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Air Pumps at U.S. Gas Stations: An Investigation into Factors Associated with Gauge Accuracy

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16. Abstract

This technical report examines the accuracy of gas station air pump gauges from two angles:

- variables which have an explanatory relationship with gauge accuracy are identified and both the direction and magnitude of this relationship is quantified.
- the question of whether there is any relationship between the accuracy of gas station air pump gauges and the prevalence of tire under-inflation in the vehicle population is investigated.

Consistent with the TREAD Act's specification of tire under-inflation as being the most serious problem, the aspect of gauge accuracy that is examined is whether or not gauges over-report the true pressure by 4 psi or more. Gauge accuracy was found to be explained to a statistically significant degree by region, volume of traffic and pump fees. In addition, statistically significant interaction effects were identified between region and traffic, between pump fees and traffic, and between traffic and station gauges in the West.

The relationship between tire pressure over-reporting by station gauges and tire under-inflation among vehicles was evaluated by comparing motorists who normally check their tires using a gauge vs. motorists who do not. The South is the only region of the country where the former group showed (as one would expect) a statistically significant advantage with respect to the fraction of vehicles having all 4 tires under-inflated by 4 psi or more. Since the South has by far the smallest percentage of stations having gauges which over-report by 4 psi or more, therefore, over-reporting among station gauges appears to be related to tire under-inflation.

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EXECUTIVE SUMMARY

This technical report examines the accuracy of gas station air pump gauges from two angles:

- variables which have an explanatory relationship with gauge accuracy are identified and both the direction and magnitude of this relationship is quantified.

- the question of whether there is a relationship between the accuracy of gas station air pump gauges and the prevalence of tire under-inflation in the vehicle population is investigated.

Methodology: variables explaining gauge accuracy

The first step is to define what is meant by "gauge accuracy". Consistent with the TREAD Act's specification of tire under-inflation as being the most serious problem, the aspect of gauge accuracy that is examined is whether or not gauges over-report the true pressure by 4 psi or more. Logistic regression is then used to examine the role 3 variables (the region in which the station is located, the volume of traffic passing through the station and whether a pump fee is charged) play in explaining station gauge over-reporting.

Methodology: station gauge accuracy and tire inflation in the vehicle population

The question of determining whether the state of accuracy among station gauges has an impact on the vehicle population was analyzed in the following way. Within each region, a test was conducted to determine if there is a statistically significant difference in tire under-inflation between those motorists who check their vehicle's tire pressure using a gauge and those who do not. The results of this test were then compared to the state of gauge accuracy in the corresponding region to determine whether the effectiveness of using a gauge on reducing under-inflation is related to the degree of station gauge accuracy in the region in question.

Results: the variables explaining gauge accuracy

Gauge accuracy was found to be explained to a statistically significant degree by region, volume of traffic and pump fees. The exact nature of the relationship is complicated by the fact that not only do these variables jointly explain gauge accuracy, but statistically significant interaction effects between region and traffic and between pump fees and traffic were identified. Thus, the effect that region has on gauge over-reporting depends on the level of traffic (and vice versa) and the effect of pump fees on gauge accuracy also depends on the level of traffic (and vice versa).

It was possible to identify a sizeable interaction effect between traffic and station gauges in the West. For low traffic stations, the odds of Western station gauges over-reporting by 4 psi or more is more than 10 times **higher** than for low traffic non-Western stations. However, this situation is completely reversed in the case of high traffic stations: the odds of a Western station gauge over-reporting by 4 psi or more is 35% **lower** than the odds of a non-Western station over-reporting by this amount.

Regarding pump fees, there is an interaction effect between pump fees and station-gauge over-reporting. For low traffic gas stations, the odds of over-reporting by 4 psi or more are 76% **lower** for pumps which charge fees relative to those which do not. However, in the case of moderate-high traffic stations this situation is completely reversed. For these stations, the odds of a station gauge over-reporting by 4 psi or more is 4.4 times **higher** for fee relative to free pumps. Thus, the impact of pump fees on over-reporting depends on the volume of traffic passing through the station.

Whether or not a fee is charged for pump use has a major impact on the probability of encountering a pump which over-reports by 4 psi or more. In the case of moderate-high traffic gas stations, the probability of encountering a station gauge with this degree of inaccuracy in the Midwest is 68% for fee pumps vs 32% for free pumps; in the Northeast it is 40% for fee vs 13% for free pumps; in the West 64% for fee pumps vs just 29% for free; and, in the South, it is 4% for fee vs just 1% for free pumps.

Thus, for the vast majority of stations (86% of U.S. gas stations fall into the moderate-high traffic category) paying a fee for pump use actually increases the likelihood that the gauge will report a pressure level 4 psi or more higher than the actual pressure. As a result, for pumps located at the vast majority of gas stations, motorists should not believe that the fact that a fee is being charged for pump use implies better quality, at least in terms of gauge accuracy

Results: station gauge accuracy and tire inflation in the vehicle population

There is evidence for the existence of a relationship between the prevalence of over-reporting among station gauges and the prevalence of under-inflation in the vehicle population. This is demonstrated by the fact that in only one region of the country is there a statistically significant difference in tire under-inflation (of all four tires) between those motorists who check their vehicle’s tire pressure using a gauge and those who do not. That region is the South. This is significant because the South is also the region that has by far the lowest percentage of gauges (1% vs 11% in the next best region) which over-report tire pressure by 4 psi or more.

Thus, the only region in which motorists who regularly check their tire pressure using a gauge show a statistically significant advantage over motorists who do not is precisely the region of the country which has by far the lowest incidence of station gauge over-reporting.

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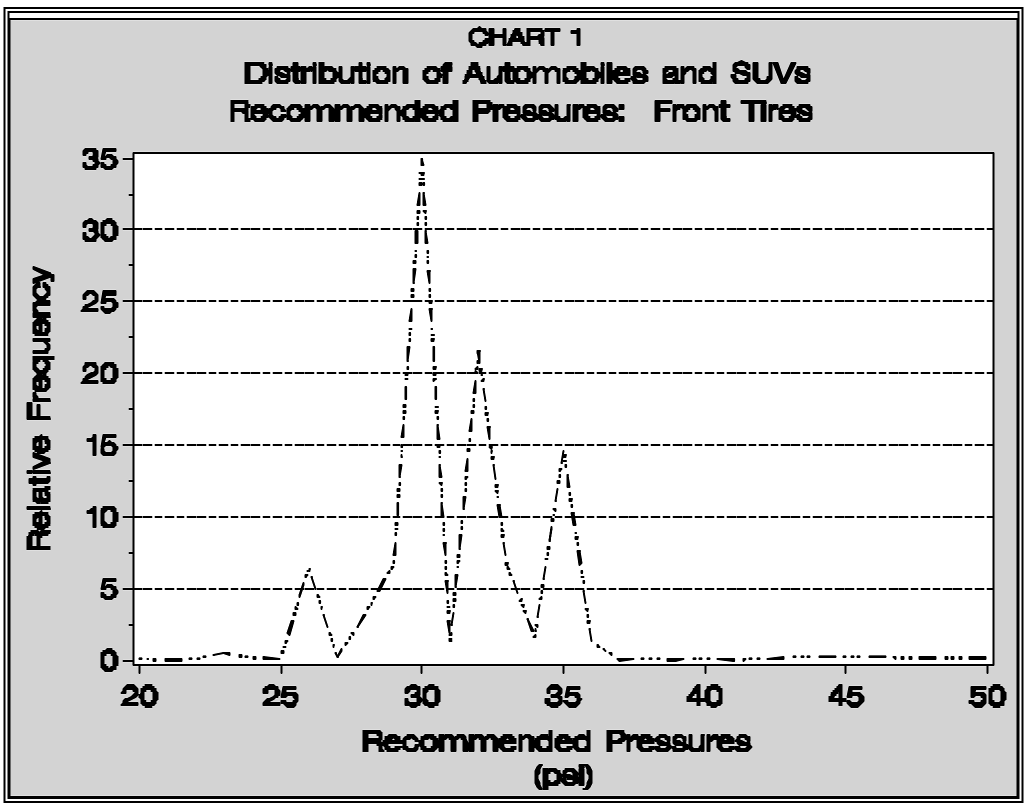
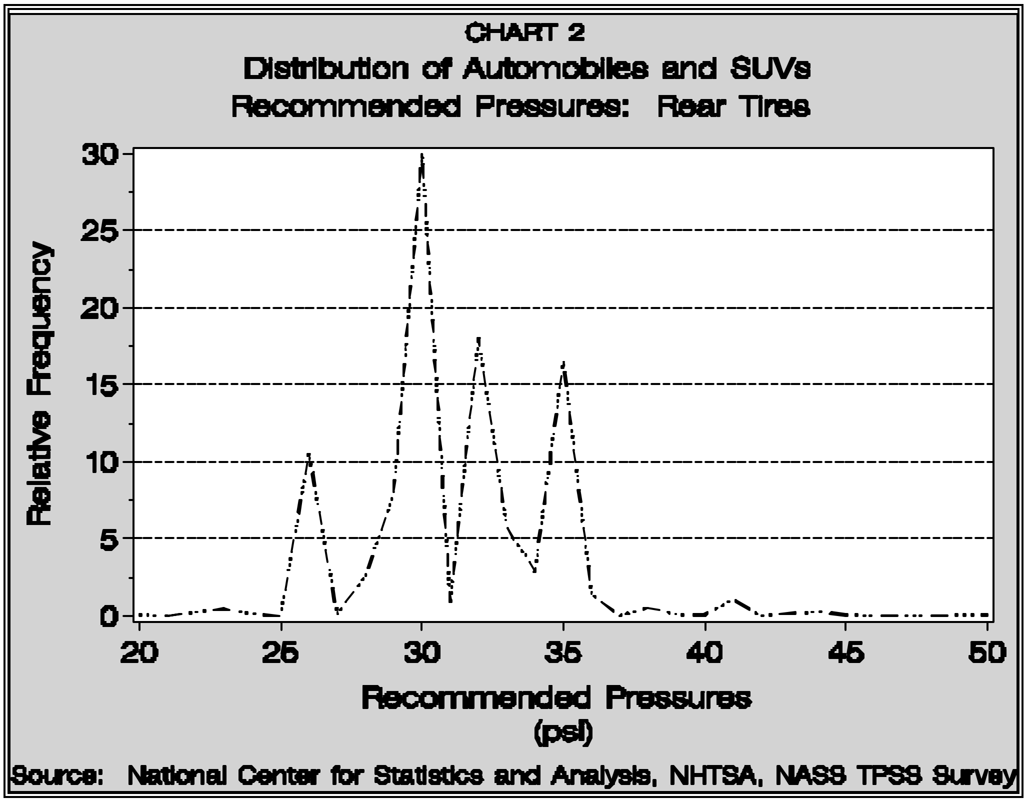
1. Introduction

Gauge accuracy was one of the topics on which the research note, *Air Pumps at U.S. Gas Stations: Major Findings Regarding Availability, Reliability and Fees*, NHTSA, November 2001, DOT HS 809 366, reported. The purpose of this technical report is to try and identify variables which appear to have an impact on gauge accuracy and, once identified, to try and quantify their effect.

