0.002	2.799386	11.73379
place_dum_33	28.32679	1.887786	15.01	0.000	24.47663	32.17696
place_dum_34	14.55209	1.887786	7.71	0.000	10.70193	18.40226
place_dum_35	3.825866	2.340391	1.63	0.112	-.9473931	8.599125
place_dum_36	(dropped)					
place_dum_37	(dropped)					
place_dum_38	27.91825	2.979447	9.37	0.000	21.84163	33.99487
place_dum_39	6.13127	1.313854	4.67	0.000	3.451647	8.810892
place_dum_40	1.16882	2.340391	0.50	0.621	-3.604439	5.942079
place_dum_41	17.12188	1.411289	12.13	0.000	14.24354	20.00022
place_dum_42	4.053306	2.979447	1.36	0.184	-2.023317	10.12993
year_dum_1	(dropped)					
year_dum_2	(dropped)					
year_dum_3	(dropped)					
year_dum_4	(dropped)					

year_dum_5	(dropped)					
year_dum_6	(dropped)					
year_dum_7	(dropped)					
year_dum_8	-12.31599	.800785	-15.38	0.000	-13.9492	-10.68278
year_dum_9	-16.98669	1.654132	-10.27	0.000	-20.36032	-13.61307
year_dum_10	-18.95333	1.281697	-14.79	0.000	-21.56737	-16.33929
year_dum_11	-12.59769	1.520902	-8.28	0.000	-15.69959	-9.495794
year_dum_12	-17.50677	1.823562	-9.60	0.000	-21.22595	-13.78759
year_dum_13	-41.80469	1.567493	-26.67	0.000	-45.00161	-38.60777
year_dum_14	-29.99696	1.893024	-15.85	0.000	-33.8578	-26.13611
year_dum_15	16.17054	1.557783	10.38	0.000	12.99342	19.34766
year_dum_16	2.547885	1.497143	1.70	0.099	-.5055584	5.601328
year_dum_17	-12.1353	1.800339	-6.74	0.000	-15.80711	-8.463483
year_dum_18	9.184791	1.710517	5.37	0.000	5.696168	12.67341
year_dum_19	42.53969	1.608884	26.44	0.000	39.25835	45.82103
year_dum_20	83.19843	1.89345	43.94	0.000	79.33671	87.06015
year_dum_21	132.8144	2.185629	60.77	0.000	128.3568	137.272
year_dum_22	130.1076	2.562584	50.77	0.000	124.8812	135.334
year_dum_23	211.4113	1.980195	106.76	0.000	207.3727	215.45
year_dum_24	81.30099	2.178395	37.32	0.000	76.85812	85.74386
year_dum_25	93.87688	2.180766	43.05	0.000	89.42918	98.32458
_cons	117.4867	3.213342	36.56	0.000	110.933	124.0403

Basic Model, 1992-2000 (Table 2, Column II)

```
Linear regression                                      Number of obs =    5129
                                                       F(  9,    31) =       .
                                                       Prob > F      =       .
                                                       R-squared     =  0.7924
                                                       Root MSE      =  8.8651

                                 (Std. Err. adjusted for 32 clusters in state)
------------------------------------------------------------------------------
             |               Robust
value_EXT~10 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         rfg |   6.492564   2.459743     2.64   0.013     1.475884    11.50924
         _78 |   1.115716   2.903807     0.38   0.703    -4.806638    7.038069
 place_dum_1 |   16.38363   4.031736     4.06   0.000     8.160851    24.60641
 place_dum_2 |    3.70045   1.638159     2.26   0.031     .3594038    7.041497
 place_dum_3 |   3.753465   1.935871     1.94   0.062    -.1947705    7.701701
 place_dum_4 |   6.461978   1.639829     3.94   0.000     3.117525    9.806431
 place_dum_5 |   14.21178   2.903807     4.89   0.000     8.289424    20.13413
 place_dum_6 |   18.43529   4.031736     4.57   0.000     10.21251    26.65807
 place_dum_7 |   20.19184   4.031736     5.01   0.000     11.96906    28.41462
 place_dum_8 |    30.1606   2.903807    10.39   0.000     24.23825    36.08295
 place_dum_9 |   11.87673   4.031736     2.95   0.006     3.653945    20.09951
place_dum_10 |    5.08954   1.13e-10        .   0.000      5.08954     5.08954
place_dum_11 |   15.96044   4.031736     3.96   0.000      7.73766    24.18322
place_dum_12 |   7.934422   4.031736     1.97   0.058    -.2883585     16.1572
place_dum_13 |   6.620759   2.649133     2.50   0.018     1.217817     12.0237
place_dum_14 |  (dropped)
place_dum_15 |   8.305667   4.031736     2.06   0.048     .0828866    16.52845
place_dum_16 |   8.304121   1.639829     5.06   0.000     4.959668    11.64857
place_dum_17 |   6.853788   4.031736     1.70   0.099    -1.368992    15.07657
place_dum_18 |  (dropped)
place_dum_19 |   13.95325   2.903807     4.81   0.000     8.030896     19.8756
place_dum_20 |   6.237105   1.639829     3.80   0.001     2.892652    9.581558
place_dum_21 |   18.71789   1.639829    11.41   0.000     15.37344    22.06234
place_dum_22 |    7.14755   2.903807     2.46   0.020     1.225196     13.0699
place_dum_23 |   13.90236   4.031736     3.45   0.002     5.679583    22.12514
place_dum_24 |   10.05264   1.639829     6.13   0.000     6.708191     13.3971
place_dum_25 |    24.1996   2.903807     8.33   0.000     18.27725    30.12195
place_dum_26 |   15.93832   2.903807     5.49   0.000     10.01597    21.86067
place_dum_27 |   7.037068   1.935871     3.64   0.001     3.088833     10.9853
place_dum_28 |   3.403972   4.031736     0.84   0.405    -4.818809    11.62675
place_dum_29 |     12.341   4.031736     3.06   0.005      4.11822    20.56378
place_dum_30 |   6.859798   2.903807     2.36   0.025     .9374449    12.78215
place_dum_31 |  (dropped)
place_dum_32 |    10.3925   3.275816     3.17   0.003     3.711429    17.07357
place_dum_33 |    30.6761   1.639829    18.71   0.000     27.33164    34.02055
place_dum_34 |   16.18646   1.639829     9.87   0.000     12.84201    19.53092
place_dum_35 |   5.657757   4.031736     1.40   0.170    -2.565024    13.88054
place_dum_36 |  (dropped)
place_dum_37 |  (dropped)
place_dum_38 |   27.90439   4.031736     6.92   0.000     19.68161    36.12717
place_dum_39 |    8.53152   1.540158     5.54   0.000     5.390348    11.67269
place_dum_40 |   3.515331   4.031736     0.87   0.390    -4.707449    11.73811
place_dum_41 |   14.34286   1.935871     7.41   0.000     10.39462     18.2911
place_dum_42 |   7.593768   4.031736     1.88   0.069    -.6290121    15.81655
  year_dum_1 |  (dropped)
  year_dum_2 |  (dropped)
  year_dum_3 |  (dropped)
  year_dum_4 |  (dropped)
  year_dum_5 |  (dropped)
  year_dum_6 |  (dropped)
  year_dum_7 |   12.31599   .8022666    15.35   0.000     10.67976    13.95222
  year_dum_8 |  (dropped)
  year_dum_9 |  -4.670706    1.79869    -2.60   0.014    -8.339158   -1.002254
 year_dum_10 |  -6.768926   1.436594    -4.71   0.000    -9.698878   -3.838973
 year_dum_11 |    -.42191   1.799966    -0.23   0.816    -4.092965    3.249145
 year_dum_12 |  -5.334122   2.063955    -2.58   0.015    -9.543585   -1.124658
```

year_dum_13	-29.64763	1.754113	-16.90	0.000	-33.22517	-26.07009
year_dum_14	-17.83821	2.133018	-8.36	0.000	-22.18853	-13.48789
year_dum_15	28.32928	1.9048	14.87	0.000	24.44442	32.21415
year_dum_16	(dropped)					
year_dum_17	(dropped)					
year_dum_18	(dropped)					
year_dum_19	(dropped)					
year_dum_20	(dropped)					
year_dum_21	(dropped)					
year_dum_22	(dropped)					
year_dum_23	(dropped)					
year_dum_24	(dropped)					
year_dum_25	(dropped)					
_cons	103.4698	4.391044	23.56	0.000	94.51417	112.4254

<u>Basic Model, 2001-2010 (Table 2, Column III)</u>

```
Linear regression                                      Number of obs =    5244
                                                       F(  8,    31) =       .
                                                       Prob > F      =       .
                                                       R-squared     =  0.9522
                                                       Root MSE      =  15.567

                                 (Std. Err. adjusted for 32 clusters in state)
------------------------------------------------------------------------------
             |               Robust
value_EXT~10 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         rfg |   6.309478   3.04e-11       .    0.000     6.309478    6.309478
         _78 |  -4.000499   1.262861    -3.17   0.003    -6.576122   -1.424876
 place_dum_1 |   10.58497   1.262861     8.38   0.000     8.009351     13.1606
 place_dum_2 |   12.06845   1.89e-11       .    0.000     12.06845    12.06845
 place_dum_3 |    1.60551   1.262861     1.27   0.213    -.9701132    4.181132
 place_dum_4 |   6.632527   1.87e-11       .    0.000     6.632527    6.632527
 place_dum_5 |   7.133754   1.262861     5.65   0.000     4.558132    9.709377
 place_dum_6 |   3.268419   1.262861     2.59   0.015     .6927964    5.844042
 place_dum_7 |   10.66365   1.262861     8.44   0.000     8.088023    13.23927
 place_dum_8 |   26.02093   1.262861    20.60   0.000     23.44531    28.59656
 place_dum_9 |   5.579686   1.262861     4.42   0.000     3.004064    8.155309
place_dum_10 |   1.992806   2.62e-11       .    0.000     1.992806    1.992806
place_dum_11 |   19.83331   .4118026    48.16   0.000     18.99343    20.67319
place_dum_12 |    3.48686   1.262861     2.76   0.010      .911237    6.062483
place_dum_13 |    8.01808   1.87e-11       .    0.000      8.01808     8.01808
place_dum_14 |  (dropped)
place_dum_15 |   1.262711   1.262861     1.00   0.325    -1.312911    3.838334
place_dum_16 |    6.83524   1.87e-11       .    0.000      6.83524     6.83524
place_dum_17 |   1.474803   1.262861     1.17   0.252     -1.10082    4.050426
place_dum_18 |  (dropped)
place_dum_19 |    6.89304   1.262861     5.46   0.000     4.317417    9.468663
place_dum_20 |   3.382941   1.86e-11       .    0.000     3.382941    3.382941
place_dum_21 |   11.23519   1.87e-11       .    0.000     11.23519    11.23519
place_dum_22 |  -1.300185   1.262861    -1.03   0.311    -3.875808    1.275438
place_dum_23 |   4.550993   1.262861     3.60   0.001     1.975371    7.126616
place_dum_24 |   6.519464   1.86e-11       .    0.000     6.519464    6.519464
place_dum_25 |   3.107101   1.262861     2.46   0.020     .5314785    5.682724
place_dum_26 |   7.409021   1.262861     5.87   0.000     4.833399    9.984644
place_dum_27 |  -1.418353   1.262861    -1.12   0.270    -3.993976    1.157269
place_dum_28 |  -1.717933   1.262861    -1.36   0.184    -4.293556    .8576896
place_dum_29 |   .7862304   1.262861     0.62   0.538    -1.789392    3.361853
place_dum_30 |   1.973651   1.262861     1.56   0.128    -.6019721    4.549273
place_dum_31 |  (dropped)
place_dum_32 |   5.212342   1.86e-11       .    0.000     5.212342    5.212342
place_dum_33 |   26.71838   1.86e-11       .    0.000     26.71838    26.71838
place_dum_34 |   13.64307   1.86e-11       .    0.000     13.64307    13.64307
place_dum_35 |   3.160479   1.86e-11       .    0.000     3.160479    3.160479
place_dum_36 |  (dropped)
place_dum_37 |  (dropped)
place_dum_38 |   24.38884   1.262861    19.31   0.000     21.81322    26.96447
place_dum_39 |  -.5596504   1.262861    -0.44   0.661    -3.135273    2.015972
place_dum_40 |  (dropped)
place_dum_41 |   15.46209   1.262861    12.24   0.000     12.88647    18.03772
place_dum_42 |   -2.95315   1.262861    -2.34   0.026    -5.528772   -.3775269
  year_dum_1 |  (dropped)
  year_dum_2 |  (dropped)
  year_dum_3 |  (dropped)
  year_dum_4 |  (dropped)
  year_dum_5 |  (dropped)
  year_dum_6 |  (dropped)
  year_dum_7 |  (dropped)
  year_dum_8 |  (dropped)
  year_dum_9 |  (dropped)
 year_dum_10 |  (dropped)
 year_dum_11 |  (dropped)
 year_dum_12 |  (dropped)
 year_dum_13 |  (dropped)
```

year_dum_14	(dropped)					
year_dum_15	(dropped)					
year_dum_16	-91.45188	2.42187	-37.76	0.000	-96.39132	-86.51245
year_dum_17	-106.1351	1.52805	-69.46	0.000	-109.2515	-103.0186
year_dum_18	-84.81498	1.961878	-43.23	0.000	-88.81625	-80.8137
year_dum_19	-51.33719	1.827703	-28.09	0.000	-55.06482	-47.60957
year_dum_20	-10.67845	1.51449	-7.05	0.000	-13.76727	-7.589631
year_dum_21	38.93749	1.369217	28.44	0.000	36.14495	41.73003
year_dum_22	36.23074	1.731736	20.92	0.000	32.69884	39.76264
year_dum_23	117.5345	.9575348	122.75	0.000	115.5816	119.4874
year_dum_24	-12.57589	1.295451	-9.71	0.000	-15.21798	-9.933802
year_dum_25	(dropped)					
_cons	216.7071	2.139168	101.30	0.000	212.3442	221.0699

