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Excise Taxation and Product Quality: The Gasoline Market

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ABSTRACT

Following Barzel (1976), product quality increases in response to unit taxation but remains unchanged by ad valorem taxation. While many tax theorists agree this argument is theoretically sound, empirical support of Barzel's theory is limited to the cigarette market. This paper tests and confirms his theory in the gasoline market, a market in which Barzel failed to find supporting evidence in his original article. Using a direct test and improved data, the estimates suggest that the market share of premium-grade gasoline increases in response to both unit taxation and ad valorem taxation.

1. INTRODUCTION

Standard tax theory shows that as the tax rate rises, individuals will purchase less of the taxed good or resource. This quantity substitution, however, is not the only margin on which individuals can act to maximize their utility given the change in the tax treatment of the good. Barzel (1976) explains that individuals may also alter their purchases of quality in response to changes in the tax rate. He theorized that for unit taxation individuals will substitute away from the taxed attribute of the good (which is quantity) and toward its untaxed attribute (which is quality). Barzel's theory suggests that while both per-unit and ad valorem taxes lead to a decline in product sales, per-unit taxes will also lead to an increase in average product quality. An alternative explanation of this quality substitution can be drawn from the Alchian and Allen (1967) theorem because the imposition of a per-unit tax (a fixed fee) causes the price of the higher-quality version of a good to fall relative to a lower-quality substitute. Both theories suggest that ad valorem taxation does not alter the relative prices of the different quality levels of the product and, thus, do not impact the purchase of quality.[2]

While Barzel's idea is both novel and widely cited, it has received limited support empirically. Indeed, until recent years, only Barzel's original article attempted to test his theory in a market other than cigarettes.[3] One pos-

sible explanation of the lack of empirical support for Barzel's theorem and the Alchian and Allen Theorem is that both assume perfectly competitive, constant-cost industries. Razzolini *et al.* (2003) show that if this assumption is relaxed to allow for monopoly power, the exact opposite conclusion can be reached; namely, that the imposition of a per unit tax (a fixed charge) can cause the lower-quality good to become relatively less expensive. It can be shown that under constant elasticity demand schedules the price of the less elastic good (the higher quality good) will increase relatively more than that of the more elastic (lower quality) good when a fixed charge is introduced.

In light of the Razzolini *et al* (2003) results, the goal of this paper is to reexamine Barzel's theory in the gasoline market. While the gasoline market is not generally characterized as having a large degree of monopoly power, neither is it perfectly competitive. The fact that the gasoline market is not perfectly competitive may explain why empirical confirmations of Barzel's theory have been sparse to this point. However, it is not clear whether this lack of support can be attributed to the market structure or to a specification bias apparent in Barzel's original model. The empirical specification used in this paper corrects for this bias and can thus be viewed as superior that used by Barzel (as will be explained below).

2. Review of the empirical literature

Barzel originally tested his hypothesis in the cigarette, gasoline, and alcohol markets, where only the cigarette market study generated statistically significant results. While his hypothesis was that state-level per unit cigarette taxes should increase the average quality of cigarettes consumed, this was impossible to test directly without objective data on the quality of cigarettes. Instead, Barzel relied on an indirect test using the price of cigarettes. His model assumed that the full burden of the tax would fall upon consumers, causing the retail price of cigarettes to increase by the full amount of the tax. Thus, if the imposition of a unit tax also causes an increase in product quality, the price change resulting from the unit tax should be greater than the amount of the unit tax itself (reflecting also the value of the quality improvement). This can be illustrated by the following equation:

$$\Delta P = T + \Delta V$$

where ΔP is the observed after-tax price change, T is the unit tax, and ΔV is the change in the valuation of the product due to a change in product quality.

Two further studies of the impact of unit taxation on product quality in the cigarette market were published shortly after and in response to Barzel's (1976) original article. Johnson (1978) and Sumner and Ward (1981) base their empirical models on Barzel's (biased) model. Johnson (1978) restructured the test on the *ad valorem* tax and added state fixed effects, find-

ing results in favor of Barzel's original hypothesis. Sumner and Ward (1981), on the other hand, find no evidence of quality substitution in cigarette consumption after adjusting the empirical model for backlogged inflation.

