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Demand for Gasoline Is More Price-Inelastic than Commonly Thought

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Demand for Gasoline Is More Price-Inelastic than Commonly Thought

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Abstract:
One of the most frequently examined statistical relationships in energy economics has been the price elasticity of gasoline demand. We conduct a quantitative survey of the estimates of elasticity reported for various countries around the world. Our meta-analysis indicates that the literature suffers from publication selection bias: insignificant and positive estimates of the price elasticity are rarely reported, although implausibly large negative estimates are reported regularly. In consequence, the average published estimates of both short- and long-run elasticities are exaggerated twofold. Using mixed-effects multilevel meta-regression, we show that after correction for publication bias the average long-run elasticity reaches -0.31 and the average short-run elasticity only -0.09.

Keywords: Gasoline demand; Price elasticity; Meta-analysis; Publication selection bias

JEL: C83; Q41; Q48

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1 Introduction

For the purposes of government policy concerning energy security, optimal taxation, and climate change, precise estimates of the price elasticity of gasoline demand are of principal importance. For example, if gasoline demand is highly price-inelastic, taxes will be ineffective in reducing gasoline consumption and the corresponding emissions of greenhouse gases. During the last 30 years the topic has attracted a lot of attention of economists who produced a plethora of empirical estimates of both short- and long-run price elasticities. Yet the estimates vary broadly.

A systematic method how to make use of all this work is to collect these numerous estimates and summarize them quantitatively. The method is called meta-analysis (Stanley, 2001) and has long been used in economics following the seminal contribution by Stanley & Jarrell (1989). Recent applications of meta-analysis in economics include, among others, Card *et al.* (2010) on the evaluation of active labor market policy, Havranek (2010) on the trade effect of currency unions, and Horvathova (2010) on the impact of environmental performance on corporate financial performance.

Two international meta-analyses of the elasticity of gasoline demand have been conducted (Espey, 1998; Brons *et al.*, 2008). These meta-analyses study carefully the causes of heterogeneity observed in the literature. The average short- and long-run elasticities found by these meta-analyses were -0.26 and -0.58 (Espey, 1998) and -0.34 and -0.84 (Brons *et al.*, 2008). None of the meta-analyses, however, corrected the estimates for publication bias. It is well-known that publication selection can seriously bias the estimates of price elasticities because positive estimates are usually inconsistent with theory: for instance, Stanley (2005) documents how the price elasticity of water demand is exaggerated *fourfold* because of publication bias.

Publication selection bias, long recognized as a serious issue in empirical economics research (De Long & Lang, 1992; Card & Krueger, 1995; Stanley, 2005), arises when statistically significant estimates or estimates with a particular sign are preferentially selected for publication. The bias stems from the preference of authors, editors, or referees for results that tell a story and are theory-consistent. Publication bias has been found in virtually all areas of empirical economics (Doucouliagos & Stanley, 2008).

The effects of publication selection differ at the study and literature levels. At the study level it is reasonable not to base discussion on the estimates of the price elasticity of gasoline demand that are positive—few would consider gasoline to be a Giffen good, and positive estimates are thus most likely due to misspecifications. On the other hand, it is far more difficult to identify large negative estimates that are also due to misspecifications. If all researchers discard positive estimates of the price elasticity but keep large negative estimates, the average impression derived from the literature will be biased toward stronger elasticity. Thus, at the literature level the mean estimate must be corrected for publication bias.

We employ recently developed meta-analysis methods to test for publication bias and estimate the corrected elasticity beyond. The mixed-effects multilevel meta-regression takes into account heteroscedasticity, which is inevitable in meta-analysis, and between-study heterogeneity, which is likely to occur in most areas of empirical economics. We do not, however, in-

vestigate heterogeneity explicitly, as this issue was thoroughly examined by the two previous meta-analyses.

The paper is structured as follows. Section 2 discusses the process of selecting studies to be included in the meta-analysis and the properties of the data. Section 3 describes the meta-analysis methods used to detect and correct for publication bias. Section 4 discusses the results of the meta-regression. Section 5 concludes.