<u>Monthly Time Trend Model (Summer Only), 1992-2010 (Table 2, Column IV)</u>

```
Fixed-effects (within) regression               Number of obs      =     10373
Group variable: place_id                        Number of groups   =        38

R-sq:  within  = 0.9806                         Obs per group: min =       272
       between = 0.0811                                        avg =     273.0
       overall = 0.9703                                        max =       273

                                                F(74,10261)        =   7015.30
corr(u_i, Xb)  = -0.0007                        Prob > F           =    0.0000
```

value_EXT~10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
rfg	6.00511	.5681404	10.57	0.000	4.891444	7.118776
_78	.7522806	.4910526	1.53	0.126	-.2102784	1.71484
time_dum_78	14.28129	1.358239	10.51	0.000	11.61888	16.94371
time_dum_79	12.66994	1.312184	9.66	0.000	10.0978	15.24208
time_dum_80	9.82346	1.358239	7.23	0.000	7.161046	12.48587
time_dum_81	9.497308	1.568359	6.06	0.000	6.423017	12.5716
time_dum_90	.5643202	1.358239	0.42	0.678	-2.098094	3.226734
time_dum_91	.3453518	1.312184	0.26	0.792	-2.226784	2.917488
time_dum_92	.3972856	1.358239	0.29	0.770	-2.265128	3.059699
time_dum_93	-5.774845	1.568359	-3.68	0.000	-8.849136	-2.700555
time_dum_102	-11.51423	1.358239	-8.48	0.000	-14.17665	-8.851819
time_dum_103	-6.372066	1.312184	-4.86	0.000	-8.944202	-3.79993
time_dum_104	.47004	1.358239	0.35	0.729	-2.192374	3.132454
time_dum_114	-1.302142	1.368419	-0.95	0.341	-3.984511	1.380227
time_dum_115	-5.810182	1.322718	-4.39	0.000	-8.402968	-3.217396
time_dum_116	-11.15555	1.368419	-8.15	0.000	-13.83792	-8.473182
time_dum_117	-13.37505	1.577184	-8.48	0.000	-16.46664	-10.28347
time_dum_126	4.315637	1.368419	3.15	0.002	1.633268	6.998006
time_dum_127	-.7138506	1.32315	-0.54	0.590	-3.307484	1.879782
time_dum_128	-3.890125	1.368837	-2.84	0.004	-6.573313	-1.206938
time_dum_129	-4.22707	1.577546	-2.68	0.007	-7.319369	-1.134771
time_dum_138	-5.701458	1.368837	-4.17	0.000	-8.384645	-3.01827
time_dum_139	-9.107927	1.32315	-6.88	0.000	-11.70156	-6.514294
time_dum_140	-3.402898	1.368837	-2.49	0.013	-6.086085	-.7197101
time_dum_141	-1.004605	1.577546	-0.64	0.524	-4.096904	2.087694
time_dum_150	-27.96159	1.368837	-20.43	0.000	-30.64478	-25.27841
time_dum_151	-28.40202	1.324355	-21.45	0.000	-30.99802	-25.80603
time_dum_152	-31.42049	1.369376	-22.95	0.000	-34.10474	-28.73625
time_dum_153	-34.43729	1.578014	-21.82	0.000	-37.53051	-31.34408
time_dum_162	-24.05391	1.370756	-17.55	0.000	-26.74086	-21.36696
time_dum_163	-17.60544	1.325136	-13.29	0.000	-20.20296	-15.00791
time_dum_164	-15.22292	1.370756	-11.11	0.000	-17.90987	-12.53597
time_dum_165	-13.10032	1.579212	-8.30	0.000	-16.19588	-10.00475
time_dum_174	37.11303	1.370756	27.07	0.000	34.42608	39.79998
time_dum_175	27.08972	1.325136	20.44	0.000	24.4922	29.68725
time_dum_176	20.71803	1.370756	15.11	0.000	18.03108	23.40498
time_dum_177	27.20219	1.579212	17.23	0.000	24.10663	30.29776
time_dum_186	27.95493	1.372075	20.37	0.000	25.2654	30.64447
time_dum_187	4.755011	1.3265	3.58	0.000	2.154811	7.355211
time_dum_188	10.99171	1.372075	8.01	0.000	8.302178	13.68125
time_dum_189	18.60508	1.580357	11.77	0.000	15.50727	21.70289
time_dum_198	-2.814273	1.372075	-2.05	0.040	-5.503809	-.1247375
time_dum_199	-1.897359	1.3265	-1.43	0.153	-4.497558	.7028411
time_dum_200	2.202977	1.372075	1.61	0.108	-.4865582	4.892513
time_dum_201	4.228018	1.580357	2.68	0.007	1.130209	7.325826
time_dum_210	9.194752	1.372075	6.70	0.000	6.505217	11.88429
time_dum_211	20.07171	1.3265	15.13	0.000	17.47151	22.67191

time_dum_212	26.1831	1.372075	19.08	0.000	23.49356	28.87263
time_dum_213	37.22773	1.580357	23.56	0.000	34.12992	40.32554
time_dum_222	57.83253	1.372917	42.12	0.000	55.14135	60.52372
time_dum_223	54.20931	1.327371	40.84	0.000	51.6074	56.81122
time_dum_224	54.81346	1.372917	39.92	0.000	52.12227	57.50464
time_dum_225	47.49279	1.581088	30.04	0.000	44.39355	50.59203
time_dum_234	75.28681	1.372917	54.84	0.000	72.59563	77.978
time_dum_235	81.38702	1.327371	61.31	0.000	78.78511	83.98892
time_dum_236	107.7795	1.372917	78.50	0.000	105.0884	110.4707
time_dum_237	143.6483	1.581088	90.85	0.000	140.5491	146.7476
time_dum_246	139.2847	1.372917	101.45	0.000	136.5935	141.9758
time_dum_247	147.0724	1.327371	110.80	0.000	144.4705	149.6743
time_dum_248	153.2544	1.372917	111.63	0.000	150.5632	155.9456
time_dum_249	132.6091	1.581088	83.87	0.000	129.5099	135.7083
time_dum_258	159.1462	1.372917	115.92	0.000	156.4551	161.8374
time_dum_259	144.1774	1.327371	108.62	0.000	141.5755	146.7793
time_dum_260	127.6876	1.372917	93.00	0.000	124.9964	130.3788
time_dum_261	130.9563	1.581088	82.83	0.000	127.8571	134.0556
time_dum_270	240.1052	1.372917	174.89	0.000	237.414	242.7964
time_dum_271	232.3077	1.327371	175.01	0.000	229.7058	234.9097
time_dum_272	206.0588	1.372917	150.09	0.000	203.3676	208.75
time_dum_273	201.7482	1.581088	127.60	0.000	198.6489	204.8474
time_dum_282	100.5023	1.372917	73.20	0.000	97.81115	103.1935
time_dum_283	85.6698	1.327371	64.54	0.000	83.06789	88.2717
time_dum_284	95.05293	1.372917	69.23	0.000	92.36174	97.74411
time_dum_285	93.73276	1.581088	59.28	0.000	90.63352	96.832
time_dum_294	105.7783	1.445642	73.17	0.000	102.9445	108.612
_cons	115.8138	1.123653	103.07	0.000	113.6112	118.0164
sigma_u	7.2426102					
sigma_e	9.668017					
rho	.35946589	(fraction of variance due to u_i)				

F test that all u_i=0: F(37, 10261) = 148.99 Prob > F = 0.0000

Monthly Time Trend Model (Summer Only), 1992-2000 (Table 2, Column V)

```
Fixed-effects (within) regression               Number of obs      =      5129
Group variable: place_id                        Number of groups   =        38

R-sq:  within  = 0.7987                         Obs per group: min =       134
       between = 0.0438                                        avg =     135.0
       overall = 0.6812                                        max =       135

                                                F(37,5054)         =    541.95
corr(u_i, Xb)  = -0.0077                        Prob > F           =    0.0000

------------------------------------------------------------------------------
value_EXT~10 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         rfg |   6.574803   .5524058    11.90   0.000     5.491848    7.657758
         _78 |   1.350208   .6865111     1.97   0.049     .0043484    2.696067
 time_dum_78 |   14.28129   1.130279    12.64   0.000     12.06546    16.49713
 time_dum_79 |   12.66994   1.091953    11.60   0.000     10.52924    14.81064
 time_dum_80 |    9.82346   1.130279     8.69   0.000     7.607623     12.0393
 time_dum_81 |   9.497308   1.305134     7.28   0.000      6.93868    12.05594
 time_dum_90 |   .5643202   1.130279     0.50   0.618    -1.651517    2.780157
 time_dum_91 |   .3453518   1.091953     0.32   0.752     -1.79535    2.486054
 time_dum_92 |   .3972856   1.130279     0.35   0.725    -1.818551    2.613122
 time_dum_93 |  -5.774845   1.305134    -4.42   0.000    -8.333473   -3.216217
time_dum_102 |  -11.51423   1.130279   -10.19   0.000    -13.73007   -9.298396
time_dum_103 |  -6.372066   1.091953    -5.84   0.000    -8.512768   -4.231364
time_dum_104 |     .47004   1.130279     0.42   0.678    -1.745797    2.685877
time_dum_114 |   -1.43484   1.141315    -1.26   0.209    -3.672313    .8026332
time_dum_115 |   -5.94288   1.103373    -5.39   0.000     -8.10597   -3.779791
time_dum_116 |  -11.28825   1.141315    -9.89   0.000    -13.52572   -9.050776
time_dum_117 |  -13.50775   1.314703   -10.27   0.000    -16.08514   -10.93036
time_dum_126 |   4.182939   1.141315     3.67   0.000     1.945466    6.420412
time_dum_127 |  -.8622836   1.103887    -0.78   0.435     -3.02638    1.301813
time_dum_128 |  -4.038558   1.141812    -3.54   0.000    -6.277005   -1.800111
time_dum_129 |  -4.375503   1.315134    -3.33   0.001    -6.953736   -1.797269
time_dum_138 |  -5.849891   1.141812    -5.12   0.000    -8.088338   -3.611444
time_dum_139 |   -9.25636   1.103887    -8.39   0.000    -11.42046   -7.092263
time_dum_140 |  -3.551331   1.141812    -3.11   0.002    -5.789777   -1.312884
time_dum_141 |  -1.153038   1.315134    -0.88   0.381    -3.731272    1.425196
time_dum_150 |  -28.11003   1.141812   -24.62   0.000    -30.34847   -25.87158
time_dum_151 |  -28.58482   1.105039   -25.87   0.000    -30.75118   -26.41847
time_dum_152 |  -31.58466   1.142594   -27.64   0.000    -33.82464   -29.34468
time_dum_153 |  -34.60146   1.315814   -26.30   0.000    -37.18103    -32.0219
time_dum_162 |  -24.21733   1.143922   -21.17   0.000    -26.45992   -21.97475
time_dum_163 |  -17.76886   1.106069   -16.06   0.000    -19.93724   -15.60049
time_dum_164 |  -15.38635   1.143922   -13.45   0.000    -17.62893   -13.14377
time_dum_165 |  -13.26374   1.316966   -10.07   0.000    -15.84557   -10.68192
time_dum_174 |    36.9496   1.143922    32.30   0.000     34.70702    39.19219
time_dum_175 |    26.9263   1.106069    24.34   0.000     24.75792    29.09467
time_dum_176 |   20.55461   1.143922    17.97   0.000     18.31203    22.79719
time_dum_177 |   27.03877   1.316966    20.53   0.000     24.45694    29.62059
       _cons |   115.5949   .9568794   120.80   0.000      113.719    117.4708
-------------+----------------------------------------------------------------
     sigma_u |  7.5682948
     sigma_e |  8.0453852
         rho |  .46947258   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(37, 5054) =   115.61            Prob > F = 0.0000
```