Each of the three studies mentioned above are subject to some extreme data limitations. First, Barzel's theory was originally formulated in terms of the quality of the product, not its price. However, price is used as the basis for testing his hypothesis in each of the models discussed above. In such a model, it is difficult to distinguish whether price increased as the result of increased quality or as the result of increased margins.[4] If the full burden of the tax is not passed on to the consumer, then the coefficient on the tax variable could be less than one but still consistent with Barzel's hypothesis. For example, if only half the tax is passed on to the consumer, then any coefficient greater than 0.5 would suggest a quality improvement consistent with Barzel's model. As a result, Sumner and Ward's finding that the tax coefficient was significantly less than one could be a rejection of the assumption that the full amount of the tax is passed on to consumers, and not a rejection of Barzel's theory. Sumner and Ward even point to some reasons why the price should not rise by the full amount of the tax, such as the ability of consumers to do cross-border shopping.

The second limitation of these earlier models is that they all estimate the quality improvement from a specific state's tax rate change in terms of a change in the price of cigarettes *in that state*. Because the empirical model is cross sectional, empirical confirmation of Barzel's theory requires that the quality of cigarettes in a specific state can vary with the unit taxes imposed in that state *independent of the quality of cigarettes in all other states*. Sumner and Ward cite this as a major limitation to Barzel's and Johnson's empirical studies. Even Barzel points to the limited ability of cigarette quality to differ across states in response to differing unit taxes.[5] If there are conditions in the cigarette market that constrain quality from differing across states, then one might expect a coefficient near one because a change in a single state's unit tax on cigarettes should result in only a small impact on the overall quality level of cigarettes in the U.S. as a whole.

Improving upon the indirect method used in the three studies discussed above, Sobel and Garrett (1997) conduct the first direct test of Barzel's theory using data that directly measures product quality. Lower quality, generic-brand cigarettes began acquiring a sizable share of the cigarette market in 1982. Generic-brand cigarettes are of a lower quality level relative to premium-brands on many margins, including taste, quality of tobacco, and freshness. The arrival of generic-brand cigarettes permitted the development of a better empirical model than had been previously estimated. In their model, Sobel and Garrett look at the market share of the higher-quality, premium-brand cigarettes relative to the market share of lower-quality, generic-brand cigarettes to directly measure the impact of state taxes on the average quality of cigarettes consumed in a state.

Sobel and Garrett interpret their results as supportive of Barzel's theory. The authors find that the market share of premium-brand cigarettes is significantly larger in states with larger unit taxes on cigarettes than it is in low-tax states. Their estimates suggest that for every three cents of a state unit tax, the market share of premium-brand cigarettes increases by about one percentage point. Furthermore, New Hampshire's cigarette specific ad valorem tax, which was the only *ad valorem* excise tax on cigarettes at the time of their study, is found to be an insignificant determinant of product quality.

Even with Sobel and Garrett's (1997) empirical confirmation of Barzel's theory in the cigarette market, it remains unclear whether Barzel's theory can be applied generally to all cases of unit and *ad valorem* taxation or whether the theory describes behavior unique to the cigarette market. This question is of concern, particularly given that Barzel, himself, was unable to find supporting evidence of his theory in any market other than cigarettes. This paper now turns to a reevaluation of the market for gasoline, one of the markets in which Barzel could not find empirical support of his theory.

3. Empirical test of the market for gasoline

Much of the existing literature studying gasoline markets focuses on estimating the demand and price elasticity of demand for gasoline, where quantity serves as the dependent variable.[6] This paper alternatively estimates the market shares of regular- and premium-grade gasoline. Because only the relative quantities of these quality grades are of importance, many of the complications associated with estimating demand directly are avoided.[7] In addition, the use of market share data allows for the average quality of gasoline to vary independently across states, addressing the second major limitation of the indirect approach to testing Barzel's theory described above.