2 The Elasticity Estimates Data Set

The first step of meta-analysis is the collection of primary studies. We examined all studies used by the most recent meta-analysis (Brons *et al.*, 2008), but because the sample used by Brons *et al.* (2008) ends in 1999, we additionally searched the EconLit and Scopus databases for new studies published between 2000 and 2011. To be able to use modern meta-analysis methods and correct for publication bias, we need the standard error of each estimate of elasticity; therefore we have to exclude studies that do not report standard errors (or any other statistics from that standard errors could be computed). Concerning the definition of short- and long-term elasticity estimates, we follow the approach of the first meta-analysis on this topic, Espey (1998).

Some meta-analysts argue for using estimates from all available studies in hope that the inclusion of unpublished studies will alleviate publication bias. Nevertheless, rational authors of primary studies are likely to polish even early drafts of their papers as they prepare for journal submission: in a large survey of economics meta-analyses, Doucouliagos & Stanley (2008) document that the inclusion of working papers does not help mitigate publication bias. Hence we collect estimates only from studies published in peer-reviewed journals—as a simple criterion of quality. In sum, our sample consists of 202 estimates of the price elasticity of gasoline demand taken from 41 journal articles.

Table 1: List of Primary Studies Used

Abdel-Khalek (1988)	Drollas (1984)	Pock (2010)
Akinboade *et al.* (2008)	Eltony (1993)	Ramanathan (1999)
Alves & Bueno (2003)	Eltony & Al-Mutairi (1995)	Ramsey *et al.* (1975)
Archibald & Gillingham (1980)	Gallini (1983)	Reza & Spiro (1979)
Archibald & Gillingham (1981)	Houthakker *et al.* (1974)	Sipes & Mendelsohn (2001)
Baltagi & Griffin (1983)	Iwayemi *et al.* (2010)	Sterner (1991)
Baltagi & Griffin (1997)	Kennedy (1974)	Storchmann (2005)
Bentzen (1994)	Kim *et al.* (2011)	Tishler (1983)
Berndt & Botero (1985)	Kraft & Rodekohr (1978)	Uri & Hassanein (1985)
Berzeg (1982)	Kwast (1980)	Wadud *et al.* (2009)
Crôtte *et al.* (2010)	Lin *et al.* (1985)	West & Williams III (2007)
Dahl (1978)	Manzan & Zerom (2010)	Wheaton (1982)
Dahl (1979)	Mehta *et al.* (1978)	Wirl (1991)
Dahl (1982)	Nicol (2003)	

All studies included in our meta-analysis are listed in Table 1. The oldest study in our

sample was published in 1974 and the most recent in 2011. Energy Economics appears to be the primary outlet for this literature—13 studies, one third of the entire usable literature, were published in Energy Economics, as well as both previous meta-analyses of the elasticity of gasoline demand.

Out of the 202 estimates we collected, 110 correspond to the short-run elasticity and 92 correspond to the long-run elasticity. Summary statistics for these estimates of elasticities are reported in Table 2: the estimates of the short-run elasticity range from -0.96 to 0.08 with the mean estimate reaching -0.23; the estimates of long-run elasticity range from -1.59 to -0.10 with the mean estimate reaching -0.69. Thus the simple averages of the estimates of both the short- and long-run elasticity in our sample are close to those reported by the earlier meta-analyses (Espey, 1998; Brons *et al.*, 2008). If there is publication selection bias, however, these mean values will exaggerate the true elasticity.

Table 2: Summary Statistics

Variable	Observations	Mean	Median	Std. Dev.	Min	Max
Short-run elasticity	110	-0.227	-0.190	0.158	-0.960	0.080
Long-run elasticity	92	-0.691	-0.632	0.332	-1.590	-0.102