Monthly Time Trend Model (Summer Only), 2001-2010 (Table 2, Column VI)

```
Fixed-effects (within) regression               Number of obs      =      5244
Group variable: place_id                        Number of groups   =        38

R-sq:  within  = 0.9775                         Obs per group: min =       138
       between = 0.0527                                        avg =     138.0
       overall = 0.9660                                        max =       138

                                                F(37,5169)         =   6071.46
corr(u_i, Xb)  = -0.0004                        Prob > F           =    0.0000

------------------------------------------------------------------------------
value_EXT~10 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         rfg |  (omitted)
         _78 |  -4.000499   1.957118    -2.04   0.041    -7.837278   -.1637206
time_dum_186 |   9.349854   1.494077     6.26   0.000     6.420831    12.27888
time_dum_187 |  -13.85007   1.443416    -9.60   0.000    -16.67977   -11.02036
time_dum_188 |  -7.613367   1.494077    -5.10   0.000    -10.54239   -4.684344
time_dum_198 |  -21.41935   1.494077   -14.34   0.000    -24.34838   -18.49033
time_dum_199 |  -20.50244   1.443416   -14.20   0.000    -23.33214   -17.67273
time_dum_200 |   -16.4021   1.494077   -10.98   0.000    -19.33113   -13.47308
time_dum_201 |  -14.37706   1.725212    -8.33   0.000    -17.75921   -10.99492
time_dum_210 |  -9.410328   1.494077    -6.30   0.000    -12.33935   -6.481305
time_dum_211 |    1.46663   1.443416     1.02   0.310    -1.363075    4.296335
time_dum_212 |   7.578015   1.494077     5.07   0.000     4.648992    10.50704
time_dum_213 |   18.62265   1.725212    10.79   0.000      15.2405    22.00479
time_dum_222 |   39.35252   1.494965    26.32   0.000     36.42176    42.28329
time_dum_223 |    35.7293   1.444334    24.74   0.000      32.8978    38.56081
time_dum_224 |   36.33345   1.494965    24.30   0.000     33.40269    39.26421
time_dum_225 |   29.01278    1.72598    16.81   0.000     25.62913    32.39644
time_dum_234 |    56.8068   1.494965    38.00   0.000     53.87604    59.73757
time_dum_235 |   62.90701   1.444334    43.55   0.000      60.0755    65.73851
time_dum_236 |   89.29953   1.494965    59.73   0.000     86.36877    92.23029
time_dum_237 |   125.1683    1.72598    72.52   0.000     121.7847     128.552
time_dum_246 |   120.8047   1.494965    80.81   0.000     117.8739    123.7354
time_dum_247 |   128.5924   1.444334    89.03   0.000     125.7609    131.4239
time_dum_248 |   134.7744   1.494965    90.15   0.000     131.8436    137.7051
time_dum_249 |   114.1291    1.72598    66.12   0.000     110.7454    117.5127
time_dum_258 |   140.6662   1.494965    94.09   0.000     137.7355     143.597
time_dum_259 |   125.6974   1.444334    87.03   0.000     122.8659    128.5289
time_dum_260 |   109.2076   1.494965    73.05   0.000     106.2769    112.1384
time_dum_261 |   112.4763    1.72598    65.17   0.000     109.0927      115.86
time_dum_270 |   221.6252   1.494965   148.25   0.000     218.6944    224.5559
time_dum_271 |   213.8277   1.444334   148.05   0.000     210.9962    216.6592
time_dum_272 |   187.5788   1.494965   125.47   0.000      184.648    190.5095
time_dum_273 |   183.2681    1.72598   106.18   0.000     179.8845    186.6518
time_dum_282 |   82.02233   1.494965    54.87   0.000     79.09157    84.95309
time_dum_283 |   67.18979   1.444334    46.52   0.000     64.35828     70.0213
time_dum_284 |   76.57292   1.494965    51.22   0.000     73.64215    79.50368
time_dum_285 |   75.25276    1.72598    43.60   0.000      71.8691    78.63641
time_dum_294 |   87.29826   1.575737    55.40   0.000     84.20914    90.38737
       _cons |   138.2241   1.417068    97.54   0.000      135.446    141.0021
-------------+----------------------------------------------------------------
     sigma_u |  7.7859499
     sigma_e |  10.634919
         rho |  .34895313   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(37, 5169) =    68.15            Prob > F = 0.0000
```

Monthly Time Trend Model (Full Year), 1992-2010 (Table 2, Column VII)

```
Fixed-effects (within) regression               Number of obs      =     36700
Group variable: place_id                        Number of groups   =        38

R-sq:  within  = 0.9747                         Obs per group: min =       959
       between = 0.1006                                        avg =     965.8
       overall = 0.9623                                        max =       966

                                                F(223,36439)       =   6286.27
corr(u_i, Xb)  = 0.0031                         Prob > F           =    0.0000
```

value_EXT~10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
rfg	3.411477	.2773987	12.30	0.000	2.867767	3.955186
_78	-.003267	.2210198	-0.01	0.988	-.4364722	.4299383
time_dum_73	-107.6781	1.161246	-92.73	0.000	-109.9542	-105.4021
time_dum_74	-105.5117	1.213749	-86.93	0.000	-107.8907	-103.1327
time_dum_75	-104.9928	1.213749	-86.50	0.000	-107.3718	-102.6138
time_dum_76	-106.7585	1.161246	-91.93	0.000	-109.0346	-104.4825
time_dum_77	-97.79499	1.213749	-80.57	0.000	-100.174	-95.416
time_dum_78	-92.40415	1.20993	-76.37	0.000	-94.77565	-90.03265
time_dum_79	-94.0155	1.157254	-81.24	0.000	-96.28375	-91.74725
time_dum_80	-96.86198	1.20993	-80.06	0.000	-99.23348	-94.49048
time_dum_81	-96.04109	1.158964	-82.87	0.000	-98.31269	-93.76948
time_dum_82	-96.98323	1.213749	-79.90	0.000	-99.36221	-94.60425
time_dum_83	-97.08436	1.213749	-79.99	0.000	-99.46334	-94.70538
time_dum_84	-102.8443	1.161246	-88.56	0.000	-105.1204	-100.5682
time_dum_85	-106.7347	1.161246	-91.91	0.000	-109.0108	-104.4586
time_dum_86	-104.8313	1.213749	-86.37	0.000	-107.2103	-102.4523
time_dum_87	-105.1644	1.213749	-86.64	0.000	-107.5434	-102.7854
time_dum_88	-106.2505	1.161246	-91.50	0.000	-108.5266	-103.9744
time_dum_89	-103.8797	1.213749	-85.59	0.000	-106.2586	-101.5007
time_dum_90	-106.1211	1.20993	-87.71	0.000	-108.4926	-103.7496
time_dum_91	-106.3401	1.157254	-91.89	0.000	-108.6083	-104.0718
time_dum_92	-106.2882	1.20993	-87.85	0.000	-108.6597	-103.9167
time_dum_93	-116.1946	1.211157	-95.94	0.000	-118.5685	-113.8207
time_dum_94	-117.4684	1.161246	-101.16	0.000	-119.7445	-115.1923
time_dum_95	-117.7157	1.213749	-96.99	0.000	-120.0947	-115.3367
time_dum_96	-123.732	1.213749	-101.94	0.000	-126.111	-121.353
time_dum_97	-126.4831	1.161246	-108.92	0.000	-128.7592	-124.207
time_dum_98	-127.0051	1.213749	-104.64	0.000	-129.3841	-124.6261
time_dum_99	-128.4136	1.213749	-105.80	0.000	-130.7926	-126.0346
time_dum_100	-125.8252	1.161246	-108.35	0.000	-128.1013	-123.5491
time_dum_101	-122.6996	1.213749	-101.09	0.000	-125.0786	-120.3206
time_dum_102	-118.1997	1.20993	-97.69	0.000	-120.5712	-115.8282
time_dum_103	-113.0575	1.157254	-97.69	0.000	-115.3258	-110.7893
time_dum_104	-106.2154	1.20993	-87.79	0.000	-108.5869	-103.8439
time_dum_105	-108.0466	1.211157	-89.21	0.000	-110.4205	-105.6727
time_dum_106	-112.331	1.161246	-96.73	0.000	-114.6071	-110.055
time_dum_107	-112.6781	1.213749	-92.83	0.000	-115.0571	-110.2991
time_dum_108	-115.7081	1.213749	-95.33	0.000	-118.0871	-113.3291
time_dum_109	-117.1449	1.156667	-101.28	0.000	-119.412	-114.8778
time_dum_110	-120.2218	1.209369	-99.41	0.000	-122.5922	-117.8514
time_dum_111	-121.5488	1.209369	-100.51	0.000	-123.9192	-119.1784
time_dum_112	-115.797	1.156667	-100.11	0.000	-118.0641	-113.5299
time_dum_113	-108.6846	1.209369	-89.87	0.000	-111.055	-106.3142
time_dum_114	-107.2282	1.206401	-88.88	0.000	-109.5928	-104.8636
time_dum_115	-111.7362	1.153563	-96.86	0.000	-113.9972	-109.4752
time_dum_116	-117.0816	1.206401	-97.05	0.000	-119.4462	-114.717
time_dum_117	-119.8337	1.207462	-99.24	0.000	-122.2003	-117.467