In *Air Pumps* (2001), the distribution of the deviation of gas station gauge measurements from measurements made by the reference gauge was estimated, plotted and studied at pressures of 25, 35, 45 and 55 psi. But which variables explain gauge accuracy? To determine this, the analysis is restricted to looking at a target pressure of **35 psi** since, of the four pressure levels at which the Air Pump Gauge Accuracy Special Study (APGAS) evaluated station gauges, 35 psi is closest to the recommended pressure level for most passenger cars and SUVs.



Charts 1 and 2 show the distribution of recommended pressures for front and rear tires for passenger cars and SUVs. Although 30 psi would be the most optimal single pressure approximating the distribution of recommended pressures, the APGAS evaluated gauges at 25, 35, 45 and 55 psi. Of these, 35 psi most closely approximates the recommended pressures.



2. Background

This technical report employs the same two data sets as did *Air Pumps* (2001): the National Highway Traffic Safety Administration (NHTSA)'s National Center for Statistics and Analysis (NCSA) National Automotive Sampling System (NASS) Tire Pressure Special Study (TPSS), conducted in February 2001, and the NASS Air Pump Gauge Accuracy Special Study (APGAS), conducted in August 2001. The TPSS gathered information regarding the prevalence and magnitude of tire under-inflation, driver attitudes and practices with respect to tire maintenance, as well as information regarding gas station air pumps and pressure gauges. The APGAS went back to those gas stations identified in the TPSS as having working air pumps equipped with pressure gauges in order to evaluate their accuracy.

Air Pumps (2001) relates in great detail the actual procedure used to evaluate gauge accuracy, however, for the purposes of this report, the essential element is the following. An air tank was pressurized and had its pressure adjusted until the station's gauge reported a measurement of 25 psi. The researcher's gauge was then used to record the actual pressure[1]. This procedure was then repeated for pressure levels of 35, 45 and 55 psi.

[1] The type of gauge (Longacre Model 50402 0-60 psi Tire Pressure Gauge) used by all the researchers was selected in large part because tests undertaken by NHTSA's Vehicle Research and Test Center (VRTC) showed that it could be relied on to report pressures with a high degree of accuracy.

3. The Aspect of Gauge Accuracy Analyzed in this Report

Gauge accuracy, which refers to the magnitude and direction of the deviation between the tire pressure reported by the station gauge and the actual tire pressure, can be quantified in various ways: the mean deviation, the variance of these deviations, etc. Does the direction of deviation matter, or should only the magnitude be taken into consideration? For example, is a gas station gauge which over-reports tire pressure by 5 psi of equal concern as one which under-reports tire pressure by this amount?

The answer to this question is that the direction of deviation turns out to be critically important:

- pressure gauges which under-report (i.e., produce pressure readings which are **less** than the actual pressure) encourage motorists to **over-inflate** their tires because when motorists fill their tires to the recommended level, they will actually be inflating to more than the recommended amount of pressure. On the other hand,

- pressure gauges which over-report (i.e., produce pressure readings which are **more** than the actual pressure) encourage motorists to **under-inflate** their tires because when motorists fill their tires to the recommended level, they will actually be inflating to less than the recommended amount of pressure.

Thus, the direction of deviation encourages very different outcomes with respect to inflation status. The Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act (enacted Nov 1, 2000) obliged the Secretary of Transportation to "complete a rulemaking for a regulation to require a warning system in new motor vehicles to indicate to the operator when a tire is significantly under-inflated."[2]

Since the rulemaking requirement specifically mandated **under-inflation** (that is, a specific direction of deviation) as the condition to be identified, therefore, Congress, acting on the best advice of safety experts, concluded that under-inflation is such a serious threat to safety that it is the one condition that the warning system **had** to be able to identify.

And, since gauge over-reporting encourages tire under-inflation, thus, this is the particular aspect of gauge accuracy which is modeled in this report.

[2] Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act, Nov 1 2000, Section 13.

4. The Explanatory Variables

4.1 The Volume of Traffic visiting the Station

A very strong predictor of gauge accuracy turns out to be the volume of traffic passing through a gas station. Partitioning the sample into stations with high and low traffic

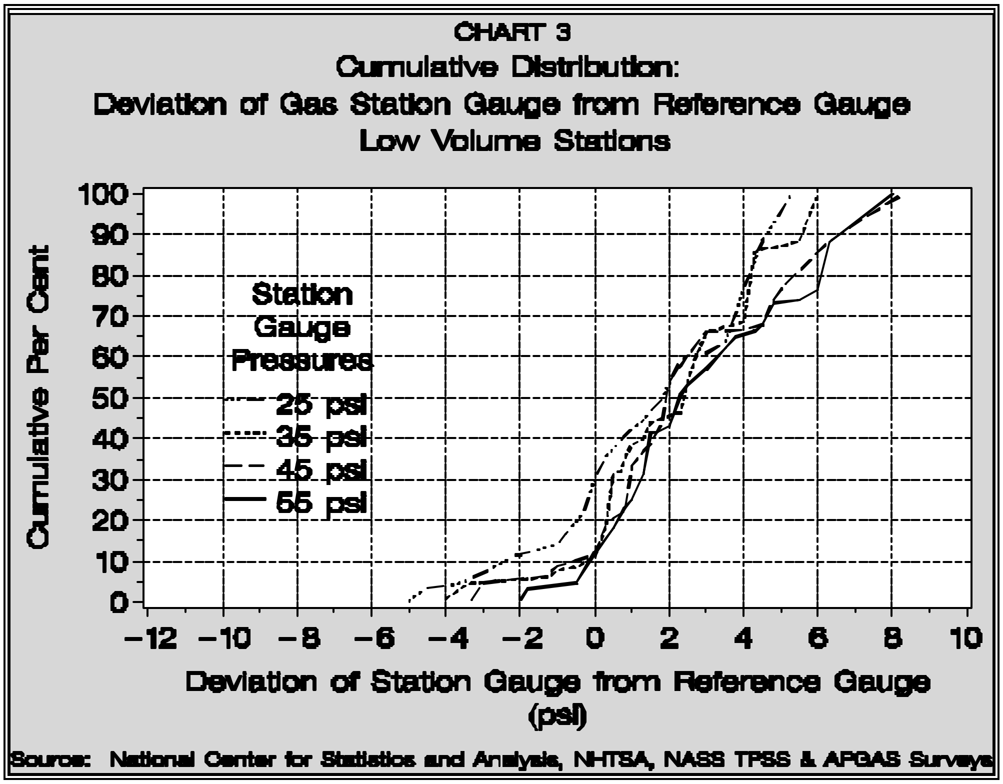
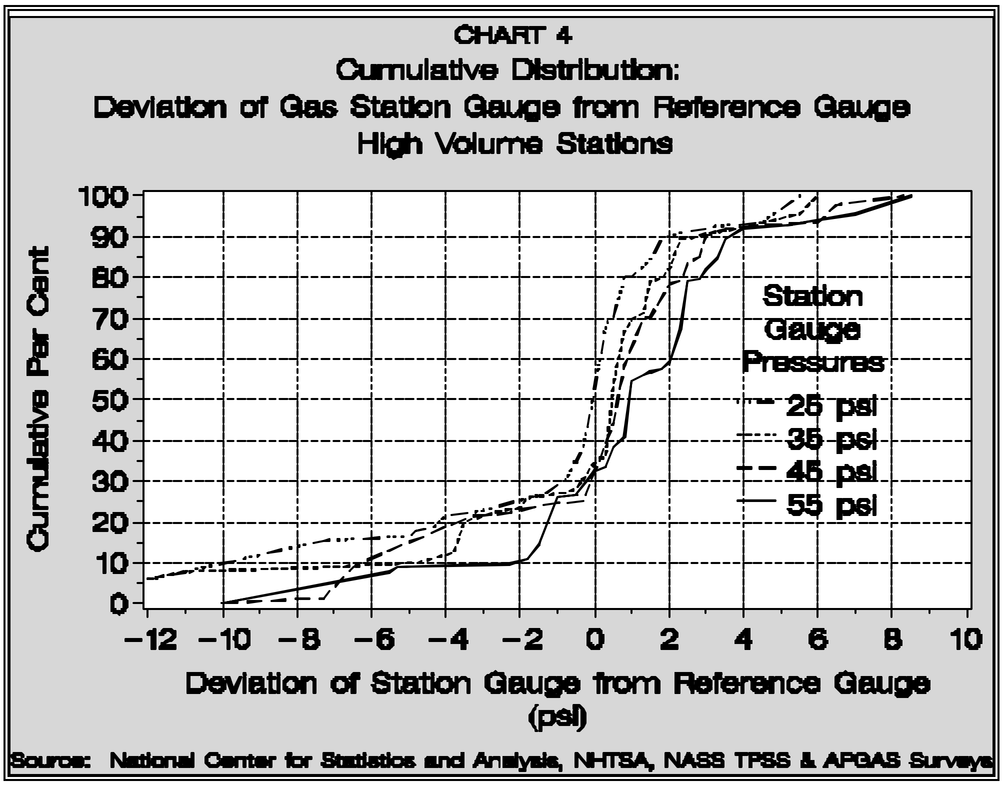


Table 1 **LOW VOLUME STATIONS** Deviation between Gas Station Gauge and Reference Gauge: Per Cent of Stations Over-Reporting			
Station Gauge Pressure (psi)	**Percent over-reporting**		
	by 4 psi or more	**by 6 psi or more**	**by 8 psi or more**
25	29	0	0
35	34	12	0
45	34	23	12
55	35	26	12

Source: National Center for Statistics and Analysis, NHTSA, TPSS (Feb. 2001) and APGAS (Aug. 2001) Surveys.

volumes[3], we find that the distribution corresponding to high traffic gas stations is very different from that corresponding to low traffic stations (Charts 3 and 4[4]; Tables 1 and 2).

It is tempting to hypothesize, due to higher wear and tear, that the gauges located at higher traffic stations will be more likely to over-report than gauges located at lower traffic stations.



However, what is in fact observed is exactly the opposite. Gauges located at **higher** traffic gas stations over-report tire pressures to a dramatically **lower** degree relative to their lower traffic counterparts. For example, at 35 psi, over-reporting by 4 psi or more occurs at 34% of lower traffic stations, but at only 9% of higher traffic stations; at 25 psi, over-reporting by 4 psi or more occurs at 29% of lower traffic stations, but at only 7% of higher traffic stations (Tables 1 and 2).

[3] See Appendix 1 for an explanation of the criteria used to partition the stations in this manner.

[4] See Appendix 2 for a note on interpreting the information conveyed by these cumulative distributions.

