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Abstract: *Alchian and Allen's "third law of demand" states that as a fixed cost increases by the same amount for high- and low-quality goods, the relative price of high-quality goods will fall and the relative quantity demanded of them will rise. We examine a more general hypothesis by relating the ratio of the quantities of sales of premium- to regular-grade gasoline to the ratio of their prices, controlling for other supply and demand factors. We find some preliminary evidence for this general hypothesis and discuss implications for Central Asia.*

Keywords: *Third Law of Demand, Price Ratios, Gasoline Grades, Substitution Effect, Income Effect*
JEL Codes: D120 - Consumer Economics: Empirical Analysis

1. Introduction

Alchian and Allen's (1967, pp. 62-64) "third law of demand" suggests that a given increase in the prices of high- and low-quality goods lowers the high-quality price relative to the low-quality one. The relative quantity demanded of the high-quality good will increase. The third law focuses on the substitution effect, but this can be swamped by the income effect of a price increase, which induces switches to the cheaper, lower-quality good if the good is normal.
We test the third law not by considering some common incremental change to prices (as in Nesbit 2005), but by looking at the more general case of a change in the price ratio of high- and low-quality goods. We find modest support for the proposition that in the market for gasoline, the relative demand for the higher-quality grade depends on its relative price. Support for this general hypothesis implies support for the special case known as the third law.

In the paper, Section 2 surveys the literature; Section 3 presents the basic theory; Section 4 discusses the empirical tests; and Section 5 concludes with implications for Central Asia.

2. Studies of the Third Law of Demand

Research first focused on the addition of some per-unit shipping cost to high- and low-quality substitutes. Under some assumptions, the third law holds only in a two-good world (Gould and Segall, 1969). When the two goods are close substitutes, the law extends to a third good, given compensated demand curves (Borcherding and Silberberg, 1978). The law also requires a fixed charge per unit (Cowen and Tabarrok, 1995). It matters whether the goods ship to the consumers or the consumers to the goods. We try to avoid the implied pitfalls of including transportation costs.

Other articles examined the effects of unit excise taxes upon the quality consumed (James and Alston, 2002). Barzel (1976) concluded that for cigarettes, such taxes can pass to consumers more than fully, because a tax increase lowers the ratio of high- to low-quality prices, inducing substitution of the expensive cigarette for the cheap one. As for gasoline and alcoholic beverages, Barzel found nothing significant.

Razzolini, Shughart and Tollison (2003) argued that a proper test of the third law must account for supply. The impact of adding a unit cost to high- and low-quality prices depends on whether a given quality was produced in a competitive or monopoly market; and on whether scale returns were increasing, decreasing or constant. While these supply considerations do affect the relative prices of the two qualities, the resulting interpretation of the third law recasts it from a demand theorem to a hypothesis about markets.

3. Theory

Gasoline demand depends on the distance traveled. In the short run, people are stuck living a certain distance from work, schools, shopping areas and friends. Similarly, they can do little to change their current means of transportation and have difficulty switching between alternative fuels. For gasoline, we observe long-run estimates of the price elasticity of demand around -0.86 and short-run estimates around -0.26 (Dahl and Sterner 1991, p. 210). While gasoline and a composite of all other goods are not close substitutes, one grade of gasoline may seem a close substitute for another, if people can substitute the grades across their vehicles.

Consider the relationship between relative purchases of premium and regular grades and the relative price of premium to regular grades, *ceteris paribus*:

$$\text{(1)} \qquad \frac{Q_p}{Q_r} = \alpha_0 + \alpha_1 \frac{P_p}{P_r}$$

where
$\boldsymbol{Q_p}$ is the quantity demanded of premium-grade gasoline,
$\boldsymbol{Q_r}$ is the quantity demanded of regular-grade gasoline,
$\boldsymbol{P_p}$ is the price of premium-grade gasoline, and
$\boldsymbol{P_r}$ is the price of regular-grade gasoline.