time_dum_118	-122.9688	1.156667	-106.31	0.000	-125.2359	-120.7017
time_dum_119	-126.6516	1.209369	-104.73	0.000	-129.022	-124.2812
time_dum_120	-126.2447	1.209369	-104.39	0.000	-128.6151	-123.8743
time_dum_121	-123.7863	1.156667	-107.02	0.000	-126.0534	-121.5192
time_dum_122	-123.3632	1.209369	-102.01	0.000	-125.7336	-120.9928
time_dum_123	-118.1607	1.209369	-97.70	0.000	-120.5311	-115.7903
time_dum_124	-106.8813	1.156667	-92.40	0.000	-109.1484	-104.6142
time_dum_125	-99.58235	1.209369	-82.34	0.000	-101.9528	-97.21195
time_dum_126	-101.6104	1.206401	-84.23	0.000	-103.975	-99.24583
time_dum_127	-106.62	1.153456	-92.44	0.000	-108.8808	-104.3592
time_dum_128	-109.7963	1.206299	-91.02	0.000	-112.1607	-107.4319
time_dum_129	-109.8624	1.154878	-95.13	0.000	-112.126	-107.5988
time_dum_130	-109.9513	1.209369	-90.92	0.000	-112.3217	-107.5809
time_dum_131	-105.9226	1.209369	-87.58	0.000	-108.293	-103.5522
time_dum_132	-105.0608	1.209369	-86.87	0.000	-107.4312	-102.6904
time_dum_133	-105.6802	1.156667	-91.37	0.000	-107.9473	-103.4131
time_dum_134	-107.3178	1.209369	-88.74	0.000	-109.6882	-104.9474
time_dum_135	-111.414	1.209369	-92.13	0.000	-113.7844	-109.0436
time_dum_136	-114.0188	1.156667	-98.58	0.000	-116.2859	-111.7517
time_dum_137	-113.3016	1.209369	-93.69	0.000	-115.672	-110.9312
time_dum_138	-111.6076	1.206299	-92.52	0.000	-113.972	-109.2432
time_dum_139	-115.0141	1.153456	-99.71	0.000	-117.2749	-112.7533
time_dum_140	-109.3091	1.206299	-90.62	0.000	-111.6734	-106.9447
time_dum_141	-107.7241	1.207331	-89.22	0.000	-110.0905	-105.3577
time_dum_142	-113.0425	1.156667	-97.73	0.000	-115.3096	-110.7754
time_dum_143	-116.6876	1.209369	-96.49	0.000	-119.058	-114.3172
time_dum_144	-121.3124	1.156667	-104.88	0.000	-123.5795	-119.0453
time_dum_145	-129.3913	1.156667	-111.87	0.000	-131.6584	-127.1242
time_dum_146	-134.9864	1.209369	-111.62	0.000	-137.3568	-132.616
time_dum_147	-137.8807	1.209369	-114.01	0.000	-140.2511	-135.5103
time_dum_148	-136.3041	1.156667	-117.84	0.000	-138.5712	-134.037
time_dum_149	-133.7651	1.209369	-110.61	0.000	-136.1355	-131.3947
time_dum_150	-133.8678	1.206299	-110.97	0.000	-136.2321	-131.5034
time_dum_151	-134.292	1.154574	-116.31	0.000	-136.555	-132.029
time_dum_152	-137.3068	1.206225	-113.83	0.000	-139.671	-134.9425
time_dum_153	-140.2311	1.207206	-116.16	0.000	-142.5973	-137.865
time_dum_154	-140.3246	1.156667	-121.32	0.000	-142.5917	-138.0575
time_dum_155	-143.4448	1.209369	-118.61	0.000	-145.8152	-141.0744
time_dum_156	-148.0379	1.209369	-122.41	0.000	-150.4083	-145.6675
time_dum_157	-149.519	1.156667	-129.27	0.000	-151.7861	-147.2519
time_dum_158	-152.1614	1.209369	-125.82	0.000	-154.5318	-149.791
time_dum_159	-143.3393	1.209369	-118.52	0.000	-145.7097	-140.969
time_dum_160	-130.5852	1.156667	-112.90	0.000	-132.8523	-128.3181
time_dum_161	-126.8996	1.209369	-104.93	0.000	-129.27	-124.5292
time_dum_162	-129.8918	1.206265	-107.68	0.000	-132.2561	-127.5275
time_dum_163	-123.4434	1.153421	-107.02	0.000	-125.7041	-121.1826
time_dum_164	-121.0608	1.206265	-100.36	0.000	-123.4251	-118.6965
time_dum_165	-118.4163	1.207274	-98.09	0.000	-120.7826	-116.05
time_dum_166	-111.9871	1.156585	-96.83	0.000	-114.2541	-109.7202
time_dum_167	-111.1322	1.20929	-91.90	0.000	-113.5024	-108.7619
time_dum_168	-99.21976	1.20929	-82.05	0.000	-101.59	-96.84952
time_dum_169	-103.3171	1.156585	-89.33	0.000	-105.5841	-101.0502
time_dum_170	-94.27029	1.20929	-77.96	0.000	-96.64054	-91.90005
time_dum_171	-84.44866	1.20929	-69.83	0.000	-86.81891	-82.07842
time_dum_172	-92.65322	1.156585	-80.11	0.000	-94.92015	-90.38628
time_dum_173	-81.14643	1.20929	-67.10	0.000	-83.51668	-78.77619
time_dum_174	-68.72488	1.206265	-56.97	0.000	-71.0892	-66.36057
time_dum_175	-78.74819	1.153421	-68.27	0.000	-81.00893	-76.48745
time_dum_176	-85.11988	1.206265	-70.56	0.000	-87.48419	-82.75556
time_dum_177	-79.40324	1.154814	-68.76	0.000	-81.66671	-77.13977
time_dum_178	-80.68364	1.20929	-66.72	0.000	-83.05388	-78.3134
time_dum_179	-88.08018	1.20929	-72.84	0.000	-90.45043	-85.70994

time_dum_180	-89.76477	1.20929	-74.23	0.000	-92.13502	-87.39453
time_dum_181	-91.92	1.156585	-79.48	0.000	-94.18694	-89.65306
time_dum_182	-94.36786	1.20929	-78.04	0.000	-96.73811	-91.99762
time_dum_183	-98.52574	1.20929	-81.47	0.000	-100.896	-96.15549
time_dum_184	-80.31046	1.156585	-69.44	0.000	-82.5774	-78.04352
time_dum_185	-66.19437	1.20929	-54.74	0.000	-68.56461	-63.82413
time_dum_186	-77.84321	1.206153	-64.54	0.000	-80.20731	-75.47912
time_dum_187	-101.0431	1.153304	-87.61	0.000	-103.3036	-98.78263
time_dum_188	-94.80643	1.206153	-78.60	0.000	-97.17053	-92.44234
time_dum_189	-86.6146	1.206731	-71.78	0.000	-88.97983	-84.24937
time_dum_190	-104.8502	1.156327	-90.68	0.000	-107.1166	-102.5837
time_dum_191	-126.6782	1.20929	-104.75	0.000	-129.0484	-124.3079
time_dum_192	-138.6561	1.20929	-114.66	0.000	-141.0263	-136.2858
time_dum_193	-135.0513	1.156585	-116.77	0.000	-137.3183	-132.7844
time_dum_194	-137.4019	1.20929	-113.62	0.000	-139.7722	-135.0317
time_dum_195	-124.035	1.20929	-102.57	0.000	-126.4052	-121.6647
time_dum_196	-110.066	1.156585	-95.16	0.000	-112.333	-107.7991
time_dum_197	-105.7589	1.20929	-87.46	0.000	-108.1291	-103.3886
time_dum_198	-108.6124	1.206153	-90.05	0.000	-110.9765	-106.2483
time_dum_199	-107.6955	1.153304	-93.38	0.000	-109.956	-105.435
time_dum_200	-103.5952	1.206153	-85.89	0.000	-105.9593	-101.2311
time_dum_201	-100.6791	1.206731	-83.43	0.000	-103.0443	-98.31385
time_dum_202	-94.94454	1.156327	-82.11	0.000	-97.21098	-92.67811
time_dum_203	-98.49523	1.20929	-81.45	0.000	-100.8655	-96.12499
time_dum_204	-106.402	1.20929	-87.99	0.000	-108.7722	-104.0318
time_dum_205	-99.14419	1.156585	-85.72	0.000	-101.4111	-96.87725
time_dum_206	-82.9718	1.20929	-68.61	0.000	-85.34204	-80.60155
time_dum_207	-73.70131	1.20929	-60.95	0.000	-76.07155	-71.33107
time_dum_208	-81.47944	1.156585	-70.45	0.000	-83.74638	-79.2125
time_dum_209	-91.59748	1.20929	-75.74	0.000	-93.96772	-89.22724
time_dum_210	-96.60339	1.206153	-80.09	0.000	-98.96749	-94.2393
time_dum_211	-85.72644	1.153304	-74.33	0.000	-87.98695	-83.46593
time_dum_212	-79.61505	1.206153	-66.01	0.000	-81.97915	-77.25096
time_dum_213	-70.52892	1.206731	-58.45	0.000	-72.89415	-68.16369
time_dum_214	-90.47007	1.156327	-78.24	0.000	-92.7365	-88.20364
time_dum_215	-93.13737	1.20929	-77.02	0.000	-95.50761	-90.76712
time_dum_216	-96.74357	1.20929	-80.00	0.000	-99.11382	-94.37333
time_dum_217	-90.2016	1.156585	-77.99	0.000	-92.46854	-87.93466
time_dum_218	-80.74285	1.20929	-66.77	0.000	-83.11309	-78.3726
time_dum_219	-73.34324	1.20929	-60.65	0.000	-75.71348	-70.97299
time_dum_220	-66.01367	1.156585	-57.08	0.000	-68.28061	-63.74673
time_dum_221	-51.17126	1.20929	-42.32	0.000	-53.5415	-48.80102
time_dum_222	-47.94573	1.206139	-39.75	0.000	-50.3098	-45.58167
time_dum_223	-51.56895	1.153289	-44.71	0.000	-53.82943	-49.30847
time_dum_224	-50.9648	1.206139	-42.25	0.000	-53.32887	-48.60074
time_dum_225	-58.82925	1.154049	-50.98	0.000	-61.09122	-56.56728
time_dum_226	-53.80346	1.20929	-44.49	0.000	-56.1737	-51.43321
time_dum_227	-55.5263	1.20929	-45.92	0.000	-57.89654	-53.15605
time_dum_228	-68.19723	1.156585	-58.96	0.000	-70.46417	-65.9303
time_dum_229	-74.56924	1.156585	-64.47	0.000	-76.83618	-72.3023
time_dum_230	-59.65084	1.20929	-49.33	0.000	-62.02108	-57.2806
time_dum_231	-42.93185	1.20929	-35.50	0.000	-45.30209	-40.56161
time_dum_232	-24.79483	1.156585	-21.44	0.000	-27.06177	-22.52789
time_dum_233	-31.13139	1.20929	-25.74	0.000	-33.50163	-28.76114
time_dum_234	-30.49145	1.206139	-25.28	0.000	-32.85552	-28.12739
time_dum_235	-24.39125	1.153289	-21.15	0.000	-26.65173	-22.13077
time_dum_236	2.001272	1.206139	1.66	0.097	-.3627949	4.36534
time_dum_237	39.49348	1.210055	32.64	0.000	37.12173	41.86522
time_dum_238	23.9743	1.162084	20.63	0.000	21.69658	26.25202
time_dum_239	-15.71172	1.20929	-12.99	0.000	-18.08196	-13.34147
time_dum_240	-32.1476	1.20929	-26.58	0.000	-34.51784	-29.77735
time_dum_241	-22.55019	1.156585	-19.50	0.000	-24.81713	-20.28325

```
time_dum_242 |   -19.5345    1.20929   -16.15   0.000    -21.90474   -17.16425
time_dum_243 |  -17.10544    1.20929   -14.15   0.000    -19.47568   -14.73519
time_dum_244 |   16.24267   1.156585    14.04   0.000     13.97573    18.50961
time_dum_245 |   36.76086    1.20929    30.40   0.000     34.39061     39.1311
time_dum_246 |    33.5064   1.206139    27.78   0.000     31.14233    35.87047
time_dum_247 |   41.29412   1.153289    35.81   0.000     39.03363     43.5546
time_dum_248 |   47.47612   1.206139    39.36   0.000     45.11205    49.84019
time_dum_249 |   12.41102   1.206644    10.29   0.000     10.04596    14.77608
time_dum_250 |  -25.47028   1.156327   -22.03   0.000    -27.73672   -23.20385
time_dum_251 |  -30.97227    1.20929   -25.61   0.000    -33.34252   -28.60203
time_dum_252 |  -26.23587   1.156585   -22.68   0.000     -28.5028   -23.96893
time_dum_253 |  -30.91165   1.156585   -26.73   0.000    -33.17859   -28.64471
time_dum_254 |   -29.3451    1.20929   -24.27   0.000    -31.71535   -26.97486
time_dum_255 |  -4.723606    1.20929    -3.91   0.000     -7.09385   -2.353363
time_dum_256 |   23.55089   1.156585    20.36   0.000     21.28395    25.81783
time_dum_257 |   53.64562    1.20929    44.36   0.000     51.27538    56.01587
time_dum_258 |   53.36798   1.206139    44.25   0.000     51.00392    55.73205
time_dum_259 |   38.39911   1.153289    33.30   0.000     36.13863     40.6596
time_dum_260 |   21.90936   1.206139    18.16   0.000     19.54529    24.27343
time_dum_261 |   24.33625   1.206644    20.17   0.000     21.97119    26.70131
time_dum_262 |   22.59644   1.156327    19.54   0.000        20.33    24.86287
time_dum_263 |    48.6379    1.20929    40.22   0.000     46.26765    51.00814
time_dum_264 |   41.61803   1.156585    35.98   0.000     39.35109    43.88497
time_dum_265 |   43.92947   1.156585    37.98   0.000     41.66254    46.19641
time_dum_266 |   46.89211    1.20929    38.78   0.000     44.52186    49.26235
time_dum_267 |   59.42599    1.20929    49.14   0.000     57.05575    61.79624
time_dum_268 |   82.16321   1.156585    71.04   0.000     79.89627    84.43015
time_dum_269 |   115.7434    1.20929    95.71   0.000     113.3732    118.1137
time_dum_270 |   134.3269   1.206139   111.37   0.000     131.9629     136.691
time_dum_271 |   126.5295   1.153289   109.71   0.000      124.269      128.79
time_dum_272 |   100.2805   1.206139    83.14   0.000     97.91644    102.6446
time_dum_273 |    93.1534   1.154049    80.72   0.000     90.89142    95.41537
time_dum_274 |   6.211824    1.20929     5.14   0.000      3.84158    8.582068
time_dum_275 |  -64.22401    1.20929   -53.11   0.000    -66.59426   -61.85377
time_dum_276 |  -97.53195    1.20929   -80.65   0.000     -99.9022   -95.16171
time_dum_277 |  -86.58067   1.156585   -74.86   0.000    -88.84761   -84.31373
time_dum_278 |  -75.83382    1.20929   -62.71   0.000    -78.20406   -73.46357
time_dum_279 |  -71.37818    1.20929   -59.02   0.000    -73.74842   -69.00793
time_dum_280 |  -62.83199   1.156585   -54.33   0.000    -65.09893   -60.56505
time_dum_281 |  -29.39209    1.20929   -24.31   0.000    -31.76233   -27.02184
time_dum_282 |  -5.275926   1.206139    -4.37   0.000    -7.639994   -2.911859
time_dum_283 |  -20.10847   1.153289   -17.44   0.000    -22.36895   -17.84799
time_dum_284 |  -10.72534   1.206139    -8.89   0.000    -13.08941   -8.361271
time_dum_285 |   -15.1498   1.206644   -12.56   0.000    -17.51486   -12.78475
time_dum_286 |  -13.29034   1.156327   -11.49   0.000    -15.55677    -11.0239
time_dum_287 |  -6.269727    1.20929    -5.18   0.000    -8.639971   -3.899483
time_dum_288 |  -9.153384    1.20929    -7.57   0.000    -11.52363    -6.78314
time_dum_289 |    .495521   1.156585     0.43   0.668    -1.771418     2.76246
time_dum_290 |  -2.925442    1.20929    -2.42   0.016    -5.295686   -.5551987
time_dum_291 |   7.513631    1.20929     6.21   0.000     5.143387    9.883875
time_dum_292 |    15.0402   1.156585    13.00   0.000     12.77326    17.30714
time_dum_293 |   12.15948    1.20929    10.06   0.000     9.789237    14.52972
time_dum_294 |  (omitted)
       _cons |   222.7775   .9217996   241.68   0.000     220.9708    224.5843
-------------+----------------------------------------------------------------
     sigma_u |  7.0085083
     sigma_e |  9.7348823
         rho |  .34137307   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(37, 36439) =   490.93           Prob > F = 0.0000
```