The effects of gasoline excise taxation on the quality of gasoline consumed, as measured by changes in the market shares of each grade of gasoline (regular and premium), is estimated following the method introduced by Sobel and Garrett (1997).[8] Annually averaged state-level daily volume sales (retail plus wholesale) by grade of gasoline for 1991-2001 are obtained from the Energy Information Administration. Data on gasoline taxes and driver characteristics were collected from *Highway Statistics* while per capita income was obtained from the Census Bureau. Descriptive statistics of the data used in this study can be found in Table 1. The year 1991 is chosen as the first observation year to avoid any interactions between leaded and unleaded gasoline.[9] All states levy a per-gallon tax on gasoline and seven states apply their *ad valorem* sales tax to gasoline sales during the sample period.[10]

A state-fixed effects model is estimated for each grade of gasoline.[11] The market share for each grade of gasoline is estimated as a function of the unit tax amount, the *ad valorem* (sales) tax rate, and a set of control variables (Γ) . The empirical model can be written:

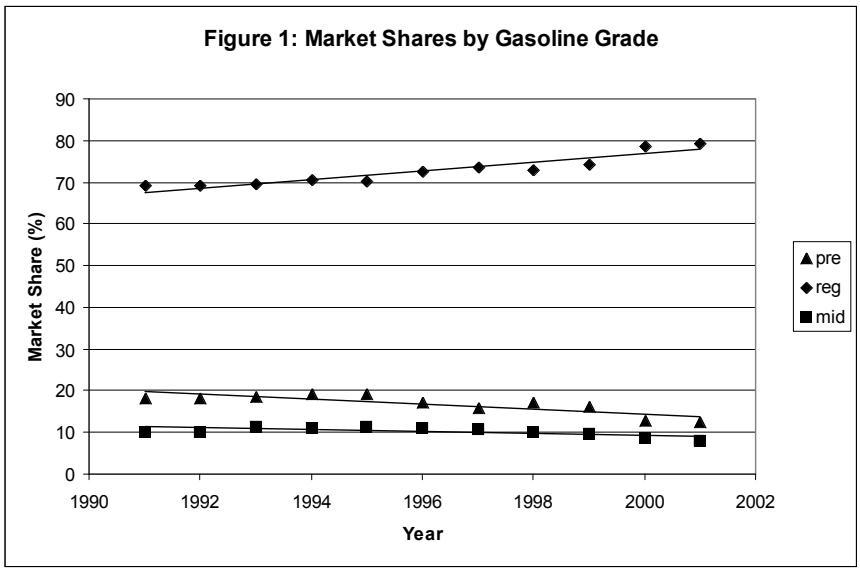
$$\%MARKET_{it} = \beta_0 + \beta_1 * UNIT\ TAX_{it} + \beta_2 * SALES\ TAX_{it} + \beta * \Gamma_{it} + \varepsilon_{it}$$

where $\%\,MARKET_{it}$ is the market share of the specified grade of gasoline (regular, mid-grade, or premium), $UNIT\ TAX_{it}$ is the sum of the federal and state tax on gasoline in cents per gallon, $SALES\ TAX_{it}$ is the sales tax rate applied to gasoline, and Γ is a matrix of other control variables, where i and t represent state and time, respectively. Γ includes per capita income, per capita income-squared (to allow for non-linearity), percent male licensed drivers, percent licensed drivers in various age groups, a consumer sentiment index, a time trend, and a FTC dummy variable.

Table 1: Descriptive Statistics, 1991-2001

	Full sample		*Within state variation*	*Between state variation*
Variable	*Mean*	*Std. dev.*		
Market Share--Regular	72.177	10.284	9342.607	39833.162
Market Share--Premium	17.025	6.878	3446.627	18551.010
Average Octane Rating	87.774	1.791	1145.968	344.828
Unit Tax (cents)	44.579	7.009	10219.983	12621.751
Sales Tax (%)	0.739	1.815	0.889	1530.364
Per Capita Income ($1,000)	27.379	4.527	1390.040	8137.805
Consumer Sentiment	95.123	9.798	43057.894	1586.078
Percent Male Drivers	50.304	1.341	0.025	0.059
Percent Drivers under Age 35	34.916	3.137	0.233	0.225
Percent Drivers over Age 54	25.539	2.753	0.044	0.309