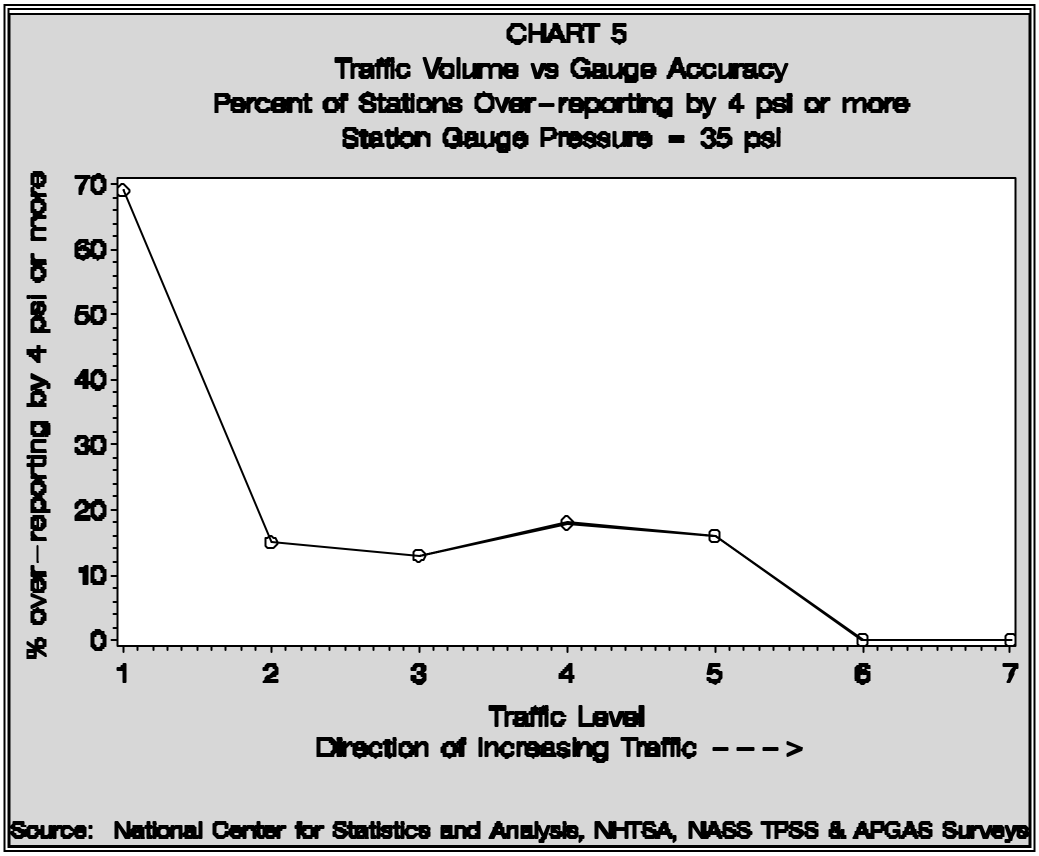
Table 2 **HIGH VOLUME STATIONS** Deviation between Gas Station Gauge and Reference Gauge: Per Cent of Stations Over-Reporting			
Station Gauge Pressure (psi)	**Percent over-reporting**		
	by 4 psi or more	**by 6 psi or more**	**by 8 psi or more**
25	7	0	0
35	9	4	0
45	8	7	2
55	10	7	4

Source: National Center for Statistics and Analysis, NHTSA, TPSS (Feb. 2001) and APGAS (Aug. 2001) Surveys.

On further investigation, it is possible to be much more specific regarding the particular level of traffic which has an impact on gauge accuracy. To do this, traffic is partitioned in a different way. Instead of using the traffic volume data to partition the stations into high and low traffic, the partitioning criteria that was used in *Air Pumps (2001)* is employed to partition them into 7 traffic categories (Table 3).

Table 3 Criteria Used to Partition Stations into Traffic Categories		
Traffic Level	Number of Vehicles in 75 mins	% of Stations in Traffic Level
1	0 -15	14%
2	16 - 25	18%
3	26 - 35	23%
4	36 - 45	20%
5	46 - 60	11%
6	61 - 75	10%
7	76 +	4%

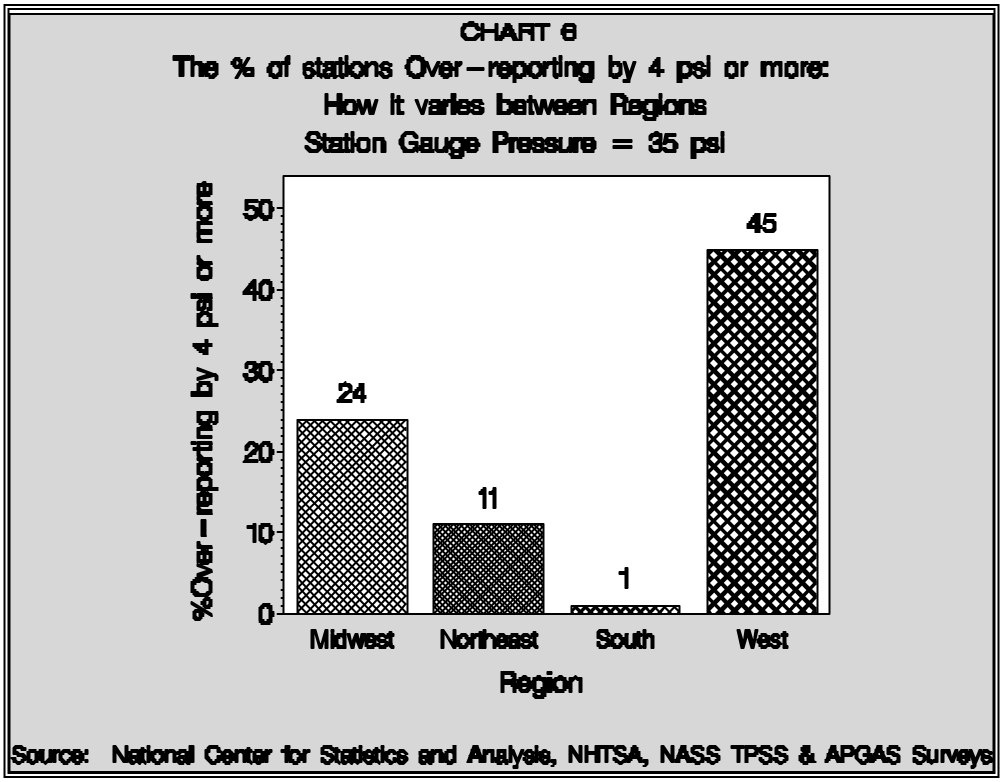
Source: National Center for Statistics and Analysis, NHTSA.



As shown in Chart 5, the level of traffic which has a positive effect on gauge accuracy is actually quite low: at all but the lowest level of traffic (accounting for only 14% of gas stations having at least two islands), over-reporting by 4 psi or more falls from nearly 70% of stations in the lowest traffic category, to between 15% and 18% in traffic categories 2 to 5, to 0% in the two highest (also accounting for 14% of two-island gas stations) categories.

4.2 The Region in which the Station is located

In addition to traffic, another variable that has a large impact on gauge accuracy is the region of the country in which a station is located. As Chart 6 shows, considering, for example, a target pressure of 35 psi, there is a large variation between regions with respect to the percentage of stations within each region whose gauges over-report by 4 psi or more.



Are these differences between regions statistically significant? To evaluate this, a logistic regression is performed with over-reporting by 4 psi as the dependent variable and region as the independent variable (with South defined as the base region). As Table 4

Table 4
Over-reporting by 4 psi or more as a function of Region

Variable	Odds Ratio	Coefficient	P-value (T-test)
Intercept	not app.	-4.41	.0029
REGION: Midwest	26.14	3.2635	.0574
REGION: Northeast	10.31	2.3331	.0731
REGION: West	66.24	4.1933	.0158
REGION: South	1.00	0.0000	not app
P-value for entire model: 0.00			

Source: National Center for Statistics and Analysis, NHTSA.

summarizes, the difference in gauge accuracy between Southern and Western gas stations is statistically significant (p-value = .02).

The odds ratio of 66.2 for West means that the odds[5] of a station gauge over-reporting by 4 psi or more is **66 times** higher in the West than in the South. Similarly, an odds ratio of 26.1 for the Midwest (significant, with p-value = .06) means that the odds of a station gauge over-reporting by 4 psi or more is 26 times higher in the Midwest than in the South. Finally, the odds ratio of 10.3 for the Northeast (significant, with p-value = .07) means that the odds of a station gauge over-reporting by 4 psi or more is 10 times higher in the Northeast than in the South. Thus, for every region the percentage of stations over-reporting by 4 psi or more differs from the South to a statistically significant degree.

4.3 Region & Traffic

4.3.1 No interaction

Since both traffic and region seem to have a great deal of explanatory power regarding over-reporting, to accurately quantify the relationship between these variables and gauge accuracy will require constructing a model which contains both these variables. Performing a logistic regression with over-reporting by 4 psi or more as the dependent variable and traffic and region as the independent variables, we find that -holding region constant- the odds of a station gauge over-reporting is 6 times lower (significant, with p-value = .01) for high traffic relative to low traffic stations (Table 5).

Table 5
Over-reporting by 4 psi or more as a function of Traffic and Region

Variable	Odds Ratio	Coefficient	P-value (T-test)
Intercept	not app	-3.45	.0153
TRAFFIC >= 34	.16	-1.8326	.0133
TRAFFIC <= 28	1.00	0.0000	not app
REGION: Midwest	34.95	3.5539	.0727
REGION: Northeast	9.79	2.2814	.0951
REGION: West	43.64	3.7760	.0214
REGION: South	1.00	0.0000	not app
P-value for entire model: 0.00			

Source: National Center for Statistics and Analysis, NHTSA.

Holding traffic constant and examining the effect of region, we find that the odds of a gas station gauge over-reporting by 4 psi or more is 44 times higher in the West than in the South (significant, with p-value = .02), that the odds of over-reporting by 4 psi or more is 35 times higher in the Midwest than in the South (significant, with p-value = .07) and that these

[5] See Appendix 3 for a brief explanation of odds and odds ratios.

odds are 10 times higher in the Northeast than in the South (borderline significant, with p-value = .1).[6]

In comparing the model of over-reporting as a function of region alone with the model with over-reporting as a function of both region and traffic, one notices that while the odds ratio associated with the Northeast remains essentially the same, the odds ratio associated with the West declines from 66 to 44, while the odds ratio associated with the Midwest increases from 26 to 35. Such a change in the odds ratio could simply be the result of correlation between traffic and region, but it could also indicate that there is an **interaction effect**[7] between region and traffic. If this is true, this would mean that the percentage by which the odds of over-reporting change due to a change in traffic varies from region to region. Likewise, it would mean that that the percentage by which the odds of over-reporting change due to a change in region varies with the level of traffic.