Monthly Time Trend Model (Full Year), 1992-2000 (Table 2, Column VIII)

```
Fixed-effects (within) regression               Number of obs      =     17859
Group variable: place_id                        Number of groups   =        38

R-sq:  within  = 0.8125                         Obs per group: min =       469
       between = 0.1019                                        avg =     470.0
       overall = 0.6966                                        max =       470

                                                F(109,17712)       =    704.23
corr(u_i, Xb)  = 0.0126                         Prob > F           =    0.0000
```

value_EXT~10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
rfg	4.38425	.2572682	17.04	0.000	3.879979	4.888521
_78	.1296661	.258798	0.50	0.616	-.3776033	.6369355
time_dum_73	-22.18348	.8483702	-26.15	0.000	-23.84637	-20.52059
time_dum_74	-20.01704	.8932749	-22.41	0.000	-21.76795	-18.26613
time_dum_75	-19.49817	.8932749	-21.83	0.000	-21.24908	-17.74727
time_dum_76	-21.26389	.8483702	-25.06	0.000	-22.92678	-19.601
time_dum_77	-12.30034	.8932749	-13.77	0.000	-14.05124	-10.54943
time_dum_78	-6.958475	.8886915	-7.83	0.000	-8.700398	-5.216553
time_dum_79	-8.56983	.8435429	-10.16	0.000	-10.22326	-6.916403
time_dum_80	-11.41631	.8886915	-12.85	0.000	-13.15823	-9.674387
time_dum_81	-10.56603	.8451528	-12.50	0.000	-12.22261	-8.909447
time_dum_82	-11.48858	.8932749	-12.86	0.000	-13.23949	-9.737675
time_dum_83	-11.58971	.8932749	-12.97	0.000	-13.34062	-9.838804
time_dum_84	-17.34967	.8483702	-20.45	0.000	-19.01256	-15.68678
time_dum_85	-21.24003	.8483702	-25.04	0.000	-22.90292	-19.57714
time_dum_86	-19.33662	.8932749	-21.65	0.000	-21.08753	-17.58571
time_dum_87	-19.66975	.8932749	-22.02	0.000	-21.42066	-17.91885
time_dum_88	-20.75587	.8483702	-24.47	0.000	-22.41876	-19.09298
time_dum_89	-18.38501	.8932749	-20.58	0.000	-20.13592	-16.63411
time_dum_90	-20.67545	.8886915	-23.27	0.000	-22.41737	-18.93353
time_dum_91	-20.89442	.8435429	-24.77	0.000	-22.54784	-19.24099
time_dum_92	-20.84248	.8886915	-23.45	0.000	-22.58441	-19.10056
time_dum_93	-30.72441	.8897098	-34.53	0.000	-32.46833	-28.98049
time_dum_94	-31.97375	.8483702	-37.69	0.000	-33.63664	-30.31087
time_dum_95	-32.22107	.8932749	-36.07	0.000	-33.97198	-30.47016
time_dum_96	-38.23736	.8932749	-42.81	0.000	-39.98826	-36.48645
time_dum_97	-40.98845	.8483702	-48.31	0.000	-42.65134	-39.32556
time_dum_98	-41.51046	.8932749	-46.47	0.000	-43.26137	-39.75955
time_dum_99	-42.91895	.8932749	-48.05	0.000	-44.66986	-41.16805
time_dum_100	-40.33056	.8483702	-47.54	0.000	-41.99345	-38.66767
time_dum_101	-37.20498	.8932749	-41.65	0.000	-38.95588	-35.45407
time_dum_102	-32.754	.8886915	-36.86	0.000	-34.49592	-31.01208
time_dum_103	-27.61183	.8435429	-32.73	0.000	-29.26526	-25.95841
time_dum_104	-20.76973	.8886915	-23.37	0.000	-22.51165	-19.02781
time_dum_105	-22.57643	.8897098	-25.38	0.000	-24.32035	-20.83252
time_dum_106	-26.83639	.8483702	-31.63	0.000	-28.49928	-25.1735
time_dum_107	-27.18348	.8932749	-30.43	0.000	-28.93439	-25.43257
time_dum_108	-30.21344	.8932749	-33.82	0.000	-31.96434	-28.46253
time_dum_109	-31.95746	.8430345	-37.91	0.000	-33.60989	-30.30503
time_dum_110	-35.03437	.888209	-39.44	0.000	-36.77534	-33.29339
time_dum_111	-36.3613	.888209	-40.94	0.000	-38.10228	-34.62032
time_dum_112	-30.60954	.8430345	-36.31	0.000	-32.26197	-28.95711
time_dum_113	-23.49715	.888209	-26.45	0.000	-25.23812	-21.75617
time_dum_114	-22.07921	.8844102	-24.96	0.000	-23.81274	-20.34568
time_dum_115	-26.58725	.8390312	-31.69	0.000	-28.23184	-24.94267
time_dum_116	-31.93262	.8844102	-36.11	0.000	-33.66615	-30.19909
time_dum_117	-34.66544	.8855198	-39.15	0.000	-36.40115	-32.92974

time_dum_118	-37.7813	.8430345	-44.82	0.000	-39.43373	-36.12887
time_dum_119	-41.46416	.888209	-46.68	0.000	-43.20514	-39.72319
time_dum_120	-41.05727	.888209	-46.22	0.000	-42.79824	-39.31629
time_dum_121	-38.59885	.8430345	-45.79	0.000	-40.25128	-36.94642
time_dum_122	-38.17577	.888209	-42.98	0.000	-39.91675	-36.4348
time_dum_123	-32.97323	.888209	-37.12	0.000	-34.71421	-31.23226
time_dum_124	-21.69383	.8430345	-25.73	0.000	-23.34626	-20.0414
time_dum_125	-14.3949	.888209	-16.21	0.000	-16.13587	-12.65392
time_dum_126	-16.46144	.8844102	-18.61	0.000	-18.19497	-14.7279
time_dum_127	-21.47454	.8389981	-25.60	0.000	-23.11906	-19.83002
time_dum_128	-24.65081	.8843788	-27.87	0.000	-26.38428	-22.91734
time_dum_129	-24.69176	.8404692	-29.38	0.000	-26.33916	-23.04436
time_dum_130	-24.76386	.888209	-27.88	0.000	-26.50483	-23.02288
time_dum_131	-20.73513	.888209	-23.34	0.000	-22.4761	-18.99415
time_dum_132	-19.87336	.888209	-22.37	0.000	-21.61434	-18.13239
time_dum_133	-20.49274	.8430345	-24.31	0.000	-22.14517	-18.84031
time_dum_134	-22.13033	.888209	-24.92	0.000	-23.87131	-20.38936
time_dum_135	-26.22657	.888209	-29.53	0.000	-27.96755	-24.48559
time_dum_136	-28.83135	.8430345	-34.20	0.000	-30.48378	-27.17892
time_dum_137	-28.11418	.888209	-31.65	0.000	-29.85516	-26.3732
time_dum_138	-26.46215	.8843788	-29.92	0.000	-28.19561	-24.72868
time_dum_139	-29.86861	.8389981	-35.60	0.000	-31.51313	-28.2241
time_dum_140	-24.16358	.8843788	-27.32	0.000	-25.89705	-22.43012
time_dum_141	-22.55759	.8853535	-25.48	0.000	-24.29297	-20.82221
time_dum_142	-27.85501	.8430345	-33.04	0.000	-29.50744	-26.20258
time_dum_143	-31.50013	.888209	-35.46	0.000	-33.24111	-29.75915
time_dum_144	-36.12499	.8430345	-42.85	0.000	-37.77742	-34.47256
time_dum_145	-44.20386	.8430345	-52.43	0.000	-45.85629	-42.55143
time_dum_146	-49.79894	.888209	-56.07	0.000	-51.53992	-48.05797
time_dum_147	-52.6932	.888209	-59.33	0.000	-54.43417	-50.95222
time_dum_148	-51.11669	.8430345	-60.63	0.000	-52.76912	-49.46426
time_dum_149	-48.57762	.888209	-54.69	0.000	-50.31859	-46.83664
time_dum_150	-48.72228	.8843788	-55.09	0.000	-50.45575	-46.98881
time_dum_151	-49.17932	.8399858	-58.55	0.000	-50.82577	-47.53286
time_dum_152	-52.1648	.8843998	-58.98	0.000	-53.89831	-50.43129
time_dum_153	-55.06642	.8852002	-62.21	0.000	-56.8015	-53.33134
time_dum_154	-55.13716	.8430345	-65.40	0.000	-56.78959	-53.48473
time_dum_155	-58.25736	.888209	-65.59	0.000	-59.99833	-56.51638
time_dum_156	-62.8504	.888209	-70.76	0.000	-64.59137	-61.10942
time_dum_157	-64.33154	.8430345	-76.31	0.000	-65.98397	-62.67911
time_dum_158	-66.97397	.888209	-75.40	0.000	-68.71494	-65.23299
time_dum_159	-58.15189	.888209	-65.47	0.000	-59.89287	-56.41092
time_dum_160	-45.39777	.8430345	-53.85	0.000	-47.0502	-43.74534
time_dum_161	-41.71219	.888209	-46.96	0.000	-43.45316	-39.97121
time_dum_162	-44.77194	.8843528	-50.63	0.000	-46.50536	-43.03852
time_dum_163	-38.32347	.8389708	-45.68	0.000	-39.96794	-36.67901
time_dum_164	-35.94096	.8843528	-40.64	0.000	-37.67437	-34.20754
time_dum_165	-33.27547	.8852964	-37.59	0.000	-35.01074	-31.54021
time_dum_166	-26.82526	.8429419	-31.82	0.000	-28.47751	-25.17301
time_dum_167	-25.97032	.8881211	-29.24	0.000	-27.71113	-24.22952
time_dum_168	-14.05791	.8881211	-15.83	0.000	-15.79871	-12.3171
time_dum_169	-18.15528	.8429419	-21.54	0.000	-19.80753	-16.50303
time_dum_170	-9.108436	.8881211	-10.26	0.000	-10.84924	-7.367632
time_dum_171	.7131958	.8881211	0.80	0.422	-1.027608	2.454
time_dum_172	-7.491357	.8429419	-8.89	0.000	-9.143606	-5.839108
time_dum_173	4.015426	.8881211	4.52	0.000	2.274622	5.75623
time_dum_174	16.395	.8843528	18.54	0.000	14.66158	18.12841
time_dum_175	6.37169	.8389708	7.59	0.000	4.727225	8.016155
time_dum_176	(omitted)					
time_dum_177	5.741828	.8404025	6.83	0.000	4.094557	7.3891
time_dum_178	4.478217	.8881211	5.04	0.000	2.737413	6.219022
time_dum_179	-2.918324	.8881211	-3.29	0.001	-4.659128	-1.17752

```
time_dum_180 |  -4.602914   .8881211    -5.18   0.000    -6.343718   -2.862109
       _cons |   137.2831   .6378873   215.22   0.000     136.0328    138.5334
-------------+----------------------------------------------------------------
     sigma_u |  7.4779156
     sigma_e |  7.7096093
         rho |  .48474802   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(37, 17712) =   434.44           Prob > F = 0.0000
```