Under the third law, if $\Delta \boldsymbol{P_p} = \Delta \boldsymbol{P_r} > 0$ (starting with $\boldsymbol{P_p} > \boldsymbol{P_r}$), then the relative price must fall, so the ratio of purchases of premium gas to those of regular gas will increase. We expect $\boldsymbol{\alpha_1}$ to be negative.

Figure 1. Choice for Gasoline Grade when Relative Prices Change, Compensated for Income Effect

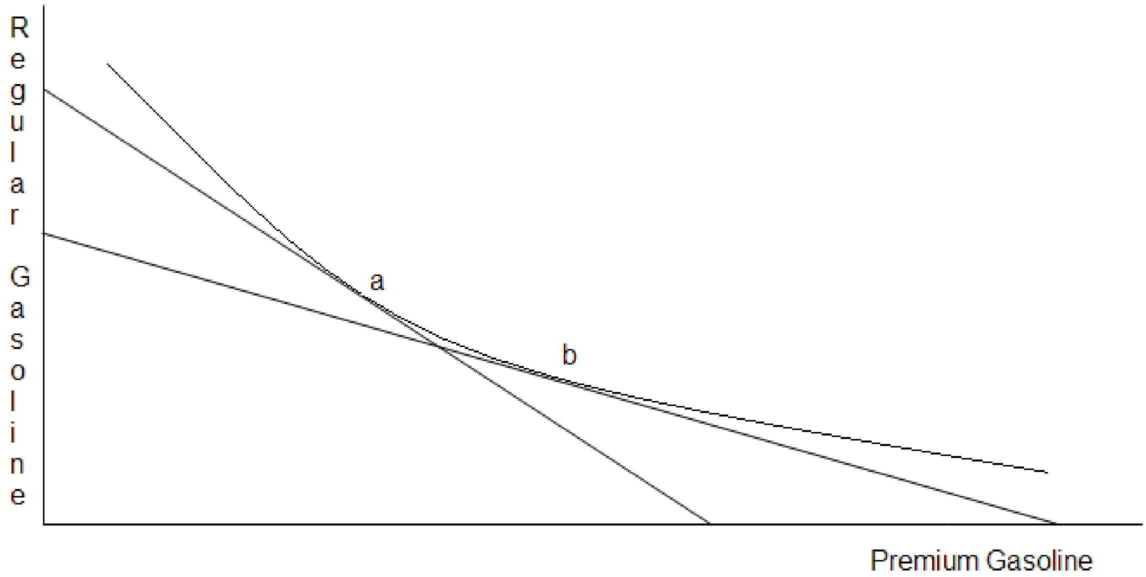
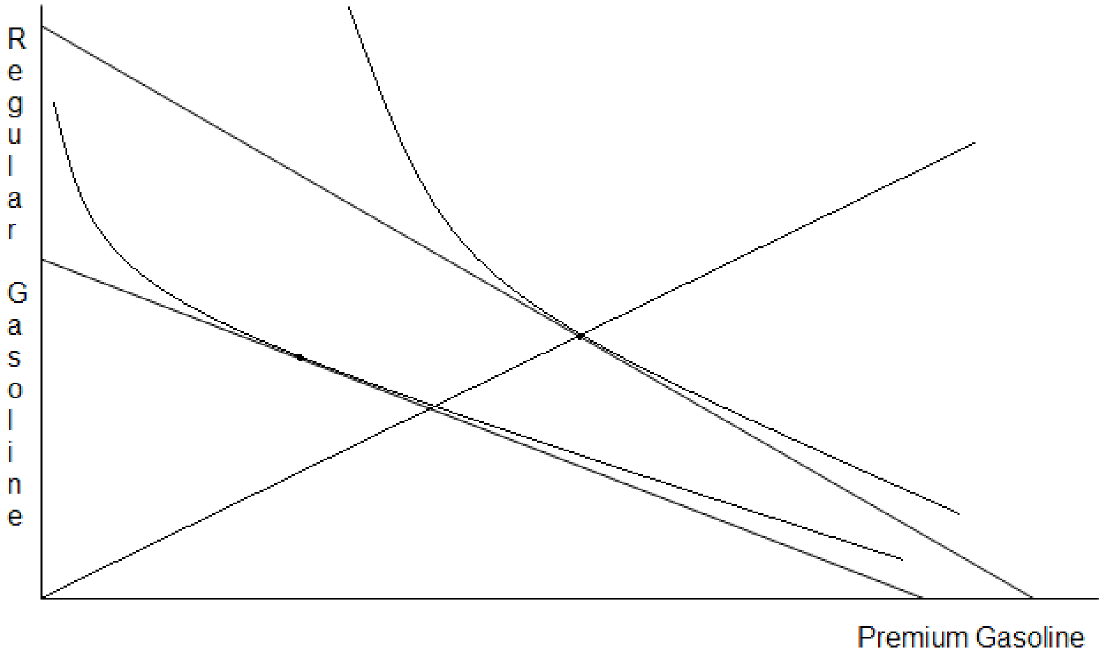