4.3.2 Interaction

Is the effect of region on over-reporting independent of the level of traffic (i.e., is the ratio of the odds of over-reporting by 4 psi or more in the West relative to the South the same regardless of whether we are referring to high or low traffic stations)? Ideally, one would want to test this by running a logistic regression with an interaction term between region and traffic. Unfortunately, when this is done, the resulting odds ratio estimates are unreliable due to the fact that too many parameters are being estimated relative to the number of observations available. However, what can be done is to examine the way in which the percentage of stations (within each region) which over-report by 4 psi or more varies if just high-traffic gas stations are considered.

Chart 6 (repeated here for convenience) shows within each region the percentage of gas station gauges which over-report by 4 psi or more. The West is by far the worst, with nearly half its station gauges over-reporting to this degree. But, if the population is restricted to high traffic stations, an **entirely different** picture emerges for some of the regions.

[6] Note that the reason for the increase in the p-values associated with region is probably not due to the inclusion of traffic per se. Rather, it is probably due to the fact that when the traffic variable is included those observations having intermediate values for traffic are (as was discussed earlier) set to missing. These observations are left out of this model, thus increasing the variance of the estimates, which tends to increase the p-values.

[7] That is, the effect that either one of these variables has on the odds varies with the particular value taken on by the other variable. For example, in comparing high with low traffic stations, the percentage by which the odds of over-reporting differ depends on the particular region of the country in which the gauge is located.

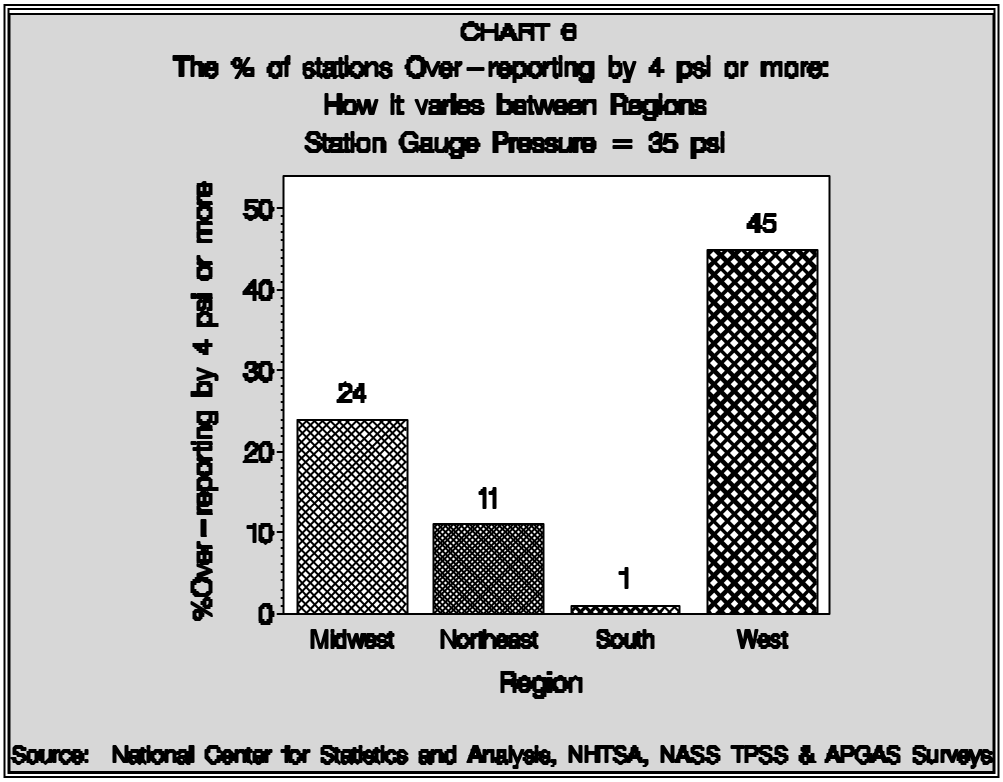


CHART 6
The % of stations Over-reporting by 4 psi or more:
How it varies between Regions
Station Gauge Pressure = 35 psi
%Over-reporting by 4 psi or more
0
10
20
30
40
50
24
11
1
45
Midwest
Northeast
South
West
Region
Source: National Center for Statistics and Analysis, NHTSA, NASS TPSS & APGAS Surveys

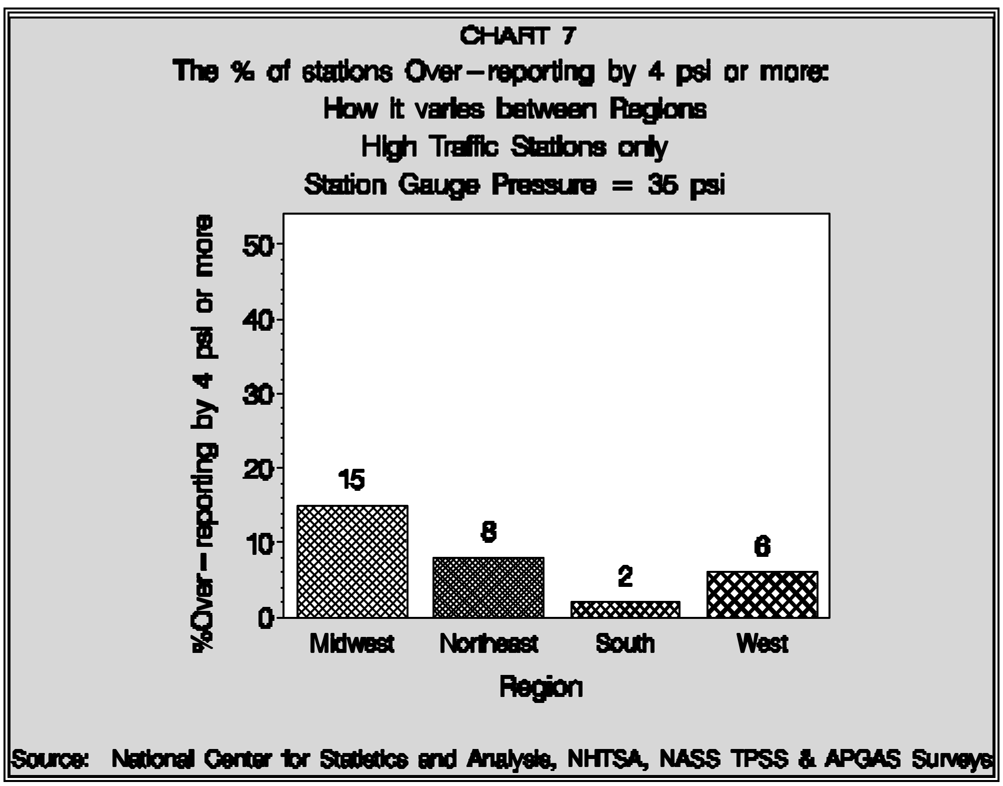


CHART 7
The % of stations Over-reporting by 4 psi or more:
How it varies between Regions
High Traffic Stations only
Station Gauge Pressure = 35 psi
%Over-reporting by 4 psi or more
0
10
20
30
40
50
15
8
2
6
Midwest
Northeast
South
West
Region
Source: National Center for Statistics and Analysis, NHTSA, NASS TPSS & APGAS Surveys

As Chart 7 shows, if only high traffic stations are considered, then while

- the percentage of stations over-reporting in the South doubles,
- this percentage decreases in all of the other regions, especially in the West.

The West goes from being by far the worst region -having close to 50% of its stations over-reporting by 4 psi or more- to only 6% of them over-reporting by at least this amount. This a good indication that there is a sizeable interaction effect between region and traffic: the percentage by which the odds change from a change in region varies with the level of traffic and vice versa.

Since gauge over-reporting in the West appears to be particularly sensitive to whether high or low traffic gas stations are being considered, therefore, it would be interesting to estimate a model involving this interaction term. To test and quantify this interaction effect, the data is re-coded so that region takes on just two values, West and non-West:

Table 6
Over-reporting by 4 psi or more as a function of Traffic, Region and the interaction between Traffic and Region

Variable	Odds Ratio	Coefficient	P-value (T-test)
Intercept	not app.	-1.80	.0031
TRAFFIC >= 34	.59	-0.5276	.5944
TRAFFIC <= 28	1.00	0.0000	not app.
REGION: West	10.77	2.3768	.0151
REGION: non- West	1.00	0.0000	not app
REGION*TRAFFIC: TRAFFIC >= 34 & REGION = West	.06	-2.8134	.0834
REGION*Traffic: TRAFFIC <= 28 & REGION = non-West or TRAFFIC >= 34 & REGION = non-West or TRAFFIC <= 28 & REGION = West	1.00	0.0000	not app.
P-value for entire model: 0.00			

Source: National Center for Statistics and Analysis, NHTSA.

a logistic regression model is then estimated having the independent variables traffic, region and traffic*region (i.e., the interaction between traffic and region). As Table 6 shows, the interaction term (significant, with p-value=.08) is very large relative to the other odds ratios in the model.

When an interaction term is present in the model, the interpretation of the odds ratios for traffic and region becomes a little more complicated. The odds ratio of traffic = .59 tells us that the odds of a pump over-reporting by 4 psi or more is 41% lower in the case of high traffic stations which are located in non-Western states relative to low-traffic stations located in non-Western states.

To calculate the odds associated with high traffic stations in Western states relative to low traffic stations in Western states, it is necessary to take account of the interaction term (since in this model low traffic is the base value for the traffic variable and non-West is the base value for the region variable). This odds ratio is .035 (.59 times .06). That is, the exponential of the coefficient of traffic times the exponential of the coefficient of the interaction term. This means that the odds of a station gauge over-reporting by 4 psi or more is 96% lower for high traffic stations in Western states than for low traffic stations in Western states.

Thus, while in general a larger volume of traffic reduces the probability of encountering a gauge which over-reports by 4 psi or more, the impact of traffic volume on reducing over-reporting is greatest in the West.

The odds ratio of 10.77 associated with the region variable means that the odds of a low traffic gas station in the West over-reporting by 4 psi or more is more than ten times **higher** than it is for low traffic stations in non-Western states. But, as the graphic analysis (Chart 7 vs Chart 6) led us to believe, this situation is **completely reversed** in the case of high traffic stations. The odds of a high traffic gas station over-reporting by 4 psi or more is 35% lower in Western than in non-Western states (10.77 times .06 yields an odds ratio of .65). Thus, Western gas stations have gauges which tend to **over-report much more** than non-Western stations if the stations being compared are **lower traffic** gas stations. Conversely, Western gas stations tend to have gauges which tend to **over-report much less** than those in the rest of the country if the stations being compared are **high traffic** gas stations. Once again, we see that region matters.