<u>Monthly Time Trend Model (Full Year), 2001-2010 (Table 2, Column IX)</u>

```
Fixed-effects (within) regression               Number of obs      =     18841
Group variable: place_id                        Number of groups   =        38

R-sq:  within  = 0.9697                         Obs per group: min =       489
       between = 0.0181                                        avg =     495.8
       overall = 0.9565                                        max =       496

                                                F(114,18689)       =   5250.66
corr(u_i, Xb)  = 0.0003                         Prob > F           =    0.0000

------------------------------------------------------------------------------
value_EXT~10 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         rfg |  (omitted)
         _78 |  -.2721105   .3485569    -0.78   0.435    -.9553137    .4110926
time_dum_181 |   14.48199   1.188823    12.18   0.000     12.15179     16.8122
time_dum_182 |   12.03413   1.253129     9.60   0.000     9.577882    14.49038
time_dum_183 |   7.876259   1.253129     6.29   0.000     5.420011    10.33251
time_dum_184 |   26.09153   1.188823    21.95   0.000     23.76133    28.42173
time_dum_185 |   40.20762   1.253129    32.09   0.000     37.75138    42.66387
time_dum_186 |   28.65783   1.259692    22.75   0.000     26.18872    31.12694
time_dum_187 |   5.457906   1.195738     4.56   0.000      3.11415    7.801662
time_dum_188 |   11.69461   1.259692     9.28   0.000     9.225498    14.16372
time_dum_189 |   19.84753   1.255553    15.81   0.000     17.38653    22.30853
time_dum_190 |   1.556064   1.188836     1.31   0.191    -.7741618     3.88629
time_dum_191 |   -20.2762   1.253129   -16.18   0.000    -22.73245   -17.81995
time_dum_192 |  -32.25407   1.253129   -25.74   0.000    -34.71032   -29.79783
time_dum_193 |  -28.64935   1.188823   -24.10   0.000    -30.97955   -26.31915
time_dum_194 |  -30.99994   1.253129   -24.74   0.000    -33.45619   -28.54369
time_dum_195 |  -17.63299   1.253129   -14.07   0.000    -20.08923   -15.17674
time_dum_196 |  -3.664032   1.188823    -3.08   0.002    -5.994233   -1.333831
time_dum_197 |   .6431392   1.253129     0.51   0.608    -1.813108    3.099387
time_dum_198 |  -2.111378   1.259692    -1.68   0.094    -4.580489    .3577328
time_dum_199 |  -1.194464   1.195738    -1.00   0.318     -3.53822    1.149293
time_dum_200 |   2.905872   1.259692     2.31   0.021     .4367615    5.374983
time_dum_201 |   5.783049   1.255553     4.61   0.000     3.322052    8.244047
time_dum_202 |   11.46169   1.188836     9.64   0.000     9.131469    13.79192
time_dum_203 |   7.906759   1.253129     6.31   0.000     5.450512    10.36301
time_dum_204 |  (omitted)
time_dum_205 |   7.257809   1.188823     6.11   0.000     4.927608     9.58801
time_dum_206 |    23.4302   1.253129    18.70   0.000     20.97395    25.88644
time_dum_207 |   32.70068   1.253129    26.10   0.000     30.24444    35.15693
time_dum_208 |   24.92256   1.188823    20.96   0.000     22.59236    27.25276
time_dum_209 |   14.80451   1.253129    11.81   0.000     12.34827    17.26076
time_dum_210 |   9.897647   1.259692     7.86   0.000     7.428537    12.36676
time_dum_211 |   20.77461   1.195738    17.37   0.000     18.43085    23.11836
time_dum_212 |   26.88599   1.259692    21.34   0.000     24.41688     29.3551
time_dum_213 |   35.93321   1.255553    28.62   0.000     33.47221    38.39421
time_dum_214 |   15.93617   1.188836    13.40   0.000     13.60594     18.2664
time_dum_215 |   13.26463   1.253129    10.59   0.000     10.80838    15.72087
time_dum_216 |   9.658419   1.253129     7.71   0.000     7.202172    12.11467
time_dum_217 |   16.20039   1.188823    13.63   0.000     13.87019    18.53059
time_dum_218 |   25.65915   1.253129    20.48   0.000      23.2029     28.1154
time_dum_219 |   33.05876   1.253129    26.38   0.000     30.60251      35.515
time_dum_220 |   40.38833   1.188823    33.97   0.000     38.05813    42.71853
time_dum_221 |   55.23073   1.253129    44.07   0.000     52.77449    57.68698
time_dum_222 |   58.56238    1.26066    46.45   0.000     56.09138    61.03339
time_dum_223 |   54.93916   1.196758    45.91   0.000     52.59341    57.28492
time_dum_224 |   55.54331    1.26066    44.06   0.000      53.0723    58.01432
time_dum_225 |   47.62793   1.190974    39.99   0.000     45.29351    49.96234
```

time_dum_226	52.59854	1.253129	41.97	0.000	50.14229	55.05479
time_dum_227	50.8757	1.253129	40.60	0.000	48.41945	53.33195
time_dum_228	38.20476	1.188823	32.14	0.000	35.87456	40.53496
time_dum_229	31.83275	1.188823	26.78	0.000	29.50255	34.16296
time_dum_230	46.75115	1.253129	37.31	0.000	44.29491	49.2074
time_dum_231	63.47014	1.253129	50.65	0.000	61.0139	65.92639
time_dum_232	81.60716	1.188823	68.65	0.000	79.27696	83.93736
time_dum_233	75.27061	1.253129	60.07	0.000	72.81436	77.72686
time_dum_234	76.01666	1.26066	60.30	0.000	73.54566	78.48767
time_dum_235	82.11687	1.196758	68.62	0.000	79.77111	84.46262
time_dum_236	108.5094	1.26066	86.07	0.000	106.0384	110.9804
time_dum_237	145.9467	1.260149	115.82	0.000	143.4766	148.4167
time_dum_238	130.3536	1.196036	108.99	0.000	128.0093	132.6979
time_dum_239	90.69028	1.253129	72.37	0.000	88.23403	93.14652
time_dum_240	74.2544	1.253129	59.26	0.000	71.79815	76.71065
time_dum_241	83.85181	1.188823	70.53	0.000	81.52161	86.18201
time_dum_242	86.8675	1.253129	69.32	0.000	84.41125	89.32374
time_dum_243	89.29656	1.253129	71.26	0.000	86.84031	91.75281
time_dum_244	122.6447	1.188823	103.16	0.000	120.3145	124.9749
time_dum_245	143.1629	1.253129	114.24	0.000	140.7066	145.6191
time_dum_246	140.0145	1.26066	111.06	0.000	137.5435	142.4855
time_dum_247	147.8022	1.196758	123.50	0.000	145.4565	150.148
time_dum_248	153.9842	1.26066	122.15	0.000	151.5132	156.4552
time_dum_249	118.8767	1.255846	94.66	0.000	116.4151	121.3383
time_dum_250	80.93595	1.188836	68.08	0.000	78.60573	83.26618
time_dum_251	75.42972	1.253129	60.19	0.000	72.97347	77.88597
time_dum_252	80.16613	1.188823	67.43	0.000	77.83593	82.49633
time_dum_253	75.49034	1.188823	63.50	0.000	73.16014	77.82054
time_dum_254	77.05689	1.253129	61.49	0.000	74.60064	79.51314
time_dum_255	101.6784	1.253129	81.14	0.000	99.22214	104.1346
time_dum_256	129.9529	1.188823	109.31	0.000	127.6227	132.2831
time_dum_257	160.0476	1.253129	127.72	0.000	157.5914	162.5039
time_dum_258	159.8761	1.26066	126.82	0.000	157.4051	162.3471
time_dum_259	144.9072	1.196758	121.08	0.000	142.5615	147.253
time_dum_260	128.4175	1.26066	101.87	0.000	125.9465	130.8885
time_dum_261	130.8019	1.255846	104.15	0.000	128.3403	133.2635
time_dum_262	129.0027	1.188836	108.51	0.000	126.6724	131.3329
time_dum_263	155.0399	1.253129	123.72	0.000	152.5836	157.4961
time_dum_264	148.02	1.188823	124.51	0.000	145.6898	150.3502
time_dum_265	150.3315	1.188823	126.45	0.000	148.0013	152.6617
time_dum_266	153.2941	1.253129	122.33	0.000	150.8379	155.7503
time_dum_267	165.828	1.253129	132.33	0.000	163.3717	168.2842
time_dum_268	188.5652	1.188823	158.62	0.000	186.235	190.8954
time_dum_269	222.1454	1.253129	177.27	0.000	219.6892	224.6017
time_dum_270	240.835	1.26066	191.04	0.000	238.364	243.306
time_dum_271	233.0376	1.196758	194.72	0.000	230.6918	235.3834
time_dum_272	206.7886	1.26066	164.03	0.000	204.3176	209.2596
time_dum_273	199.6106	1.190974	167.60	0.000	197.2762	201.945
time_dum_274	112.6138	1.253129	89.87	0.000	110.1576	115.0701
time_dum_275	42.17798	1.253129	33.66	0.000	39.72173	44.63423
time_dum_276	8.870041	1.253129	7.08	0.000	6.413793	11.32629
time_dum_277	19.82132	1.188823	16.67	0.000	17.49112	22.15152
time_dum_278	30.56818	1.253129	24.39	0.000	28.11193	33.02443
time_dum_279	35.02382	1.253129	27.95	0.000	32.56757	37.48006
time_dum_280	43.57001	1.188823	36.65	0.000	41.23981	45.90021
time_dum_281	77.00991	1.253129	61.45	0.000	74.55366	79.46616
time_dum_282	101.2322	1.26066	80.30	0.000	98.76118	103.7032
time_dum_283	86.39965	1.196758	72.19	0.000	84.0539	88.74541
time_dum_284	95.78278	1.26066	75.98	0.000	93.31177	98.25379
time_dum_285	91.31586	1.255846	72.71	0.000	88.85429	93.77744
time_dum_286	93.1159	1.188836	78.33	0.000	90.78568	95.44613
time_dum_287	100.1323	1.253129	79.91	0.000	97.67602	102.5885

```
time_dum_288 |   97.24861   1.253129    77.60   0.000     94.79236    99.70486
time_dum_289 |   106.8975   1.188823    89.92   0.000     104.5673    109.2277
time_dum_290 |   103.4766   1.253129    82.57   0.000     101.0203    105.9328
time_dum_291 |   113.9156   1.253129    90.90   0.000     111.4594    116.3719
time_dum_292 |   121.4422   1.188823   102.15   0.000      119.112    123.7724
time_dum_293 |   118.5615   1.253129    94.61   0.000     116.1052    121.0177
time_dum_294 |   106.5081   1.360509    78.29   0.000     103.8414    109.1748
       _cons |   117.5435   .8860963   132.65   0.000     115.8067    119.2804
-------------+----------------------------------------------------------------
     sigma_u |  7.4531883
     sigma_e |  10.924529
         rho |   .3176186   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(37, 18689) =   209.99           Prob > F = 0.0000
```