Figure 2. Consumer Choice for Gasoline Grades--
Uncompensated



With no income effects, as we see in Figure 1, decreases in the price ratio of premium to regular gasoline must increase the ratio of consumption of premium to regular gasoline, which is implied in the movement from point *a* to point *b*. Figure 2 allows income effects. Here, the price ratio of premium to regular gasoline again falls, as the prices of both increase by the same amount. The original bundle of premium and regular gasoline is where the equal-expenditure line is tangent to the higher indifference curve. At the point of optimal consumption, the ratio of regular to premium gasoline is the slope of a line out of the origin. This line divides those bundles with relatively less premium gasoline (up and to the left of the line from the origin) from those with relatively more premium gasoline (below and to the right of the line). For one to consume in a way counter to the third law would require him to have an indifference map similar to that in Figure 2. Here regular gasoline is an inferior good, such that as total expenditures on gasoline decreased, regular gas would be substituted for premium gas. This seems plausible, suggesting that the third law, as Borcherding and Silberberg note, applies to compensated demands and not necessarily to uncompensated demands. In the latter case, the third law must be addressed empirically.

4. Empirical Tests

4.1 Data

The dependent variable, *Prgas*, is the ratio of the number of gallons of premium gasoline sold to the number of gallons of regular gasoline sold in a given month and a given state in the United States, or $\frac{Q_p}{Q_r}$. The first difference of this variable is *Prgdiff*.

The concurrent price variable is *Prprice,* the ratio of the price of a gallon of premium gasoline to the price of a gallon of regular gasoline in a given month and state, or $\frac{P_p}{P_r}$. A distinctive feature of this paper is that the prices estimated include local, state and federal fuel taxes. The differenced price variable is *Prpdiff.*

An *n*-month lag of a variable is denoted with the prefix *Ln*. For example, the one-month lag of the dependent variable is *L1.prgas*.

Data on sales and prices excluding taxes come from the Web page of the U.S. Energy Information Administration. Data on state fuel taxes were collected from the *Highway Statistics* and *Monthly Motor Fuel Reported by States* series of the U.S. Highway Administration; corrections were provided, by e-mail or by phone, by the transportation or finance departments of the state governments. The states also provided data on local fuel taxes, which we weighted by population when adding them to fuel prices. The state taxes include sales taxes, environmental taxes (such as fees for a Leaking Underground Storage Tank fund), and inspection fees based on the number of gallons used. The local and federal taxes are excise taxes that are quantity-based or (for many local taxes) sales-based.