4.4 Pump Fees

4.4.1 Are Pump Fees Associated with more Accurate Gauges?

A reasonable hypothesis would be that gauge accuracy should be positively related to pump fees: if a fee is charged for pump use, one would think that the accompanying gauge would tend be more accurate than the gauges accompanying free pumps. When the distribution of deviations between the pressure level reported by the gas station's gauge and that reported by the researcher's gauge is examined, stations which charge fees **do** seem to have more accurate gauges than those which do not (Charts 8 and 9, Tables 7 and 8).

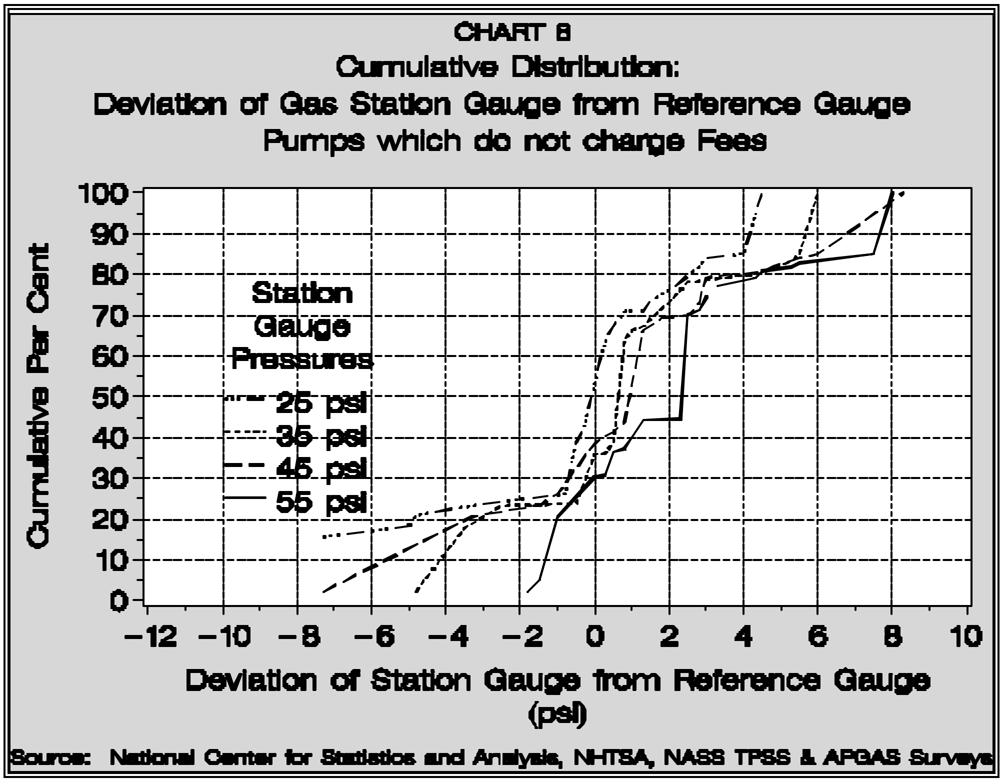


Table 7 **No Fee Charged** Deviation between Gas Station Gauge and Reference Gauge: Per Cent of Stations Over-Reporting			
Station Gauge Pressure (psi)	**Percent over-reporting**		
	by 4 psi or more	**by 6 psi or more**	**by 8 psi or more**
25	16	0	0
35	21	15	0
45	21	16	15
55	23	17	15

Source: National Center for Statistics and Analysis, NHTSA, TPSS (Feb. 2001) and APGAS (Aug. 2001) Surveys.

The distribution of station gauge deviations from actual pressure for pumps charging a fee lies nearly everywhere to the left of the corresponding distribution for free pumps (indicating a lower degree of over-reporting by the gauges of pumps charging fees). As Tables 7 and 8 show, the degree of over-reporting by at least 4, 6 and 8 psi at nearly all pressure levels is less for fee than for no-fee pumps (major exception: over-reporting by 6 psi or more at the 25 psi level).

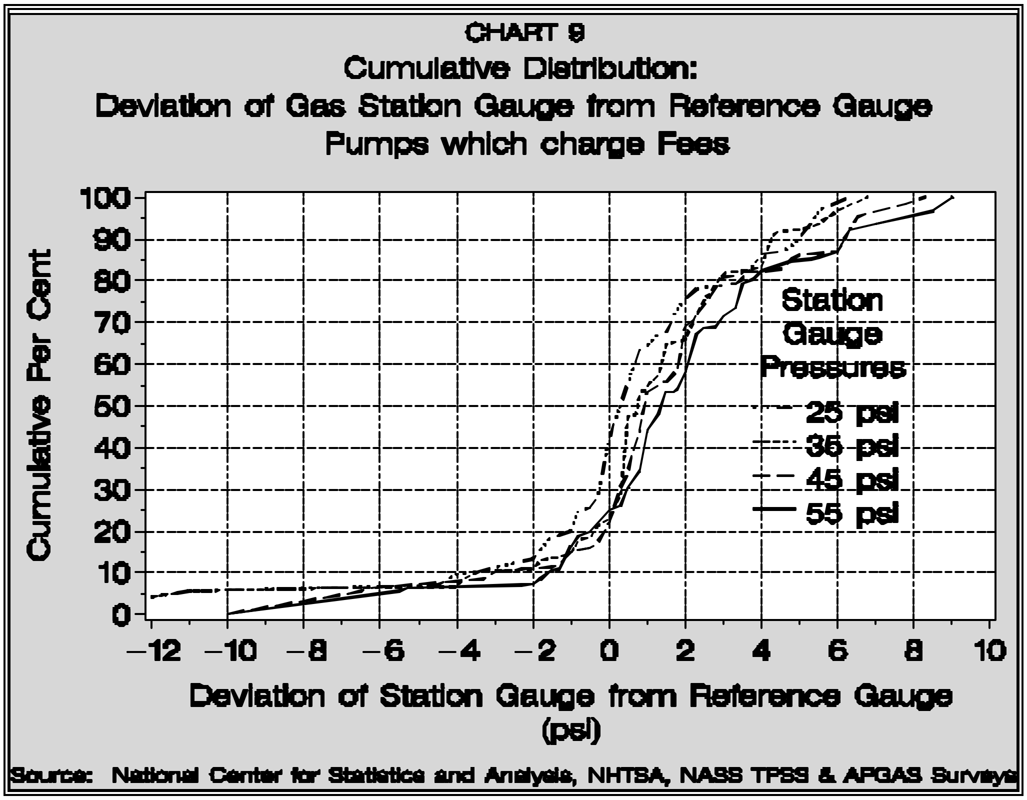
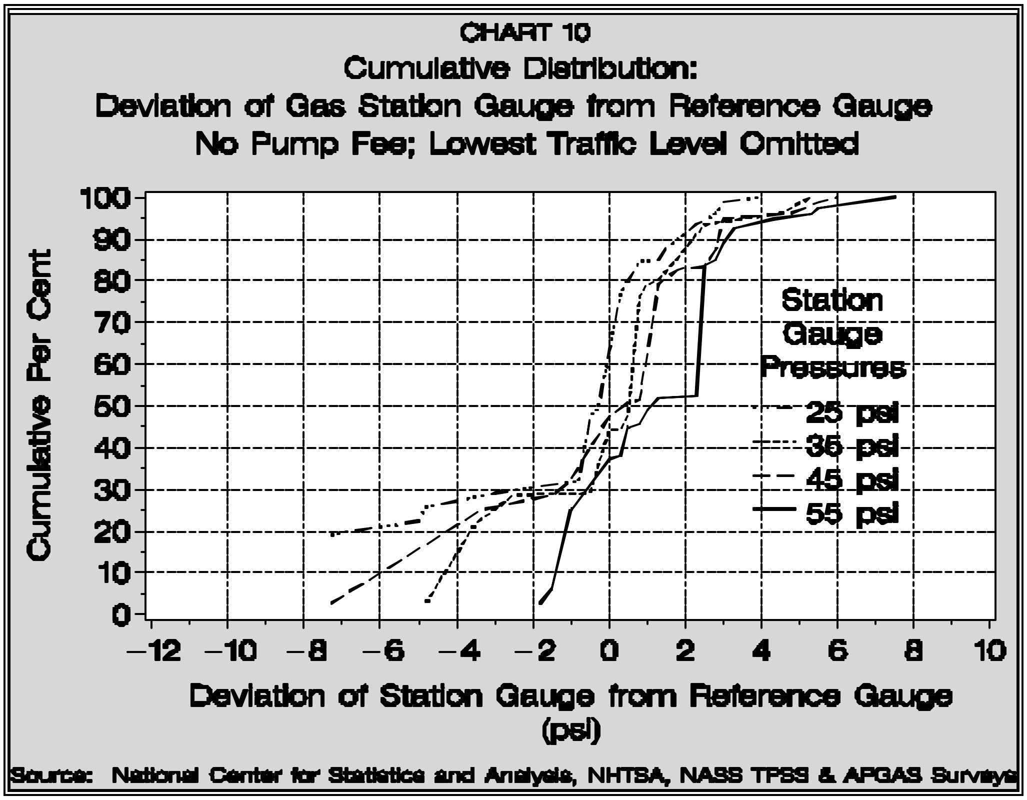


Table 8
Pump Fees Charged
Deviation between Gas Station Gauge and Reference Gauge:
Per Cent of Stations Over-Reporting

Station Gauge Pressure (psi)	Percent over-reporting		
	by 4 psi or more	by 6 psi or more	by 8 psi or more
25	16	3	0
35	19	7	0
45	18	13	2
55	20	14	7

Source: National Center for Statistics and Analysis, NHTSA, TPSS (Feb. 2001) and APGAS (Aug. 2001) Surveys.

Thus, it seems that pump fees do have a positive effect on gauge accuracy. However, as tempting as it is to accept this hypothesis, it is necessary to be more careful. As was seen earlier (Chart 5), the lowest traffic category is heavily populated with inaccurate gauges (recall: over-reporting by 4 psi or more occurs in nearly 70% of the station gauges in this category vs less than 20% for the 2nd worst traffic category). If gas stations in the lowest traffic category are eliminated (accounting for only 14% of U.S. gas stations having 2 or more islands), a **totally different** picture emerges: the **no** fee gas stations appear to be **much more** accurate than their fee counterparts (Charts 10 and 11, Tables 9 and 10).



This difference is quite impressive: for example, at the 35 psi level, while 14% of the fee pumps over-report by 4 psi or more, only 5% of the **no fee** pumps do so (Tables 9 and 10). Although this difference looks very large, to what extent it is statistically significant is another matter.

Table 9
No Fee Charged
Lowest Level of Traffic Omitted
Deviation between Gas Station Gauge and Reference Gauge:
Per Cent of Stations Over-Reporting

Station Gauge Pressure (psi)	Percent over-reporting		
	by 4 psi or more	by 6 psi or more	by 8 psi or more
25	1	0	0
35	5	0	0
45	5	1	0
55	7	3	0

Source: National Center for Statistics and Analysis, NHTSA, TPSS (Feb. 2001) and APGAS (Aug. 2001) Surveys..