Two-way fixed effects models are generally preferable to the use of a time trend in a one-way fixed effects model. However, the latter specification is used in this paper for two primary reasons. First, as is depicted in Figure 1 for the market share of each grade of gasoline appears to closely follow a trend line, suggesting that a trend variable may capture this variation in the dependent variable. Second, the reliability of the estimates in the model including the trend is greater due to the small degree of within state variability of the variables of interest (unit tax and sales tax). For instance, fourteen of the 48 states in the sample do not change their unit tax rate and an additional 8 states have at least 9 consecutive years without changing the tax rate. Thus, the inclusion of period dummy variables would capture much of the explanatory power of the variables of interest.[12] The consumer sentiment variable, obtained from the Michigan Consumer Sentiment Index (MCSI), has been included in the model to control for the variation in the dependent variable that can be explained by movements in the national business cycle — these influences should be fairly constant across states.



The FTC dummy variable is included in all specifications of the model to estimate the impact of education campaigns resulting from the 1997 settlement between the Federal Trade Commission (FTC) and Exxon. In 1996 the FTC charged Exxon with making exorbitant advertising claims concerning the ability of Exxon 93 Supreme to clean engines and reduce automobile maintenance costs. Exxon agreed to replace their previous advertisements with educational advertising concerning the choice of gasoline grades. The primary message of the new advertising was that premium-grade gasoline does not significantly improve engine performance. If the FTC's efforts were effective, there should be a significant decline in the market share of premium gasoline starting in 1997, which needs to be controlled for in the analysis.

According to Barzel, the coefficient on $UNIT\ TAX_{it}$ should be positive and significant in the $\%PREMIUM$ model and negative and significant in the $\%REGULAR$ model. The coefficient on $SALES\ TAX_{it}$ should be insignificant from zero for all three grades because the tax induces no change in relative prices. The results of this baseline specification for both regular- and premium-grade gasoline are provided in columns [1] and [3] of Table 2. I have omitted regression results for mid-grade gasoline, as these results can be inferred from those of the regular- and premium-grade models (market shares add to one and the change in market shares add to zero).

The coefficient on $UNIT\ TAX_{it}$ is significant at the one percent level and is of the predicted sign for both regular- and premium-grade gasoline models. For the sake of brevity, I will discuss only the results for the model for premium-grade gasoline, for the estimates in the model of regular-grade gasoline are generally of the same significance level but of the opposite sign, as expected.

The estimates imply that a one cent increase in the unit tax, either at the state or federal level, causes a 0.18 percentage point increase in the market share of premium gasoline while causing the market share of regular gasoline to fall by nearly an equal amount. The coefficient of $SALES\ TAX_{it}$ is statistically insignificant for both grades. While statistically insignificant, we cannot claim with certainty that changes in the sales tax rate exert no influence on product quality. The large magnitude of the estimated coefficients on the sales tax rate, the fact that there is very little within-state variation of the sales tax rate, and the fact that only seven of forty-eight states impose the sales tax on gasoline suggests that this coefficient may be economically important.

Table 2: State fixed-effects models† 1991-2001

	Market share for regular gasoline		*Market share for premium gasoline*	
	(1)	*(2)*	*(3)*	*(4)*
Unit Tax (cents)	-0179***	-0.161***	0.180***	0.159***
	(4.90)	(3.90)	(9.95)	(9.00)
Average of Past 3 Years Unit Tax (cents)		0.281**		-0.103**
		(2.41)		(2.06)
Sales Tax Rate (%)	-2.378		1.45	
	(0.75)		(0.93)	
Per capita income ($1,000)	-2.575***	-2.306**	2.722***	1.898***
	(3.72)	(2.41)	(7.92)	(4.62)
Per capita income Squared ($1,0002)	0.041***	0.035***	-0.042***	-0.028***
	(4.32)	(2.85)	(8.87)	(5.24)
Consumer Sentiment Index	-0.052**	-0.062**	0.030**	0.018
	(2.01)	(2.05)	(2.34)	(1.40)
Percent Male Licenced Drivers	-0.146	-0.427*	0.151	0.262**
	(0.70)	(1.76)	(1.46)	(2.51)
Percent licenced drivers under the age of 35	-0.218*	-0.241*	0.049	0.055
	(1.73)	(1.74)	(0.78)	(0.93)
Percent licenced drivers over the age of 54	0.665***	0.350	-0.191*	0.096
	(2.91)	(1.32)	(1.68)	(0.85)
FTC Dummy	0.443	-0.702)	-1.700***	-0.884***
	(0.79)	(1.11)	(6.15)	(3.27)
Trend	0.918***	1.096***	-0.557***	-0.769***
	(5.55)	(4.32)	(6.79)	(7.07)
R-squared	0.928	0.931	0.961	0.971
Observations	466	382	466	382