A control for cost factors is *Crude*, which measures the real acquisition cost of crude oil per barrel to the U.S. refineries each month, based on a composite of foreign and imported oil and deflated by the producer price index for oil refineries (in 1982 dollars). The cost data were collected from various issues of the *Monthly Energy Review* of the U.S. Energy Information
Administration. The deflator is from the U.S. Bureau of Labor Statistics. The differenced variable is *Crudediff.*

Income represents disposable personal income per capita in a given month and state, expressed by the number of gallons of regular gasoline that the income could purchase. We constructed it from quarterly income and tax data as well as from annual population data, and we deflated it by the monthly price of regular gasoline from the U.S. Energy Information Administration. Population data were from the U.S. Census Bureau's *Statistical Abstract of the United States.* Income data were from the *State Quarterly Personal Income* series of the U.S. Bureau of Economic Analysis. Tax data were from the Census Bureau's *Quarterly Summary of State and Local Tax Revenues* and from its *Federal Tax Collections by State,* based on the *Internal Revenue Service Data Book* for various years. Differenced income is *Incomediff.*

We collected time series of 75 months – from January 1998 through March 2004 – for each of the 50 states. Table 1 presents summary statistics. The price of premium gasoline exceeds the price of regular gasoline by only 13 percent, but Americans buy only a sixth
as much of premium as of regular. The relative price of premium varies from 1.3 (Georgia, February 1999) to 1 (North Dakota, October 2001). Relative purchases of premium vary from 0.51 (New Jersey, February 1999) to 0.04 (North Dakota, March 2000). Annual per-capita disposable income averages 16,283 gallons of regular gasoline, ranging from 9,298 gallons in Georgia (January 2001) to 29,600 gallons in Florida (February 1999).

Table 1. Summary statistics

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Prprice	3727	1.129	0.035	1.002	1.299
Prgas	3705	0.176	0.082	0.035	0.508
Crude	3750	23.307	2.235	18.627	27.767
Income	3750	16283.010	2896.010	9297.701	29600.210
Prgdiff	3644	-0.001	0.013	-0.097	0.294
Prpdiff	3655	-0.000	0.023	-0.067	1.135
Incomediff	3700	-34.796	972.842	-4065.449	4937.794
Crudediff	3700	0.044	1.260	-3.033	3.448

4.2 Empirical Results

We estimated the model by three-stage least squares in order to disentangle the effects of supply and demand. Otherwise, in a separate estimation of a demand equation, the price variable on the right-hand side (which is determined in the market simultaneously with quantity) may correlate with the error term, rendering coefficient estimators biased and inconsistent. The model is in first differences, rather than levels, in part because our variables for the relative consumption of premium gasoline and for its relative price, *Prgas* and *Prprice,* may follow random walks and thus induce a spurious correlation; and in part because we wished to remove the effects of unobservable variables that were fixed over time and that may correlate with explanatory variables, since this too could render the coefficient biased and inconsistent. We calculated robust standard errors (White, 1980; Wooldridge, 2003) because tests indicated heteroskedasticity in the 3SLS equations. Serial correlation is also present but insignificant in magnitude.

The model estimated was

$$\text{(2)}\quad \begin{aligned} Demand &= a_0 + \sum_{i=1}^{n} a_i Li.prpdiff + a_{n+1} Incomediff \\ Supply &= b_0 + \sum_{i=1}^{n} b_i Li.prpdiff + b_{n+1} Crudediff, \end{aligned}$$

where *Demand* and *Supply* refer to *Prgdiff.*

Table 2 gives the results. The intercepts indicate that the relative quantity of premium gasoline may have fallen over time, holding prices, income and crude costs constant, all expressed in first differences.

The inferred evidence for the third law of demand is moderate. In differences, the relative sales of premium gasoline respond negatively and highly significantly (in a statistical sense) to an increase in the relative price of premium gasoline with a two-month lag; the negative coefficient on the three-month lag is significant at the 10% level for a one-tailed test but not at the 5% level.[i] The price elasticity of demand for premium gasoline, relative to regular gasoline, is -0.83 with a two-month lag and -0.43 with a three-month lag (Appendix). These elasticities are rather small, suggesting little substitution across grades. They are a little larger than the short-run elasticity of -0.26 for gasoline, reported by Dahl and Sterner (1991, pp. 210).