Figure 1: Kernel Density of the Estimated Elasticities

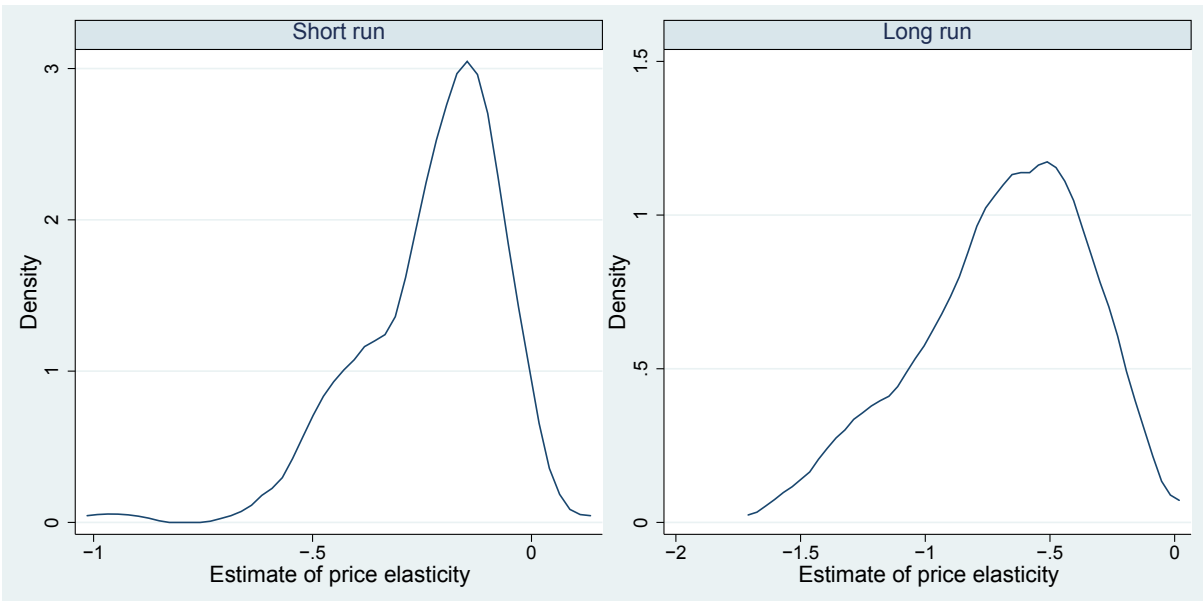

Figure 1 depicts the kernel density of the estimates of short- and long-run elasticites; we use the Epanechnikov kernel in the estimation. It is apparent that both distributions are strongly skewed. Positive estimates of the price elasticity of demand are rarely published, so that the negative (that is, left-hand-side) tails of the distributions get much heavier. This suggests that something more than pure sampling error is driving the distribution of the results: by no means are they distributed normally around a hypothetical true effect, which is also confirmed by

goodness-of-fit tests. Nevertheless, more specialized methods are needed to establish robust evidence for publication bias.

3 Meta-Analysis Methodology

A common method of assessing publication bias is an examination of the so-called funnel plot (Stanley & Doucouliagos, 2010). The funnel plot depicts the estimated elasticity on the horizontal axis against the precision of the estimate of elasticity (the inverse of the standard error) on the vertical axis. The most precise estimates will be close to the true effect, but the less precise ones will be more dispersed; in consequence the cloud of estimates should resemble an inverted funnel. When the literature is free of publication bias the funnel will be symmetrical since all imprecise estimates of elasticity will have the same chance of being reported. While the funnel plot is a useful device, more formal econometric methods are needed to estimate precisely the true elasticity beyond publication bias.

In the absence of publication bias the estimates of semi-elasticities are randomly distributed around the true mean elasticity, e_0. Nevertheless, if some estimates end in the file drawer because they are insignificant or have a positive sign, the reported estimates will be correlated with their standard errors (Card & Krueger, 1995; Ashenfelter *et al.*, 1999):

$$e_i = e_0 + \beta_0 \cdot Se(e_i) + u_i, \quad u_i|Se(e_i) \sim N(0, \delta^2), \tag{1}$$

where β_0 measures the magnitude of publication bias. For example, if a statistically significant effect is required, an author who has few observations may run a specification search until the estimate becomes large enough to offset the high standard errors. Specification (1) can be interpreted as a test of the asymmetry of the funnel plot; it follows from rotating the axes of the plot and inverting the values on the new horizontal axis. A significant estimate of β_0 then provides formal evidence for funnel asymmetry. Because specification (1) is likely heteroscedastic (the explanatory variable is a sample estimate of the standard deviation of the response variable), in practice it is usually estimated by weighted least squares (Stanley, 2005, 2008):

$$e_i/Se(e_i) = t_i = e_0 \cdot 1/Se(e_i) + \beta_0 + \xi_i, \quad \xi_i|Se(e_i) \sim N(0, \sigma^2). \tag{2}$$

Monte Carlo simulations and many recent meta-analyses suggest that this parsimonious specification is also effective in testing the significance of the true elasticity beyond publication bias, coefficient e_0 (Stanley, 2008).