Determining if there is a statistically significant relationship between whether a fee is charged and the outcome in terms of over-reporting can be determined by performing a logistic regression with over-reporting by 4 psi as the dependent variable and the

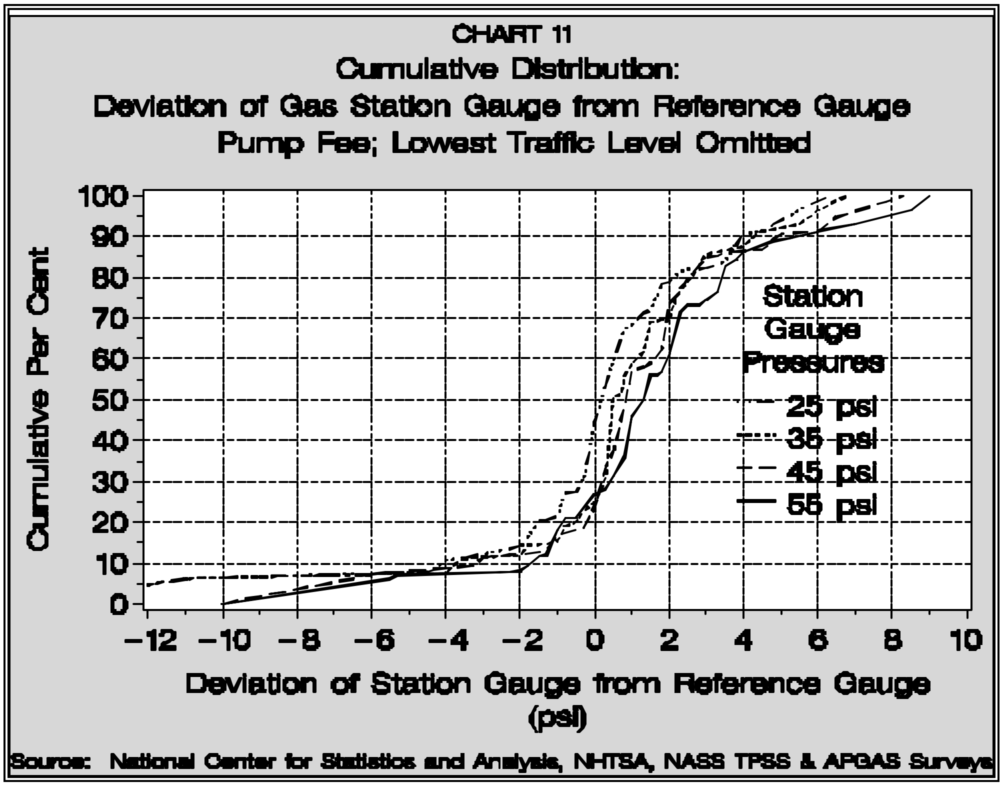


Table 10
Fee Charged
Lowest Level of Traffic omitted
Deviation between Gas Station Gauge and Reference Gauge:
Per Cent of Stations Over-Reporting

Station Gauge Pressure (psi)	**Percent over-reporting**		
	by 4 psi or more	**by 6 psi or more**	**by 8 psi or more**
25	12	4	0
35	14	7	0
45	14	9	2
55	16	10	7

Source: National Center for Statistics and Analysis, NHTSA, TPSS (Feb. 2001) and APGAS (Aug. 2001) Surveys.

presence of a pump fee as the independent variable. In addition, since we already have demonstrated that over-reporting is related to region and the level of traffic, therefore, accurately estimating the odds ratio associated with pump fees will require also including these two variables in the model.

Performing this regression we find that there is no significant difference (p-value, .6263) between fee and no fee pumps with regards to gauge accuracy (Table 11).

Table 11
Over-reporting by 4 psi or more as a function of Fee, Traffic and Region

Variable	Odds Ratio	Coefficient	P-value (T-test)
Intercept	not app.	-3.79	.0195
Fee	1.41	0.3435	.6263
No Fee	1.00	0.0000	not app
TRAFFIC >= 34	0.17	-1.772	.0177
TRAFFIC <= 28	1.00	0.0	not app
REGION: Midwest	36.97	3.6101	.0625
REGION: Northeast	10.42	2.3437	.0865
REGION: West	50.12	3.9144	.0128
REGION: South	1.00	0.0000	not app
P-value for entire model: 0.00			

Source: National Center for Statistics and Analysis, NHTSA.

However, the dramatic change that occurs in the cumulative distribution (Chart 8 vs Chart 10; Table 7 vs Table 9) when the stations at the lowest level of traffic are removed makes one believe that there is an interaction[8] effect between fee and the volume of traffic. Perhaps it is the absence of an interaction term in this model that accounts for the estimated odds ratio corresponding to fee not being significantly different from one.

Estimating the same model (but this time with an interaction term between fee and traffic) we run into a problem due to the way traffic is divided into high (counted vehicles > = to 34) and low (counted vehicles < = to 28): among the stations charging no fees, there were no stations at the high traffic level which over-reported by 4 psi or more. Result: when traffic is divided in this way, an estimate cannot be obtained for the coefficient of the interaction term.

To get around this problem, we redefine what is meant by high and low traffic: since the big shift in the distribution of deviations between station and reference gauge coincided with the deletion of just the stations in the lowest traffic category, therefore, (just in this case) low traffic is redefined to be the stations in this category and moderate-high traffic to be all the other stations (thus, in this case, no observations are being omitted in estimating the parameters). First, estimating the model without an interaction term, the

[8] That is, the odds of over-reporting by fee relative to no fee pumps depend on whether the pump is located at a high or low traffic station.

result is, once again, that the odds ratio corresponding to fees is not significant (p-value, .3374) (Table 12). Thus, seeming to indicate that fees have no impact on gauge accuracy.

Table 12
Over-reporting by 4 psi or more as a function of Fee, Traffic and Region

Variable	Odds Ratio	Coefficient	P-value (T-test)
Intercept	not app.	-3.01	.0601
Fee	1.96	0.6729	.3374
No Fee	1.00	0.0000	not app.
TRAFFIC >= 16	.05	-2.9957	.0000
TRAFFIC <= 15	1.00	0.0000	not app
REGION: Midwest	71.39	4.2682	.0251
REGION: Northeast	23.62	3.1620	.0461
REGION: West	55.96	4.0246	.0121
REGION: South	1.00	0.0000	not app.
P-value for entire model: 0.00			

Source: National Center for Statistics and Analysis, NHTSA.

Table 13
Over-reporting by 4 psi or more as a function of Fees, Traffic, Region and the interaction between Fees and Traffic

Variable	Odds Ratio	Coefficient	P-value (T-test)
Intercept	not app.	-1.41	.4204
Fee	.24	-1.4271	.2773
No Fee	1.00	0.0000	not app.
TRAFFIC >= 16	.01	-4.6052	.0068
TRAFFIC <= 15	1.00	0.0000	not app
REGION: Midwest	47.74	3.8658	.0234
REGION: Northeast	15.43	2.7363	.0512
REGION: West	41.57	3.7274	.0108
REGION: South	1.00	0.0000	not app.
FEE*TRAFFIC: Fee & TRAFFIC >= 16	18.14	2.8981	.0866
FEE*TRAFFIC: No Fee & TRAFFIC >= 16 or Fee & TRAFFIC <= 15 or No Fee & TRAFFIC <= 15	1.00	0.0000	not app.
P-value for entire model: 0.00			

Source: National Center for Statistics and Analysis, NHTSA.

But, when this model is estimated with an interaction term, the interaction term turns out to be significant (p-value = .0866) (Table 13). Thus fees **do** have an impact on gauge accuracy: but it turns out to be more complicated than one might think. If a pump is located at a low traffic station, then an odds ratio of .24 for fee means that the odds of the pump's gauge over-reporting by 4 psi or more is more than four times (1/.24) **lower** if the pump charges a fee.

On the other hand, if the pump is located at a moderate-high traffic station, then the odds ratio associated with the interaction term has to be taken into account (since the base value for traffic is low traffic) in interpreting the effect of charging a fee. If a station has a moderate-high volume of traffic, the odds that the gauge will over-report by 4 psi or more is 4.4 times **higher** if a fee is charged ($= OR_{Fee} * OR_{interaction}$ =.24*18.14 = 4.35) relative to a moderate-high traffic station not charging a fee for pump use.

Thus, the effect that a fee has on gauge accuracy **cannot be answered without knowing** whether the station at which the gauge is located is a low or moderate-high traffic station.

To summarize, at **low traffic** stations, the odds that pumps which charge fees will over-report by 4 psi or more are 76% **less** than the odds of free pumps doing so.[9] Thus, for low traffic stations, pump fees are associated with **more accurate** gauges. On the other hand, at **moderate-high traffic** stations, the odds that pumps which charge fees will over-report by 4 psi or more are more than 4 times **greater** than the odds of free pumps doing so. Thus, at moderate-high traffic stations, pump fees are associated with **less accurate** gauges.

Thus, if the model takes into account the interaction effect between fee and the volume of traffic, then it is possible to confirm statistically what Charts 10 and 11 appeared to indicate. Namely, that

- gauge accuracy does depend on pump fees, but that
- the precise direction of the effect depends on the volume of traffic.

What seemed to be a reasonable hypothesis -that fee pumps have gauges which are more accurate than those accompanying free pumps- turns out to be true only for stations in the lowest 14% of traffic volume. For all other stations, fee pumps are not only no better than their free counterparts: they actually are much more likely to over-report the actual tire pressure, thus encouraging tire under-inflation.

[9] Or, to say things equivalently, at low traffic stations, the odds of over-reporting by 4 psi or more is four times lower if the pump charges a fee than if it does not.

Thus, for pumps located at the vast majority of gas stations, motorists should not believe that 'you get what you pay for', at least in terms of gauge accuracy.[10]

4.4.2 How Pump Fees Affect the Probability of Encountering Inaccurate Gauges

In the previous section, the odds ratios associated with the various variables affecting gauge accuracy were quantified. The odds ratios indicate what happens to the odds of a gauge over-reporting by 4 psi or more as one variable is changed, e.g. changing from no fee to fee, and all the other variables in the model are held constant. The purpose of this section is to investigate what these odds ratio estimates imply regarding the probability of encountering station gauges which over-report by 4 psi or more.