Table 2. Estimates of the 3SLS model

Equation	Demand	Supply
N	3409	3409
Parameters	3	3
RMSE	0.0098	0.0117
Independent Variables	Coefficient {Robust Standard Error}	Coefficient {Robust Standard Error}
Constant[ii]	-0.0011	-0.0005
	(0.0002)	(0.0002)
L2.prpdiff	-0.1049	
	{0.0101}	
L3.prpdiff	-0.0151	
	{0.0107}	
Incomediff	5.99e-06	
	{0.0114}	
Prpdiff		0.9641
		{0.0250}
L1.prpdiff		0.0845
		{0.0141}
Crudediff		-0.0003
		{0.0109}

The coefficient on per-capita personal disposable income, *Incomediff,* expressed in gallons of regular gasoline, is positive but not significant. The income elasticity of relative demand for premium gasoline is 0.66. The income effect may thus be weak.

In the supply model, the coefficients on price and its one-month lag are positive and highly significant: Measured in differences, the relative supply of premium gasoline rises with the relative price. Sellers seem quite sensitive to price: The price elasticity of relative supply for premium gasoline is 7.65 in the current month and 0.63 with a one-month lag. This sensitivity may be consistent with profit-maximizing behavior when sellers can quickly substitute one grade of gasoline for another; or it may reflect the imprecision of estimates in the supply function. The coefficient on *Crude* is negative but statistically insignificant. The elasticity of the relative supply of premium gasoline with respect to crude costs is small, as expected: -0.03. The lack of explanatory power of the supply equation is disappointing, but we are primarily interested in the substitution effect in the demand equation, controlling for supply.

Some doubts about the third law's application to the gasoline market may remain. Borcherding and Silberberg suggest two problems for the third law. In a world of more than two goods, the two goods must be close substitutes. Our evidence seems to suggest that the cross elasticities of premium and regular gasoline are small, although they are large enough to produce a relative-price effect that is statistically significant. Second, the income effects can be large relative to the substitution effects. However, controlling for real income, the substitution effect in the demand equation of the 3SLS model is negative as expected.

5. Conclusions and Discussion

We find modest support for the third law of demand in the market for premium gasoline, in a simultaneous-equations model that avoids conflating demand and supply factors. For an oil exporter, like Kazakhstan, that mulls whether to branch out into refined products, the results suggest caution. The short-run elasticity of relative demand for premium gasoline, with respect to the relative price, is small. If the relative price in major importers is falling over time, as was the case for the time period studied in the United States, then import sales revenues due to switching from regular to premium production may also fall.

6. Appendix

Elasticities were estimated from a 3SLS model of the first differences of natural logs. Since values determined at time *t-1* should be treated as constants at time *t*, the coefficient in the regression model is

$$\frac{\partial[\ln Y(t) - \ln Y(t-1)]}{\partial[\ln X(t) - \ln X(t-1)]} = \frac{\partial[\ln(Y(t)]}{\partial[\ln(X(t)]}$$

from which the ordinary elasticity (*dY/dX*)(*X/Y*) immediately follows. These are not the conventional price elasticities, $e_{ordinary} = \frac{dQ}{dP} x \frac{P}{Q}$; they are elasticities of relative demand,

$e_{relative} = \frac{d\left[\frac{Q_P}{Q_R}\right]}{d\left[\frac{P_P}{P_R}\right]} x \frac{\frac{P_P}{P_R}}{\frac{Q_P}{Q_R}}$. Similarly, the income elasticity is $e_{income} = \frac{d\left(\frac{Q_P}{Q_R}\right)}{d(Income)} x \frac{Income}{\left(\frac{Q_P}{Q_R}\right)}$.

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[i] The current relative price and its one-month lag were dropped from the model for statistical insignificance. Price coefficient signs are sensitive to the lag structure. We prefer inclusion of the longer lags, since people may not have time within only a month to adjust measurably to price changes.

[ii] Robust standard errors were not calculated for the intercepts.