†The impact on the market share of mid-grade gas can be inferred from this table, as the sum of the market shares add to 100. Significance levels of 1, 5, and 10% are denoted by ***, **, and *, respectively. *t*-ratios appear in parenthesis. Regressions also include state dummy variables, which are not reported.

In an attempt to explore the economic importance of the estimated coefficients on the unit tax and sales tax, consider the impact of a ten-percent (10%) change in each tax rate from their respective means. The average unit tax rate in the sample is 44.608 cents; based on the estimate from column 3 of Table 2, a ten percent increase in the unit tax will cause the market share of premium-grade gasoline to rise by 0.803 percentage points, or 4.72 percent. Likewise, the mean sales tax rate (of those states who apply the sales tax to gasoline purchases) is 5.042 percent. A ten percent increase in this tax rate

Table 3: State specific time-trend models† 1991-2001

	Market share for regular gasoline		*Market share for premium gasoline*	
	(1)	*(2)*	*(3)*	*(4)*
Unit Tax (cents)	-0.137**	-0.161***	0.139***	0.130***
	(2.33)	(2.08)	(3.95)	(4.17)
Average of Past 3 Years Unit Tax (cents)		0.571***		-0.391***
		(4.51)		(5.69)
Sales Tax Rate (%)	0.963***		-0.387**	
	(2.95)		(1.97)	
Per capita income ($1,000)	-1.747*	-3.991***	0.584	2.003***
	(1.78)	(3.84)	(0.99)	(3.55)
Per capita income Squared ($1,000^2)	0.009	0.059***	0.009	-0.023**
	(0.47)	(3.07)	(0.83)	(2.20)
Consumer Sentiment Index	-0.075*	-0.082*	0.062**	0.047**
	(1.67)	(1.92)	(2.31)	(2.03)
Percent Male Licenced Drivers	0.102	-0.013	0.283	0.195
	(0.32)	(0.04)	(1.47)	(1.04)
Percent licenced drivers under the age of 35	-0.578***	-0.360*	0.337***	0.228**
	(2.79)	(1.71)	(2.70)	(1.99)
Percent licenced drivers over the age of 54	0.883***	0.510*	-0.364**	-0.096
	(3.50)	(1.76)	(2.40)	(0.61)
FTC Dummy	1.315	-0.928	-2.123***	-0.157
	(1.35)	(1.00)	(3.62)	(0.31)
R-squared	0.764	0.817	0.809	0.876
Observations	466	382	466	382

† The impact on the market share of mid-grade gas can be inferred from this table, as the sum of the market shares add to 100. Significance levels of 1, 5, and 10% are denoted by ***, **, and *, respectively. *t*-ratios appear in parenthesis. Regressions also include state dummy variables, which are not reported.

would be a little more than half a percentage point, leading to a 0.731 percentage point (or a 4.3 percent) increase in the market share of premium-grade gasoline. Thus, changes in both the unit tax and the sales tax appear to exert economically significant influences on product quality.