In meta-analysis we have to take into consideration that estimates coming from one study are likely to be dependent. A common way how to cope with this problem is to employ the mixed-effects multilevel model (Doucouliagos & Stanley, 2009), which allows for unobserved between-study heterogeneity. Between-study heterogeneity is likely to be substantial since in our case the primary studies use data from different countries. We specify the model following

Havranek & Irsova (2010):

$$t_{ij} = e_0 \cdot 1/Se(e_{ij}) + \beta_0 + \zeta_j + \epsilon_{ij}, \quad \zeta_j|Se(e_{ij}) \sim N(0, \psi), \quad \epsilon_{ij}|Se(e_{ij}), \zeta_j \sim N(0, \theta), \tag{3}$$

where i and j denote estimate and study subscripts. The overall error term (ξ_{ij}) now breaks down into study-level random effects (ζ_j) and estimate-level disturbances (ϵ_{ij}). The variance of these error terms is additive because both components are assumed to be independent: $\text{Var}(\xi_{ij}) = \psi + \theta$, where ψ denotes within-study variance (that is, between-study heterogeneity) and θ between-study variance. When ψ approaches zero the benefit of using the mixed-effect multilevel estimator instead of simple ordinary least squares (OLS) becomes negligible; we will use likelihood-ratio tests to examine this condition.

The mixed-effects multilevel model is analogous to the random-effects model commonly used in panel-data econometrics. The terminology, however, follows hierarchical data modeling: the model is called "mixed-effects" since it contains a fixed (e_0) as well as a random part (ζ_j). For the purposes of meta-analysis the multilevel framework is more suitable because it takes into account the unbalancedness of the data (the maximum likelihood estimator is used instead of generalized least squares) and allows for nesting multiple random effects (author-, study-, or country-level), and is thus more flexible.

The high degree of unbalancedness of the data in meta-analysis makes a reliable testing of the exogeneity assumptions behind the mixed-effects model difficult; fixed effects in the panel-data sense are generally inappropriate for meta-analysis since some studies report only one usable estimate. We follow the recommendation of an authoritative survey of meta-analyses in environmental and resource economics (Nelson & Kennedy, 2009, p. 358): "The advantages of random-effects estimation [in meta-analysis] are so strong that this estimation procedure should be employed unless a very strong case can be made for its inappropriateness." As a robustness check, however, we also employ OLS with clustered standard errors. Large differences between the estimates based on OLS and on mixed effects may signal a violation of the exogeneity assumptions.

Specification (3) enables us to examine the significance and magnitude of publication bias (β_0) and the *significance* of the true elasticity beyond publication bias (e_0). To examine the *magnitude* of the true elasticity, Stanley & Doucouliagos (2007) recommends an augmented version of (3); this specification is also supported as the best method to correct for publication bias by a survey of meta-analysis methods published in the British Medical Journal (Moreno *et al.*, 2009). The specification is based on the assumption that the relation between standard errors and publication bias in (1) is quadratic; the model is called the Heckman meta-regression (see Stanley & Doucouliagos, 2007, for details). When heteroscedasticity and between-study heterogeneity are taken into account, the specification takes the following form:

$$t_{ij} = e_0 \cdot 1/Se(e_{ij}) + \beta_0 SE + \zeta_j + \epsilon_{ij}, \quad \zeta_j|Se(e_{ij}) \sim N(0, \psi), \quad \epsilon_{ij}|Se(e_{ij}), \zeta_j \sim N(0, \theta), \tag{4}$$

where e_0 measures the magnitude of the average elasticity corrected for publication bias.

4 Results

Figure 2 depicts the funnel plot for the estimates of the price elasticity of gasoline demand. The funnel is heavily asymmetrical: the right-hand part of the funnel is almost completely missing, hence we have a good reason to believe that publication selection bias in this literature is strong. The estimates with the highest precision are negative but close to zero, positive estimates are almost never published, while imprecise negative estimates are published regularly—therefore the average reported estimate is likely to be biased downwards. But will the results hold even when more formal methods are employed to detect publication bias?