As explained in Appendix 3, the odds of an event is the probability of that event occurring divided by the probability of that event not occurring (in this case, the event occurs when a station gauge reports a value for air pressure which is 4 psi or more higher than the actual pressure). That is,

$$\text{Odds} = \frac{\text{Prob of event}}{1 - \text{Prob of event}} \text{ .}$$

Thus, rearranging one gets

$$\text{Prob of event} = \frac{\text{Odds of the event}}{1 + \text{Odds of the event}} .$$

Also, from Appendix 3, recall that the odds of an event are equal to the product of the exponential of the logistic regression coefficients corresponding to those variables in the model which are not at their base value. Thus, the odds that a pump will over-report by 4 psi or more if it charges a fee and is located at a moderate-high volume gas station in the Midwest is equal to $\text{OR}_{\text{Fee}} * \text{OR}_{\text{Traffic}} * \text{OR}_{\text{Region=MW}} * \text{OR}_{\text{interaction}}$ = (.24)*(.01)*(47.74)*(18.14) = 2.078 (the exponential of the intercept term not appearing in this product since it is not statistically significant). Thus, the **probability** that a randomly selected station (with a working pump and gauge) will over-report by this amount is given by 2.078/3.078 = .675. That is, more than two-thirds of the gauges located at high-moderate volume, fee-charging, stations in the Midwest will over-report tire pressure by 4 psi or more.

And what about stations which do not charge fees for pump use? In this case, not only does the fee term drop out, but so does the interaction term (since there is no fee,

[10] However, as was reported in *Air Pumps* (2001), there is at least one positive effect of pump fees: pumps which charge them are much more likely to have a gauge.

therefore, there is no interaction between fee and traffic). The odds are thus given by $OR_{Traffic} * OR_{Region=MW}$ = (.01)*(47.74) = .4774 and, thus, the corresponding probability is .4774/1.4774 = .323. Thus, at moderate-high traffic gas stations in the Midwest, selecting a pump which does not charge a fee reduces by more than 50% (68% vs 32%) the probability that the accompanying gauge will over-report by 4 psi or more.

As Table 14 summarizes, in most regions of the country there are very similar, impressive reductions in the probability of gauge over-reporting among moderate-high traffic stations at free as opposed to fee pumps.

Table 14
Moderate to High Volume Stations:
Probability (in %)
of encountering a Gauge which over-reports by 4 psi or more
by Region and Fee Status

Region	Fee	No Fee
Midwest	68	32
Northeast	40	13
West	64	29
South	4	1

Source: National Center for Statistics and Analysis, NHTSA.

In the West, the result is virtually the same as in the Midwest: the probability of a station gauge over-reporting by 4 psi or more drops by more than half, from 64% to 29%. In the Northeast, the difference is even more impressive, the probability dropping from nearly one out of every two stations (40%) to a little over one station in ten (13%). Even in the South (which, as was seen in Section 4.2, tends to have very good gauges) there is a four-fold drop in the probability of a gauge over-reporting by 4 psi or more: from 4% to 1%.

Thus, in all regions of the country, and at the vast majority[11] of gas stations, going to a station which charges a pump fee increases the probability that the station's gauge will report an air pressure which is 4 psi or more higher than it actually is, thus leading these drivers to unknowingly under-inflate their tires. As the following section demonstrates, over-reporting of tire pressures has a statistically significant impact on the vehicle population.

[11] To reiterate: 86% of U.S. gas stations (having two islands or more) would be classified as moderate-high volume according to the definition used here.

5. Relationship between the Prevalence of Over-reporting in Station Gauges and Tire Under-inflation

The TPSS study, conducted in February 2001, surveyed 11530 vehicles: recording the recommended and actual pressure of the tires and asking the drivers various questions with respect to tire maintenance.[12] Examining vehicles with recommended tire pressures of from 29 to 41 psi (which includes virtually every passenger car and SUV), we find that, nationally, one vehicle in five has **all four tires** under-inflated by 4 psi or more. Is this related to poor tire maintenance on the part of drivers, or does this have something to do with over-reporting of tire pressures by station gauges? That is, as was reported in *Air Pumps* (2001), since about one station gauge in five over-reports tire pressure by 4 psi or more, this means that motorists using such gauges to inflate their tires to the recommended pressure would, in fact, be under-inflating their tires by 4 psi or more.

Thus, one would expect there to be some relationship between inaccurate reporting by station gauges and improper tire inflation. But is there any evidence showing a relationship between gauge over-reporting of tire pressures and the prevalence of under-inflation in the vehicle population? If such a relationship exists, then regional variation in gauge over-reporting should, to some extent, be mirrored in regional variations with regard to tire under-inflation.[13]

Nationally, the proportion of vehicles with all four tires under-inflated by 4 psi or more is 18.3%, if the driver regularly checks tire pressure using a gauge, vs 20.7%, if the driver does not.[14] The difference between these two proportions is not statistically significant (p-value, .17). When the same analysis is performed by region, the South turns out to

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[12] Bondy, Nancy; Thiriez, Kristin, *Tire Pressure Special Study: Vehicle Observation Data*, NHTSA, August 2001, DOT-HS-809-317.

[13] Particularly under-inflation involving all four tires since one would think that motorists who bother to check their tires using a gauge would check all their tires, thus all four tires would tend to be under-inflated by the same amount.

[14] These figures were arrived at (*Tire Pressure Special Study: Data Documentation*, DOT, NHTSA, NCSA, 2001) by taking account of only those vehicles whose drivers answered affirmatively to both “Are you responsible for the maintenance of this vehicle?” and “Are you this vehicle’s primary driver?” At this point, the answer to the question “How do you **normally** check your tires for proper inflation?” (emphasis theirs) was used to partition the remaining vehicles into those whose drivers stated that they used a pressure gauge to do this and those who gave some other response (e.g., “Waits for vehicle servicing” or “Does not check”).

Of those stating that they were the principal driver of the vehicle and who also said that they were responsible for the vehicle’s maintenance (and whose vehicle had recommended tire pressures in the 29-41 psi range), 3473 (46%) stated that they normally used a gauge to check their vehicle’s tire pressure.

Table 15 Percent of Vehicles for which all 4 Tires are Under-inflated by 4 psi or more			
Region	Driver regularly checks tire pressure using a gauge	Driver gives some other response to this question	P-value (null hypothesis of no difference between these two proportions)
Midwest	21.5	26.9	.21
Northeast	21	17.4	.17
West	17.2	16.3	.73
South	11.2	17.7	.01
All regions	18.3	20.7	.17

Source: National Center for Statistics and Analysis, NHTSA, TPSS Survey, Feb. 2001.

be the only region in the country where there is a statistically significant difference in the proportion of vehicles which have all 4 tires under-inflated by 4 psi or more between those drivers who regularly use a gauge to check their tire pressure and those who do not (Table 15). What is interesting about this is that, as was seen above (Chart 6), the South had by far the lowest proportion of station gauges over-reporting by 4 psi or more (1% vs 11% in the next closest region[15]).

Furthermore, as Table 15 reports, it is **only** among drivers who regularly check their tire pressure using a gauge that the South is significantly better than the other regions with respect to tire under-inflation: among drivers who do not do this, the South is no better than the West and Northeast.[16]

To repeat, the South has three characteristics which seem to be related:

1- it is the only region of the country in which drivers who regularly check their tire pressure using a gauge have a statistically significant advantage over drivers who do not with respect to the percentage of vehicles for which all 4 tires are **under-inflated** by 4 psi or more.

Note that from this response it is not possible to tell whether they used their own gauge or a station gauge to do this.

[15] At a reference pressure of 35 psi.

[16] Among drivers who do not normally check their tire pressures using a gauge, 17.7% of Southern vehicles have all 4 tires under-inflated by at least 4 psi vs 16.3% of Western vehicles and 17.4% of vehicles in the Northeast (Table 15).

2- This difference **only** exists among those drivers who regularly check[17] their tire pressure using a gauge. And,

3- it is the region which (to a statistically significant degree) has by far the lowest percentage of gas stations having gauges which **over-report** tire pressure by 4 psi or more.

Thus, it is in the region whose gauges over-report the **least**, where drivers seem to benefit the **most** from regularly using a gauge to check their tire pressure. Certainly, such a result should not be surprising: if many of the drivers who regularly check their tire pressure using a gauge do so using a gas station gauge and, if a large percentage of these gauges over-report, one would expect to find that many of these diligent drivers are, in fact, under-inflating their tires. (Not only that but, they wouldn't be under-inflating just one or two tires, but all 4 tires).[18]

6. Summary of Findings

This report has identified three variables which have a statistically significant impact on the degree to which gas station pressure gauges over-report (i.e., report pressures which are higher than the actual pressure): the level of traffic visiting the station, the region of the country in which the station is located and whether or not a fee is charged for pump use.

The level of traffic has a negative effect on over-reporting: gauges located at higher traffic stations tend to over-report less than gauges at low traffic stations.

The likelihood of a station gauge over-reporting by 4 psi or more varies quite a bit between regions, with the South being by far the best (only about 1% of their station gauges over-report by 4 psi or more) and the West being the worst (nearly half of their station gauges over-report by this magnitude).

When traffic and region appear together in the same model, the result is that both have a statistically significant effect on the degree of over-reporting.

However, if only higher traffic stations are considered, Western stations go from 45% of their gauges over-reporting by 4 psi or more to only 6% of their gauges over-reporting to

[17] This is an important point because, as is discussed in Appendix 4, there is a question regarding the role played by winter temperatures (the TPSS was conducted in February) on the degree of under-inflation that was detected.

[18] Note that several cautionary remarks regarding these conclusions have to be made due to the fact that the tire pressure data was gathered in February. See Appendix 4 for a discussion of these issues.

this degree. This suggests that there is interaction taking place between Western gas stations and the level of traffic.

Constructing a model with this interaction effect built in, we find that its coefficient is indeed significant: thus, the odds that a Western gas station gauge will over-report by 4 psi or more relative to the odds of a non-Western station gauge doing so depends on the level of traffic passing through that station.

The relationship between fees and the degree of over-reporting depends on the level of traffic. At low traffic gas stations, the presence of fees significantly reduce the odds that a gauge will over-report; while at moderate-high traffic stations, fees have the **opposite** effect: significantly **increasing** the odds of over-reporting by 4 psi or more.

The result is that fees have a major (and quite surprising, given the general belief that if something costs more, it must be better) impact on the probability of encountering a pump which over-reports by 4 psi or more. In the case of moderate-high traffic gas stations, the probability of encountering a station gauge with this degree of inaccuracy in the Midwest is 68% for fee pumps vs 32% for free pumps; in the Northeast it is 40% for fee vs 13% for free pumps; in the West 64% for fee pumps vs just 29% for free; and, in the South, it is 4% for fee vs just 1% for free pumps.

Thus, for the vast majority of stations (86% of U.S. gas stations fall into the moderate-high traffic category) paying a fee for pump use actually **increases** -and, in most regions, quite substantially- the likelihood that the gauge will report a pressure level 4 psi or more higher than the actual pressure.