Multiple RVP Regulations Model, 1992-2010 (Table 2, Column X)

```
Linear regression                                      Number of obs =   10373
                                                       F( 20,    31) =       .
                                                       Prob > F      =       .
                                                       R-squared     =  0.9662
                                                       Root MSE      =  12.808

                                  (Std. Err. adjusted for 32 clusters in state)
------------------------------------------------------------------------------
             |               Robust
value_EXT~10 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         rfg |    7.37854   2.155464     3.42   0.002     2.982443    11.77464
      rvp_78 |   .5505076   1.594406     0.35   0.732    -2.701305    3.802321
         _72 |   8.017467   2.389813     3.35   0.002     3.143412    12.89152
 place_dum_1 |   16.30594   2.914906     5.59   0.000     10.36095    22.25093
 place_dum_2 |    4.99383   1.850952     2.70   0.011     1.218789    8.768871
 place_dum_3 |   4.781862   1.331592     3.59   0.001     2.066062    7.497662
 place_dum_4 |    4.01644   1.827179     2.20   0.036      .289885    7.742996
 place_dum_5 |   12.65489   1.594406     7.94   0.000     9.403073     15.9067
 place_dum_6 |   13.62202   2.914906     4.67   0.000     7.677027    19.56701
 place_dum_7 |   18.22889   2.914906     6.25   0.000      12.2839    24.17388
 place_dum_8 |   30.08903   1.594406    18.87   0.000     26.83722    33.34084
 place_dum_9 |    11.5471   2.914906     3.96   0.000     5.602112    17.49209
place_dum_10 |   3.524158   2.14e-10        .   0.000     3.524158    3.524158
place_dum_11 |   19.22131   2.476925     7.76   0.000     14.16958    24.27303
place_dum_12 |   8.539699   2.914906     2.93   0.006     2.594709    14.48469
place_dum_13 |   6.714208   1.976222     3.40   0.002     2.683675    10.74474
place_dum_14 |  (dropped)
place_dum_15 |   7.598987   2.914906     2.61   0.014     1.653997    13.54398
place_dum_16 |   2.978498   1.981014     1.50   0.143    -1.061808    7.018803
place_dum_17 |   6.988236   2.914906     2.40   0.023     1.043246    12.93323
place_dum_18 |  (dropped)
place_dum_19 |   12.40536   1.594406     7.78   0.000      9.15355    15.65718
place_dum_20 |   5.626826   1.800167     3.13   0.004      1.95536    9.298291
place_dum_21 |   15.76791   1.800167     8.76   0.000     12.09644    19.43938
place_dum_22 |   4.898276   1.594406     3.07   0.004     1.646464    8.150089
place_dum_23 |   12.02879   2.914906     4.13   0.000     6.083802    17.97378
place_dum_24 |   9.099126   1.800167     5.05   0.000     5.427661    12.77059
place_dum_25 |   15.55847   1.594406     9.76   0.000     12.30666    18.81028
place_dum_26 |   13.64782   1.594406     8.56   0.000       10.396    16.89963
place_dum_27 |   4.877076   1.331592     3.66   0.001     2.161276    7.592875
place_dum_28 |   3.668373   2.914906     1.26   0.218    -2.276618    9.613363
place_dum_29 |   9.353623   2.914906     3.21   0.003     3.408633    15.29861
place_dum_30 |   6.410888   1.594406     4.02   0.000     3.159075    9.662701
place_dum_31 |  (dropped)
place_dum_32 |   8.405619     2.1274     3.95   0.000     4.066758    12.74448
place_dum_33 |   29.50798   1.800167    16.39   0.000     25.83651    33.17944
place_dum_34 |   15.73328   1.800167     8.74   0.000     12.06181    19.40474
place_dum_35 |   4.948383   2.281295     2.17   0.038     .2956525    9.601114
place_dum_36 |  (dropped)
place_dum_37 |  (dropped)
place_dum_38 |    28.9808   2.914906     9.94   0.000     23.03581    34.92579
place_dum_39 |   4.728011   1.275314     3.71   0.001     2.126991    7.329032
place_dum_40 |   2.291337   2.281295     1.00   0.323    -2.361394    6.944068
place_dum_41 |    17.0228   1.331592    12.78   0.000       14.307     19.7386
place_dum_42 |   5.115855   2.914906     1.76   0.089    -.8291356    11.06085
  year_dum_1 |  (dropped)
  year_dum_2 |  (dropped)
  year_dum_3 |  (dropped)
  year_dum_4 |  (dropped)
  year_dum_5 |  (dropped)
  year_dum_6 |  (dropped)
  year_dum_7 |  (dropped)
  year_dum_8 |  -12.31599   .8008238   -15.38   0.000    -13.94928    -10.6827
  year_dum_9 |  -16.98669   1.654212   -10.27   0.000    -20.36048   -13.61291
 year_dum_10 |  -19.60582   1.251106   -15.67   0.000    -22.15747   -17.05417
 year_dum_11 |  -13.24789   1.464121    -9.05   0.000    -16.23399    -10.2618
 year_dum_12 |  -18.35264   1.665816   -11.02   0.000    -21.75009   -14.95518
```

year_dum_13	-42.65562	1.445107	-29.52	0.000	-45.60293	-39.7083
year_dum_14	-30.68354	1.88243	-16.30	0.000	-34.52278	-26.8443
year_dum_15	15.48395	1.432337	10.81	0.000	12.56268	18.40522
year_dum_16	1.671044	1.490665	1.12	0.271	-1.369188	4.711275
year_dum_17	-13.20864	1.669502	-7.91	0.000	-16.61361	-9.803667
year_dum_18	8.111451	1.649634	4.92	0.000	4.746999	11.4759
year_dum_19	41.46947	1.426911	29.06	0.000	38.55927	44.37968
year_dum_20	82.12821	1.793891	45.78	0.000	78.46955	85.78688
year_dum_21	131.7442	2.142725	61.48	0.000	127.374	136.1143
year_dum_22	128.8409	2.395149	53.79	0.000	123.956	133.7258
year_dum_23	210.1446	1.873785	112.15	0.000	206.323	213.9662
year_dum_24	80.03427	2.184808	36.63	0.000	75.57833	84.49022
year_dum_25	92.61017	2.130892	43.46	0.000	88.26418	96.95615
_cons	117.2296	3.174991	36.92	0.000	110.7542	123.7051

City-Specific Price Effects Model, 1992-2010 (Table 4)

Linear regression

Number of obs = 10373
F(17, 31) = .
Prob > F = .
R-squared = 0.9666
Root MSE = 12.74

(Std. Err. adjusted for 32 clusters in state)

value_EXT~10	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
rfg_C_Balt~e	10.69774	1.346945	7.94	0.000	7.950625	13.44485
rfg_C_Boston	8.762365	1.346945	6.51	0.000	6.015252	11.50948
rfg_C_Chic~o	19.31887	1.346945	14.34	0.000	16.57176	22.06599
rfg_C_Dallas	4.667675	1.346945	3.47	0.002	1.920562	7.414789
rfg_C_Hous~n	9.210128	1.346945	6.84	0.000	6.463015	11.95724
rfg_C_Loui~e	11.16145	1.346945	8.29	0.000	8.414336	13.90856
rfg_C_Milw~e	.6719575	1.346945	0.50	0.621	-2.075156	3.419071
rfg_C_New_~k	-11.45196	1.346945	-8.50	0.000	-14.19908	-8.704851
rfg_C_Newark	-.6226307	1.346945	-0.46	0.647	-3.369744	2.124483
rfg_C_Norf~k	5.996799	1.346945	4.45	0.000	3.249685	8.743912
rfg_C_Phil~a	5.435525	1.346945	4.04	0.000	2.688411	8.182638
rfg_C_St_L~s	2.102438	.9442895	2.23	0.033	.1765472	4.02833
rfg_C_Wash~n	16.28946	1.346945	12.09	0.000	13.54235	19.03657
rvp_C_Atla~a	4.216518	.0026769	1575.17	0.000	4.211058	4.221977
rvp_C_Balt~e	(dropped)					
rvp_C_Birm~m	2.815328	1.39e-10	.	0.000	2.815328	2.815328
rvp_C_Dallas	1.22283	1.124921	1.09	0.285	-1.071463	3.517122
rvp_C_Denver	4.438322	1.063788	4.17	0.000	2.268712	6.607933
rvp_C_Detr~t	9.744879	1.189899	8.19	0.000	7.318065	12.17169
rvp_C_Hous~n	-6.095025	1.124921	-5.42	0.000	-8.389318	-3.800733
rvp_C_Kans~y	3.828748	1.39e-10	.	0.000	3.828748	3.828748
rvp_C_Memp~s	1.061479	1.39e-10	.	0.000	1.061479	1.061479
rvp_C_Miami	11.20256	1.39e-10	.	0.000	11.20256	11.20256
rvp_C_New_~s	4.533779	1.39e-10	.	0.000	4.533779	4.533779
rvp_C_Norf~k	(dropped)					
rvp_C_Pitt~h	-2.226706	.9545282	-2.33	0.026	-4.173479	-.2799326
rvp_C_Port~d	24.94263	1.39e-10	.	0.000	24.94263	24.94263
rvp_C_SLC	11.16793	1.39e-10	.	0.000	11.16793	11.16793
rvp_C_San_~o	.7346776	.8503763	0.86	0.394	-.9996762	2.469031
rvp_C_St_L~s	(dropped)					
rvp_C_Tulsa	-.2833764	.8503763	-0.33	0.741	-2.01773	1.450977
rvp_C_Wash~n	(dropped)					
year_dum_1	(dropped)					
year_dum_2	(dropped)					
year_dum_3	(dropped)					
year_dum_4	(dropped)					
year_dum_5	(dropped)					
year_dum_6	(dropped)					
year_dum_7	42.28139	1.507019	28.06	0.000	39.20781	45.35498
year_dum_8	29.9654	1.687781	17.75	0.000	26.52315	33.40766
year_dum_9	25.2947	1.539	16.44	0.000	22.15589	28.43351
year_dum_10	23.0498	1.256693	18.34	0.000	20.48676	25.61284
year_dum_11	29.23029	.9724822	30.06	0.000	27.2469	31.21368
year_dum_12	24.25752	.901412	26.91	0.000	22.41908	26.09596
year_dum_13	(dropped)					
year_dum_14	11.92756	1.167826	10.21	0.000	9.545765	14.30936
year_dum_15	58.09506	1.329558	43.70	0.000	55.3834	60.80671
year_dum_16	44.49574	1.627958	27.33	0.000	41.1755	47.81599
year_dum_17	29.81256	1.29554	23.01	0.000	27.17029	32.45483
year_dum_18	51.13265	1.170374	43.69	0.000	48.74566	53.51964
year_dum_19	84.38836	.9116251	92.57	0.000	82.52909	86.24763
year_dum_20	125.0471	1.26833	98.59	0.000	122.4603	127.6339
year_dum_21	174.663	1.884776	92.67	0.000	170.819	178.5071
year_dum_22	171.9563	1.943554	88.48	0.000	167.9924	175.9202
year_dum_23	253.26	1.495538	169.34	0.000	250.2098	256.3102
year_dum_24	123.1497	1.661277	74.13	0.000	119.7615	126.5379
year_dum_25	135.7256	1.761914	77.03	0.000	132.1321	139.319