The results also suggest that the educational advertisements mandated by the FTC to educate consumers of the limited benefits of using high-octane fuel were effective. The market share of premium-grade gasoline fell by 1.70 percentage points (or roughly ten percent) in response to these campaigns. Increases in income are also shown to increase the market share of premium-grade gasoline, but at a decreasing rate. Only at incomes in excess of about $65,000 will an increase in income lead to reductions in the market share of premium-grade gasoline.[13]

To measure the more long-term adjustment of average product quality in response to increased unit taxation, an additional variable (the moving average of the past three years' unit tax rate) is added to the model. It is expected that this variable will capture the effect of substitution in the type of automobile driven. If the unit tax has been high over the past three years, some consumers may purchase another vehicle that requires lower-octane fuel and may achieve better gas mileage such that they purchase proportionately more regular-grade gasoline and less premium-grade gasoline. The first three years of the data set (1991-1993) were dropped as a result of the inclusion of these variables. Unfortunately, eliminating these three years also removes all of the within-state variation in the sales tax variable and caused multicolinearity issues between the sales tax rate and the fixed effects. Therefore, the sales tax rate was removed from the specification.

The results of the alternative specification are presented in columns [2] and [4] of Table 2. The inclusion of the 3-year moving average of the unit tax does not appear to impact the qualitative interpretation of the other variables, so I will concentrate my discussion on the interpretation of the unit tax variables. The results indicate that a ten percent increase in the unit tax increases the market share of premium-grade gasoline in the current year by approximately 4.2 percent. If that tax increase becomes permanent over the next three years, however, the market share of premium-grade gasoline falls by 2.7 percent three years from the initial change.

To test the robustness of the results estimated in the baseline model described above, two alternative models are estimated. First, the model is re-estimated using a state-specific time trend, rather than a universal time trend and state dummy variables. This model allows each state to follow a separate trend and is, therefore, a less restrictive model. The results of this model are presented in Table 3. In comparing the results of Table 3 to those of Table 2, three major differences are apparent. First, the sales tax variable switches sign and becomes statistically significant in the state-specific time trend model. Based on column [3] of Table 3, a ten percent increase in the sales tax (for those states in which the sales tax applies to gasoline purchases) is shown

to lead to a 1.1 percent reduction in the market share of premium-grade gasoline. Second, the magnitude of the coefficient on the moving average of the unit tax variable is substantially larger in the state-specific time trend model. Indeed, the coefficient increases almost four-fold in the case of premium-grade gasoline (it more than doubles in size for regular-grade gasoline). This indicates that the long-run response to unit taxation may be much larger than suggested in Table 2. And, finally, the coefficient of the FTC Dummy variable is much smaller in magnitude and becomes statistically insignificant when comparing column [4] of Tables 2 and 3. While it cannot be concluded that the mandated educational advertisements of the limited benefits of high-

Table 4: State fixed-effects models† 1991-2001

	Average octane rating (weighted by market shares)	
	(1)	*(2)*
Unit Tax (cents)	0.047**	0.008***
	(2.42)	(6.35)
Average of Past 3 Years Unit Tax (cents)		-0.009**
		(2.38)
Sales Tax Rate (%)	-1.206	
	(0.72)	
Per capita income ($1,000)	0.393	0.102***
	(1.07)	(3.44)
Per capita income Squared ($1,0002)	-0.008*	-0.002***
	(1.65)	(3.98)
Consumer Sentiment Index	0.021	0.002*
	(1.56)	(1.90)
Percent Male Licenced Drivers	0.156	1.641**
	(1.42)	(2.18)
Percent licenced drivers under the age of 35	0.012	0.006
	(0.18)	(1.52)
Percent licenced drivers over the age of 54	-0.206*	-0.004
	(1.70)	(0.47)
FTC Dummy	-0.582**	-0.014
	(1.97)	(0.71)
Trend	0.271***	-0.045***
	(3.09)	(5.69)
R-squared	0.336	0.957
Observations	466	382

† Regressions also include state dummy variables, which are not reported. Significance levels of 1, 5, and 10% are denoted by ***, **, and *, respectively. *t*-ratios appear in parenthesis.

octane fuels had no impact on consumption patterns, this result may suggest that the effect is small.

In the second robustness check, the model is re-estimated with a new dependant variable that measures the average octane rating weighted by market share.[14] Barzel's theory would suggest that the average octane rating should rise as the unit tax is increased. The results of this specification can be found in Table 4. Based on the estimate in column [1] of Table 4, a ten percent increase in the unit tax will lead to a 0.21 unit increase in the average octane rating. This 0.21 unit change in octane rating represents about 4.2 percent of the difference between regular- and premium-grade gasoline. Thus, this seemingly small change should not be considered economically insignificant. Furthermore, the estimates produced from this specification should be interpreted as supportive of the earlier findings in this paper.