Figure 2: Funnel Plot of the Estimated Elasticities

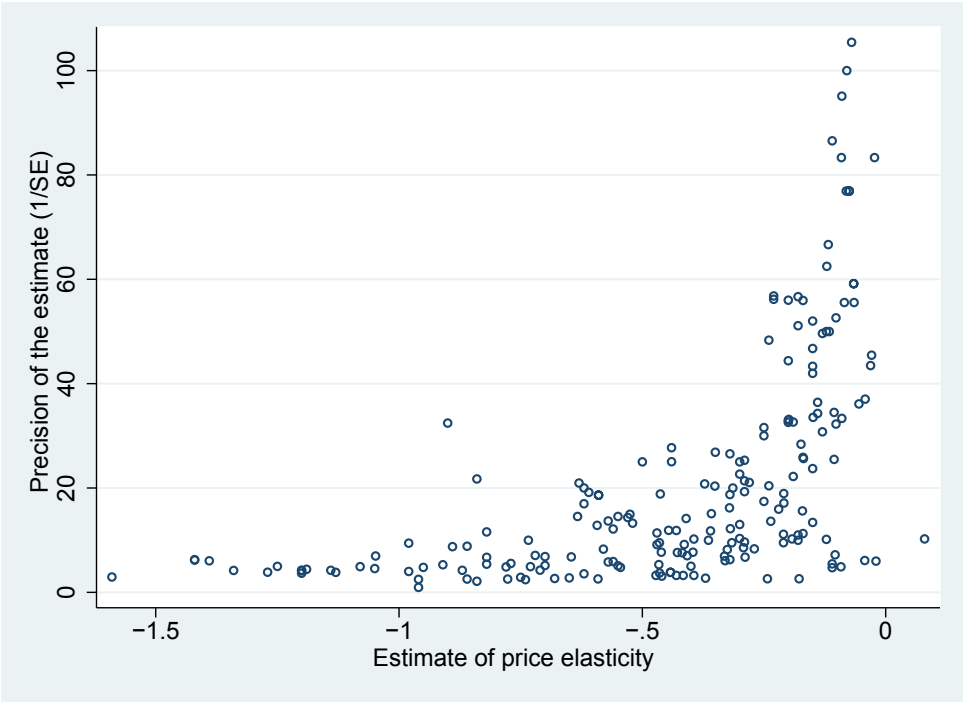

Table 3 summarizes the results of a regression based on specification (3). The regression is estimated separately for the short- and long-run elasticity to obtain precise estimates of these individual elasticities in the later stage of our analysis. Likelihood-ratio tests reject the null hypothesis, which suggests that between-study heterogeneity is substantial, the OLS is misspecified, and the mixed-effects model is thus more reliable. Moreover the differences between the OLS and the mixed-effects model are small, indicating that the exogeneity assumptions behind the mixed-effects model are not seriously violated. We also estimated several nested models with additional author- and country-level random effects, but according to likelihood-ratio tests these models do not significantly differ from the baseline model that only accounts for between-study heterogeneity.

As expected after examining the funnel plot, the meta-regression identifies downward publication bias, significant at the 1% level for all specifications. In all cases the bias is also larger

than two in the absolute value. According to Doucouliagos & Stanley (2008), such magnitude of publication bias is considered "severe" and signals serious selection efforts: if the true elasticity was zero and only negative and significant estimates were reported, the estimated coefficient for publication bias would approach two, the most commonly used critical value of the t-statistic. Publication bias in this literature is hence strong enough to produce a significant average estimate of the effect even if there was none in reality.

Table 3: Test of Publication Bias

	Mixed-effects multilevel		Clustered OLS	
Response variable: t-statistic	Short run	Long run	Short run	Long run
Constant (publication bias)	-2.587***	-2.491***	-2.890***	-3.570***
	(0.465)	(0.707)	(0.595)	(0.808)
$1/SE$	-0.0611***	-0.237***	-0.0651***	-0.189*
	(0.0111)	(0.0393)	(0.0152)	(0.111)
Observations	110	92	110	92
Likelihood-ratio test (χ^2)	21.78***	19.71***		

Notes: Standard errors, clustered at the study level for OLS, in parentheses. Null hypothesis for the likelihood-ratio test: no between-study heterogeneity (that is, the mixed-effects multilevel model has no benefit over OLS). ***, **, and * denote significance at the 1%, 5%, and 10% levels.