place_dum_1	11.19008	1.39e-10	.	0.000	11.19008	11.19008
place_dum_2	(dropped)					
place_dum_3	-3.015327	1.124921	-2.68	0.012	-5.30962	-.721035
place_dum_4	(dropped)					
place_dum_5	6.383309	1.124921	5.67	0.000	4.089017	8.677602
place_dum_6	8.506162	1.39e-10	.	0.000	8.506162	8.506162
place_dum_7	13.11303	1.39e-10	.	0.000	13.11303	13.11303
place_dum_8	15.00103	1.124921	13.34	0.000	12.70674	17.29532
place_dum_9	6.431248	1.39e-10	.	0.000	6.431248	6.431248
place_dum_10	(dropped)					
place_dum_11	12.78103	.3623894	35.27	0.000	12.04193	13.52013
place_dum_12	3.423844	1.39e-10	.	0.000	3.423844	3.423844
place_dum_13	-4.12769	.910948	-4.53	0.000	-5.985581	-2.269799
place_dum_14	(dropped)					
place_dum_15	2.483132	1.39e-10	.	0.000	2.483132	2.483132
place_dum_16	(dropped)					
place_dum_17	1.872381	1.39e-10	.	0.000	1.872381	1.872381
place_dum_18	(dropped)					
place_dum_19	4.130155	1.124921	3.67	0.001	1.835862	6.424447
place_dum_20	(dropped)					
place_dum_21	(dropped)					
place_dum_22	5.383524	1.124921	4.79	0.000	3.089231	7.677816
place_dum_23	6.912938	1.39e-10	.	0.000	6.912938	6.912938
place_dum_24	(dropped)					
place_dum_25	26.16919	1.124921	23.26	0.000	23.8749	28.46348
place_dum_26	15.21426	1.124921	13.52	0.000	12.91997	17.50855
place_dum_27	1.005946	1.124921	0.89	0.378	-1.288347	3.300238
place_dum_28	-1.447482	1.39e-10	.	0.000	-1.447482	-1.447482
place_dum_29	4.237768	1.39e-10	.	0.000	4.237768	4.237768
place_dum_30	2.917771	1.124921	2.59	0.014	.623479	5.212064
place_dum_31	(dropped)					
place_dum_32	5.080202	.6153735	8.26	0.000	3.82514	6.335265
place_dum_33	(dropped)					
place_dum_34	(dropped)					
place_dum_35	-.2605684	.4298605	-0.61	0.549	-1.137275	.616138
place_dum_36	(dropped)					
place_dum_37	(dropped)					
place_dum_38	23.86494	1.39e-10	.	0.000	23.86494	23.86494
place_dum_39	4.711812	.5811012	8.11	0.000	3.526648	5.896976
place_dum_40	-2.402994	.4298605	-5.59	0.000	-3.2797	-1.526287
place_dum_41	4.555605	1.124921	4.05	0.000	2.261312	6.849897
place_dum_42	(dropped)					
_cons	79.59499	.7281074	109.32	0.000	78.11	81.07997

REFERENCES

Auffhammer, Maximilian, and Ryan Kellogg. "Clearing the Air? The Effects of Gasoline Content Regulation on Air Quality." *American Economic Review (forthcoming)*.

Borenstein, Seth. "EPA 'Value of Life': Gov't Wants to Change Human Price Tag." *Huffington Post* 1 Jan 2011.

Borenstein, Severin, A. Colin Cameron, and Richard Gilbert. "Do Gasoline Prices Respond Asymmetrically to Crude Oil Price Changes?" *The Quarterly Journal of Economics* 112.1 (1997): 305-39.

Brown, Jennifer, Justine Hastings, Erin T. Mansur, and Sofia B. Villas-Boas. "Reformulating Competition? Gasoline Content Regulation and Wholesale Gasoline Prices." *Journal of Environmental Economics and Management* 55.1 (2008): 1-19.

Center, Al. Personal interview. 2010.

Chakravorty, Ujjayant, Celine Nauges, and Alban Thomas. "Clean Air Regulation and Heterogeneity in US Gasoline Prices." *Journal of Environmental Economics and Management* 55.1 (2008): 106-22.

Chouinard, Hayley, and Jeffrey Perloff. "Gasoline Price Differences: Taxes, Pollution Regulations, Mergers, Market Power, and Market Conditions." *The B.E. Journal of Economic Analysis & Policy* 7.1 (2007): 1-26.

Crouch, Edmund, and Richard Wilson. "Regulation of Carcinogens." *Risk Analysis* 1 (1981): 47-57.

Dahl, Carol, and Thomas Sterner. "Analysing Gasoline Demand Elasticities: A Survey." *Energy Economics* (1991): 203-10.

Energy Independence and Security Act of 2007. Public Law 110-140, 2007.

Energy Policy Act of 2005. Public Law 109-58, 2005.

Espey, Molly. "Gasoline Demand Revisited: An International Meta-Analysis of Elasticities." *Energy Economics* 20 (1998): 273-96.

Gibbs, Lew, et al. *Motor Gasolines Technical Review*. Vol. FTR-1. Chevron Corporation, 2009.

Greene, William H. *Econometric Analysis*. 6th ed. Upper Saddle River, NJ: Prentice Hall, 2007.

Hastings, Justine. "Wholesale Price Discrimination and Regulation: Implications for Retail Gasoline Prices." *Unpublished first draft* (2009). <https://vlab.decisionsciences.columbia.edu/newsletter/nov2209/Hastings_WPD_Draft2009 10.pdf>.

Karrenbrock, Jeffrey D. "The Behavior of Retail Gasoline Prices: Symmetric Or Not?" *Federal Reserve Bank of Saint Louis Review* July (1991): 19-29.

Lichtenberg, Erik, and David Zilberman. "Efficient Regulation of Environmental Health Risks." *The Quarterly Journal of Economics* 103.1 (1988): 167-78.

Lidderdale, Tancred C. M. *Environmental Regulations and Changes in Petroleum Refining Operations*. U.S. Energy Information Administration, 1999a.

---. "Motor Gasoline Outlook and State MTBE Bans." U.S. Energy Information Administration. 6 April 2003 2003b. <http://www.eia.doe.gov/steo/special/mtbeban.html>.

Marathon Oil Corporation. "RFG Attachment I." 7 May 2010. <http://www.marathonpetroleum.com/Products/RFG_and_RVP_Summer_Regulatory_Requirements/Summer_2010_Reformulated_Gasoline_RFG_Regulatory_Requirements/RFG_Attachment_I/>.

Martineau, Robert J., and David P. Novello, eds. *The Clean Air Act Handbook*. 2nd ed. Chicago: American Bar Association, 2004.

Muehlegger, Erich. *Gasoline Price Spikes and Regional Gasoline Content Regulation: A Structural Approach*. KSG Working Paper ed. Vol. RWP06-015. Cambridge, MA: 2006.

National Petrochemical & Refiners Association. "Refinery Statistics." <http://www.npra.org/ourIndustry/refineryFacts/?fa=refineryStatistics>.

Noel, Michael D. "Edgeworth Price Cycles, Cost-Based Pricing, and Sticky Pricing in Retail Gasoline Markets." *The Review of Economics and Statistics* 89.2 (2007): 324-34.

Parry, Ian W. H., and Kenneth A. Small. "Does Britain or the United States Have the Right Gasoline Tax?" *American Economic Revie*w 95.4 (2005): 1276-89.

Perman, Roger, Yue Ma, James McGilvray, and Michael Common. *Natural Resource and Environmental Economics*. 3rd ed. Addison Wesley, 2003.

Peterson, Bruce, Shih-Miao Chin, and Sujit Das. *Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints*. Oak Ridge National Laboratory, 2009.

Reiss, Peter C., and Frank A. Wolak. "Structural Econometric Modeling: Rationales and Examples from Industrial Organization." *Handbook of Econometrics, Volume 6A.* Elsevier B.V., 2007.

Renewable Fuels Association. "Federal Regulations: RFG Required Areas." 2010. <http://www.ethanolrfa.org/pages/federal-regulations-rfg-required-areas/>.

Shurtleff, D. Sean, and H. Sterling Burnett. "Increasing America's Domestic Fuel Supply by Building New Oil Refineries." *Brief Analysi*s. 15 November 2007.

Texas State Energy Conservation Office. "MTBE & Ethanol." <http://www.seco.cpa.state.tx.us/re_ethanol_mtbe.htm>.

Timmins, Christopher, and Wolfram Schlenker. "Reduced-Form Versus Structural Modeling in Environmental and Resource Economics." *Annual Review of Resource Economics* 1 (2009): 351-80.

U.S. Census Bureau. "MSA/CMSA - U.S. Census Bureau." <http://www.census.gov/acs/www/data_documentation/custom_tabulation_request_form/msa_cmsa.html>.

U.S. Energy Information Administration. *Petroleum Marketing Annual 200*9. DOE/EIA-0487(2009). 2010.

U.S. Environmental Protection Agency, and U.S. Department of Energy. *EPAct Section 1541(c) Boutique Fuels Report to Congres*s. EPA420-R-06-901.

U.S. Environmental Protection Agency. "Air Emission Sources." 4 November 2009. <http://www.epa.gov/air/emissions/index.htm>.

---. *The Benefits and Costs of the Clean Air Act from 1990 to 202*0. 2011b.

---. *The Benefits and Costs of the Clean Air Act: 1990 to 2020 - Summary Report (August 16, 2010 External Review Draft*). 2010b.

---. "Ground-level Ozone: Health and Environment." 29 October 2010. <http://www.epa.gov/glo/health.html>.

---. *Guide on Federal and State Summer RVP Standards for Conventional Gasoline Onl*y. Vol. EPA-420-B-10-018, 2010.

---. "History of the Clean Air Act." 19 December 2008. <http://epa.gov/oar/caa/caa_history.html>.

---. *National Ambient Air Quality Standards for Ozone; Proposed Rule*. 75 FR 11, 2938-3052. Washington: GPO, 2010.

---. *National Ambient Air Quality Standards for Ozone; Final Rule*. 73 FR 60, 16436-16514. Washington: GPO, 2008.

---. *Phase II Reformulated Gasoline: The Next Major Step Toward Cleaner Ai*r. EPA420-F99-042, 1999. < http://www.epa.gov/OMS/rfg/f99042.pdf>.

---. "Reformulated Gas: Where You Live." 16 July 2008. <http://www.epa.gov/otaq/rfg/whereyoulive.htm>.

---. *Regulation of Fuels and Fuel Additives: Standards for Gasoline Volatility; and Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines: Standards for Particulate Emissions from Urban Buses; Final Rule*. 56 FR 239, 64704-64713. Washington: GPO, 1991.

---. *Regulation to Mitigate the Misfueling of Vehicles and Engines with Gasoline Containing Greater than Ten Volume Percent Ethanol and Modifications to the Reformulated and Conventional Gasoline Programs; Proposed Rule*. 75 FR 213, 68044-68091. Washington: GPO, 2010.

---. "State Actions Banning MTBE (Statewide)." August 2007. <http://www.epa.gov/mtbe/420b07013.pdf>.

---. *State Winter Oxygenated Fuel Program Requirements for Attainment or Maintenance of CO NAAQ*S. Vol. EPA420-B-08-006. 2008.

---. "Tier 2 Vehicle & Gasoline Sulfur Program: Frequent Questions." 19 September 2007. <http://www.epa.gov/tier2/faqs.htm>.

---. *Volatility Regulations for Gasoline and Alcohol Blends Sold in Calendar Years 1989 and Beyond; Notice of Final Rulemaking*. 54 FR 54, 11868-11911. Washington: GPO, 1989.

---. *Volatility Regulations for Gasoline and Alcohol Blends Sold in Calendar Years 1992 and Beyond; Notice of Final Rulemaking*. 55 FR 112, 23658-23667. Washington: GPO, 1990.

U.S. Government Accountability Office. *Special Gasoline Blends Reduce Emissions and Improve Air Quality, but Complicate Supply and Contribute to Higher Price*s. Ed. Jim Wells. GAO-05-421. Washington DC: 2005.

Walls, W. David, and Frank W. Rusco. "Price Effects of Boutique Motor Fuels: Federal Environmental Standards, Regional Fuel Choices, and Local Gasoline Prices." *The Energy Journa*l 28.3 (2007): 145-64.

Wooldridge, Jeffrey M. "Cluster-Sample Methods in Applied Econometrics." *American Economic Review* 93.2 (2003): 133-8.

---. *Econometric Analysis of Cross Section and Panel Data*. Cambridge, MA: The MIT Press, 2001.

Yacobucci, B. D. *"Boutique Fuels" and Reformulated Gasoline: Harmonization of Fuel Standard*s. Order Code RL31361. Congressional Research Service, 2006.