4. Conclusion

Although Barzel's theory has become accepted as a standard idea in tax theory, supportive empirical evidence has been scarce outside the cigarette market. This paper provides some support for Barzel's theory as it relates to unit taxation in the gasoline market. The results presented here suggest that per-unit gasoline taxes lead to proportionately more consumption of higher-quality, premium-grade gasoline and proportionately less of lower-quality, regular-grade gasoline. A five cent increase in the combined state and federal unit tax on gasoline is shown increase the market share of premium gasoline by approximately 0.80 percentage points (4.7 percent) and reduce the market share of regular gasoline by an equal amount (1.1 percent). The results concerning the estimated impact of unit taxation on gasoline grade are also consistent with the claim that retail gasoline stations possess little monopoly power; if monopoly power was large we would expect a negative relationship between the unit tax and the market share of premium-grade gasoline. Ad valorem taxation, while not always statistically significant, may exert an economically significant influence on quality purchased. However, the direction of the impact of *ad valorem* taxation on product quality is sensitive to model specification, likely the result of the small degree of within-state variation of this variable.

Endnotes

1. The author would like to thank Russell Sobel, Yoram Barzel, George Hammond, participants at the 2003 Southern Economic Association meeting, and an anonymous referee for helpful comments. All remaining errors are the responsibility of the author.

2. See Borcherding and Silberberg (1978), Umbeck (1980), Leffler (1982), Bertonazzi *et al* (1993), Cowen and Tabarrok (1995), and Razzolini *et al* (2003) for more detailed discussions of Barzel's theorem and the Alchian and Allen theorem.

3. In a related analysis, Barzel and Hall (1977) find evidence of quality substitution in response to import quotas on crude oil.

4. This is a non-issue in perfectly competitive markets; however, as Paton et al (2002) show, the possibility of changing margins becomes problematic and can diminish the reliability of the estimates when monopoly power exists.

5. Barzel mentions that some within state changes in consumer choices of quality levels could be toward higher-priced 100mm cigarettes and those from vending machines.

6. Archibald and Gillingham (1980) and, Kayser (2000) estimate gasoline demand using household-level data with the latter finding a price elasticity of -0.23.

7. There is also a strand of literature examining the long-run adjustment, namely the choice of fuel type (gasoline, diesel, and LPG), in response to tax policy changes, such as Rouwendal and de Vries (1999). These studies are different from the current study in that they reflect long-run adjustments rather than short-run adjustments to a change in tax policy.

8. Barzel's theory also suggests that the octane rating for all grades of gasoline may rise in response to unit taxation. I am indebted to Yoram Barzel for this insight. Data limitations prevent the testing of this effect here.

9. Prior to 1991 both leaded gasoline and unleaded gasoline were sold at retail stations, whereas only unleaded gasoline has been sold at retail stations since 1991.

10. These seven states are CA, GA, HA, IN, IL, MI, and NY. All observations from North Dakota, South Dakota, and Wyoming were excluded from the sample due to data limitations.

11. The Hausman test was conducted, and the results indicate marginal support for the random-effects specification. The seemingly unrelated regression (SUR) model is generally more efficient that ordinary least squares (OLS) since my dependent variables (market shares) are correlated. However, since all right-hand-side variables are identical, there are no efficiency gains to using SUR. Thus, single-equation OLS is the efficient estimator.

12. The results of the two-way fixed effects model are available in an unpublished appendix and can be obtained from the author upon request.

13. Many normal goods can be classified as such only up to a given income threshold. At income levels above that threshold, the good becomes inferior as consumers substitute towards other high-quality goods. In the case of premium-grade gasoline, this might include substitution toward more airplane flights and the purchase of pricier alternative fuel vehicles.

14. While the octane ratings of regular-, mid-, and premium-grade gasoline varies by state largely depending on elevation, the Energy Information Administration reports that the typical octane rating for each grade are 87, 89, and 92, respectively.

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