Nevertheless, Table 3 also shows that the estimate of the true effect (the coefficient for $1/SE$) is significant at least at the 10% level for all specifications; it is significant even at the 1% level in our preferred mixed-effects model. Thus, on average, both the short- and long-run price elasticity of gasoline demand is statistically different from zero even after correcting for publication bias. To estimate the true average elasticity precisely, we need to employ the Heckman meta-regression proposed by Stanley & Doucouliagos (2007) and corroborated by Moreno *et al.* (2009). This is achieved by estimating regression (4); the results are reported in Table 4. Similarly to the previous case, likelihood-ratio tests suggest that the OLS is misspecified, and we therefore only comment the results of the mixed-effects model.

After correcting for publication bias, our best estimate indicates that the mean short-run elasticity reaches -0.09 with a 95% confidence interval (-0.12, -0.07). The corrected estimate of the long-run elasticity reaches -0.31 with a 95% confidence interval (-0.38, -0.25). This sharply contrasts to the simple uncorrected averages amounting to -0.23 and -0.69: publication bias exaggerates the average reported elasticity more than twofold. For instance, concerning the short-run elasticity, only 18 out of the 110 estimates we collected are smaller in the absolute value than the true average effect (-0.09). Therefore as much as 74 positive (or negative but insignificant) estimates of the short-run price elasticitiy of gasoline were likely not reported because of publication selection. In other words, about 40% of all estimated elasticities may be put into the file drawer.

Table 4: Test of the True Elasticity Beyond Publication Bias

	Mixed-effects multilevel		Clustered OLS	
Response variable: t-statistic	Short run	Long run	Short run	Long run
$1/SE$ (true elasticity)	-0.0913***	-0.314***	-0.120***	-0.307**
	(0.0120)	(0.0334)	(0.0145)	(0.115)
SE	-0.975	-2.396	-4.960*	-9.343***
	(2.094)	(2.668)	(2.558)	(3.054)
Observations	110	92	110	92
Likelihood-ratio test (χ^2)	37.28***	34.45***		

Notes: Standard errors, clustered at the study level for OLS, in parentheses. Null hypothesis for the likelihood-ratio test: no between-study heterogeneity (that is, the mixed-effects multilevel model has no benefit over OLS). ***, **, and * denote significance at the 1%, 5%, and 10% levels.

5 Conclusion

We conduct a quantitative survey of journal articles estimating the price elasticity of gasoline demand. In contrast to previous meta-analyses on this topic, we take into account publication selection bias using the mixed-effects multilevel meta-regression. Publication bias in this area is strong; when we correct for the bias, we obtain estimates of short- and long-run elasticities that are approximately *half*, compared to the results of the previously published meta-analyses and also to the simple mean of all estimates in our sample of literature. If the simple mean reflects our profession's impression about the magnitude of the price elasticity of gasoline demand, the impression exaggerates the true elasticity twofold.

The estimated elasticities corrected for publication bias, -0.09 for the short run and -0.31 for the long run, are average across many countries, methods, and time periods; we report them as reference values. A similar pattern of publication bias, however, is likely to appear in any subset of the literature. Large negative estimates of price elasticities should therefore be taken with a grain of salt.

Concerning future research, authors interested in figures for individual countries may collect more estimates from working papers, dissertations, and other mimeographs, which should provide enough degrees of freedom to estimate the price elasticity of gasoline demand for each country using the methodology described in this paper. Next, since previous meta-analyses suggest that study design may affect results in a systematic way, researchers could define best-practice methodology and estimate price elasticities conditional on such best practice to filter out the effects of misspecifications. Finally, given the number of studies conducted on this topic each year, in the meta-analysis framework it is also possible to test whether the price elasticity of gasoline demand changed during the last decade when the prices of petroleum products surged.

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