Finally, investigating the question of whether the prevalence of over-reporting among station gauges has an impact on the prevalence of tire under-inflation among vehicles, we find evidence of a connection between the two. In comparing drivers who normally check their tire pressure using a gauge with those who do not, one would think that the latter would have a greater likelihood of having all four tires under-inflated by 4 psi or more. However, it turns out that the South is the **only** region of the country in which this is true (to a statistically significant degree). Since the South has by far the lowest percentage of station gauges over-reporting by 4 psi or more (1% vs 11% in the next best region), this is at least tentative evidence of a relationship between the state of accuracy among station gauges and the level of under-inflation in the vehicle population.[19]

[19] As mentioned earlier, Appendix 4 contains a discussion of another possible explanation for this result.

Appendix 1

Criteria Used to Partition the Gas Stations in the APGAS Sample into High and Low Volume Stations

The TPSS survey provided the estimates for station traffic by counting the number of vehicles coming in to the gas pumps during five 15 minute periods starting at 8 am, 10 am, 12 pm, 2 pm and 4 pm. Thus, the station traffic was arrived at by taking the sum of the traffic during these five 15 minute periods.

Since our goal is to determine whether there are any differences in gauge accuracy between high and low traffic gas stations, therefore, the partitioning was done by

i. calculating the median traffic level of gas stations in the study (31 vehicles in 75 minutes) and

ii. creating a new variable called 'traffic' to which values were assigned in the following way:

- stations with traffic levels close to the median (29, 30, 31, 32, 33 vehicles in 75 minutes) were assigned a missing value for 'traffic' (thus, in calculations involving just this particular variable, these observations were not taken into account)

- stations with 28 or fewer observed vehicles were assigned a value of 1 (indicating 'low' traffic) and

- stations with 34 or more observed vehicles were assigned a value of 2 (indicating 'high' traffic).

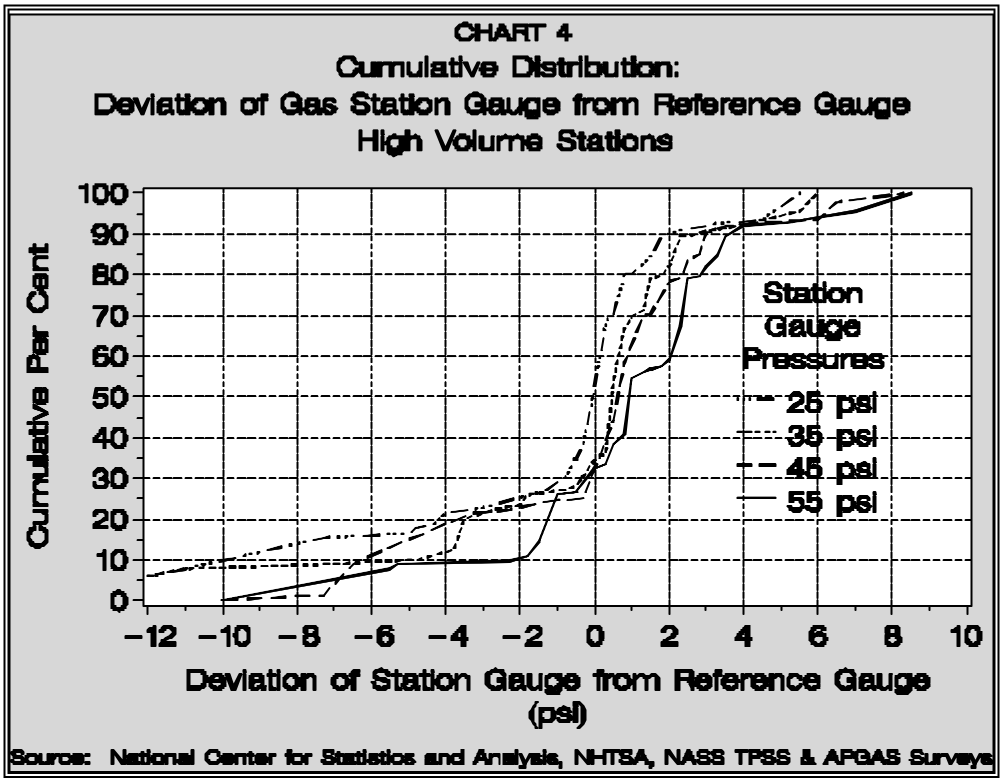
Result: the traffic variable partitions the data into two groups of stations which truly differ from one another with respect to the volume of traffic. Thus, it is possible meaningfully speak of high and low traffic stations. [20]

[20] Note that the source of the traffic data is the TPSS. Since the TPSS was conducted in February, these traffic estimates will have been subject to greater variance (due to more severe and variable weather conditions) than would've been the case had the data been gathered during the summer.

Appendix 2

A Note on Interpreting the Information Conveyed by the Cumulative Distributions

The absolute values of the numbers along the X axis indicate the magnitude of the deviation between the station's gauge and the researcher's gauge, and the direction of deviation is given by their sign. For example, referring to Chart 4, what does the intersection of the X axis reading of -4 and the 35 psi cumulative distribution indicate? Since the Y axis reading at this point is 12%, this means that at an estimated 12% of high volume stations in the U.S. when the station's gauge reports a reading of 35 psi, the actual pressure is 39 psi or higher (i.e., the station's reading is 4 psi or more **below** what it actually is, hence the negative sign).



Similarly, for the intersection of the X axis reading of 4 psi and the 35 psi cumulative distribution. When the station's gauge reports a reading of 35 psi, the corresponding Y axis reading is 91%, which means that at an estimated 9% of high volume stations in the U.S. the actual pressure is 31 psi or lower (i.e., the station's reading is 4 psi or more **above** what it actually is, hence the positive sign).

Finally, in comparing the tables accompanying each cumulative distribution (e.g., Table 2 and Chart 4) one will frequently note that there is a slight discrepancy between the percentage of over-reporting given by the table and what appears on the graph. For example, Table 2 reports that, at a target pressure of 35 psi, 9% of high volume U.S.

Table 2 **HIGH VOLUME STATIONS** Deviation between Gas Station Gauge and Reference Gauge: Per Cent of Stations Over-Reporting			
Station Gauge Pressure (psi)	**Percent over-reporting**		
	by 4 psi or more	**by 6 psi or more**	**by 8 psi or more**
25	7	0	0
35	9	4	0
45	8	7	2
55	10	7	4

Source: National Center for Statistics and Analysis, NHTSA, APGAS Survey, Aug. 2001

gas station gauges over-report by 4 psi or more, while from the accompanying graph (Chart 4), a figure of 8% appears more appropriate. However, it is important to realize that the figures reported in the tables will always be more accurate because they are calculated from the sample data. On the other hand, the corresponding cumulative densities involve approximations since they are **continuous** functions constructed from **discrete** sample data.

Appendix 3

A Brief Explanation of Odds and Odds Ratios

The odds of an event is the probability of that event occurring, Prob(event | X), divided by the probability of that event not occurring, 1 - Prob(event | X). Where X = $(X_1, X_2, \ldots, X_k)$ is a vector consisting of k explanatory variables and where the vertical slash, |, tells us that this probability varies with X (i.e., as one or more of $X_1, X_2, \ldots, X_k$ change in value, so does the probability).

Thus, in the case of the logistic regression results presented in Table 4,

- the odds in question are simply the probability that a randomly selected gauge will over-report by 4 psi or more divided by the probability that it won't $\frac{\text{Prob(event | Region)}}{1 - \text{Prob(event | Region)}}$; and
- k = 3, since the vector X consists of the 3 regions Midwest, Northeast and West (South is the base region, that is, the region to which each of the other regions are compared and, thus, it does not appear as a separate variable).

The odds ratio, on the other hand, is simply the ratio of two odds. The odds ratio associated with an explanatory variable has a special meaning: it tells us the multiple by which the odds have changed as the value of that variable, say X_2, changes from its base value to the value in question (the values of all the other variables in the model being held constant).

Thus, an odds ratio of 26.14 for Midwest tells us that the odds of a station gauge over-reporting by 4 psi or more is twenty-six times higher in the Midwest than in the South. The odds ratio associated with a given random variable is very easy to calculate: it is simply the exponential of its logistic regression coefficient. Eg., 26.14 = exp(3.2635).

Table 4
Over-reporting by 4 psi or more as a function of Region

Variable	Odds Ratio	Coefficient	P-value (T-test)
Intercept	not app.	-4.41	.0029
REGION: Midwest	26.14	3.2635	.0574
REGION: Northeast	10.31	2.3331	.0731
REGION: West	66.24	4.1933	.0158
REGION: South	1.00	0.0000	not app
P-value for entire model: 0.00			

Source: National Center for Statistics and Analysis, NHTSA.

Appendix 4

Winter Weather, Tire Under-inflation and Tire Pressure Maintenance

One of the referees (NHTSA's Vehicle Research and Test Center) of this report pointed out that because the tire pressure survey was done in February, adverse weather conditions would've affected the results discussed in Section 5 in two ways.

First, since tire pressure falls with air temperature, the colder February weather would've caused tire pressures to be lower relative to what they would've been a few months before (particularly outside of the South). Thus, if no adjustments were made to add additional air, this would cause there to be a greater tire pressure differential over this period of time in the colder regions.

Note that, everything else equal, this fact would just strengthen and not weaken the conclusions of Section 5. The reason being that it is precisely those drivers who normally check their tires using a gauge who would be most likely to detect and adjust for (by adding additional air) this seasonal drop in tire pressure. Thus, it is among this group (**especially** in winter, when the decline in air temperatures should exacerbate the prevalence of under-inflation in the vehicle population) where the benefits of regularly checking tire pressure with a gauge should be most easily seen. Thus, low February temperatures in the Northeast, Midwest and West should make it **easier** -and not more difficult- to detect differences between these two groups of drivers. The fact that despite this, a difference existed to a statistically significant degree only in the very region (the South) where this difference should have been **hardest** to detect, underlines the importance of the relationship between the prevalence of over-reporting among station gauges and the pervasiveness of under-inflation in the vehicle population. As nice as this sounds, this argument has a weakness: it assumes that winter weather does not discourage those motorists who normally check their tire pressure with a gauge from continuing to do so.

Which is precisely their second point: colder weather will not only cause tire pressure to be lower, but it would also discourage motorists from checking their tires and, therefore, the degree of discouragement would be greater outside of the South. Thus, are the regional differences (or lack of them) between the two groups of drivers due to regional differentials in gauge accuracy or is it due to this exacerbated by regional differentials in seasonal temperature variation (which affects both tire pressure and, quite possibly, the extent to which drivers who normally check their pressures using a gauge actually do so)?

While there is no doubt that unpleasant weather will have a negative effect on the diligence with which motorists check their tires, it is equally true that even during winters, there will be some days with pleasant weather. Thus, will drivers who **normally** (which is what the drivers were asked) check their tire pressure using a gauge simply cease doing so during the winter, or will they merely shift their activities to days with milder weather?

This is a question which is impossible to answer from the data. And, for this reason, a definitive answer on the relationship between station gauge accuracy and tire under-inflation in the vehicle population awaits a future tire pressure study, conducted during the milder months.