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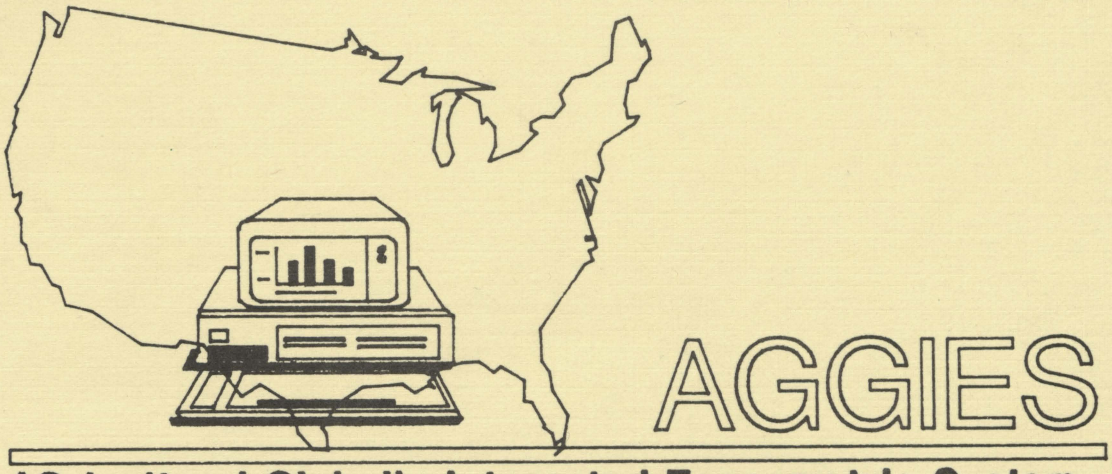

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PRICE DETERMINATION IN STRUCTURAL MODELS: A COMPARISON OF ALTERNATIVE INVERSE DEMAND SPECIFICATIONS

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Abstract

A theoretical framework is proposed to evaluate price determination behavior of alternative inverse demand specifications of structural models. Price impacts of a wheat model to a supply shock indicated that inverse domestic demand and inverse export demand were inappropriate specifications, while inverse stock demand specification generated credible results.

Keywords

Inverse demand, price determination, structural model, shocks, wheat.

Price Determination in Structural Models: A Comparison of Alternative Inverse Demand Specifications

Dean T. Chen and Gerard S. Dharmaratne*

Inverse demand functions have been widely adopted as a price determination mechanism in structural econometric models. Although, the theoretical foundation of inverse demands has been well developed (Waugh; Anderson; Chambers and McConnell; Fox; Heien), and although they have been popularly used in structural models (Meilke and Young; Salathe et al.; Subotnik and Houck; Adams and Behrman), virtually no literature exists on the price determination behavior in structural models with inverse demand specifications.

In structural models with inverse demand specifications, price is expressed as a function of a specific demand e, g., for exports, domestic use, inventory stocks, etc. The price-dependent (inverse) demand function is linked to other demand functions through the market clearance, which balances supply and demand. Quantity changes for other demands affect the price of the commodity through the simultaneous equations solution. Validity and performance of such models are largely dependent on the model's specification and estimated parameters. Price flexibility of the inverse demand function, price elasticities of other demand functions, and demand shares are the key determinants of the price outcome. These relationships provide useful information on the capability and performance of structural models.

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This study explores the implication of this price determination behavior of structural models in three major contexts. First, a theoretical framework is developed for empirical investigation of the influence of price flexibilities, price elasticities, and demand shares on price. Second, the statistical difference of single-equation price solution against structural model price solution is examined. Third, appropriateness of alternative inverse demand specifications is evaluated on the basis of price response behavior to a supply shock and their theoretical merit.

Alternative Inverse Demand Specifications

In inverse demand models, price is explicitly determined through the specific demand function which is normalized on price, i.e., a price-dependent demand function. Thus a structural model can be represented in alternative price-dependent forms depending on which demand function is normalized on price. The basic form of a price-dependent structural model can be expressed as

(1) $$P = f(Q_i; X_i)$$

(2) $$\Sigma_j Q_j = \Sigma_j g_j(P; X_j)$$

(3) $$Q_s = Q_s(\Pi(P); X_s)$$

(4) $$Q_i = Q_s + X_k - (\Sigma_j Q_j)$$

where Q_s refers to quantity supplied and Q with subscripts, i and j, denote quantities of demands, with i for inverse demand, and j for other demand components. X_i, X_j and X_s refer to relevant exogenous variables. Profits are denoted by $\Pi(P)$, and exogenous components in the market clearance identity, such as beginning stocks, imports, etc., are denoted by X_k.

This study examines three commonly used inverse demand specifications. They are:

(1) inverse stock demand model, (2) inverse domestic demand model, and (3) inverse export demand model. A seven-equation simultaneous system of supply, demand, and market clearance identity is presented in Table 1 to describe these alternative forms of price-dependent structural models. The only differences of these models are the price determination equation and the market clearance identity. To satisfy the model solution requirement, the left-hand-side variable of the identity must be the same quantity demand variable of the inverse demand function.

Table 1. Alternative P-dependent (Inverse Demand) Structural Models

	Structural Mode Specification[1]		
	P-dependent Domestic Demand	P-dependent Export Demand	P-dependent Stock Demand
Inventory Demand	$Q_h=Q_h(P; Z_h)$	$Q_h=Q_h(P; Z_h)$	$P=P(Q_h; Z_h)$
Domestic Demand	$P=P(Q_o; Z_o)$	$Q_o=Q_o(P; Z_o)$	$Q_o=Q_o(P; Z_o)$
Export Demand	$Q_x=Q_x(P; Z_x)$	$P=P(Q_x; Z_x)$	$Q_x=Q_x(P; Z_x)$
Feed Demand	$Q_e=Q_e(P; Z_e)$	$Q_e=Q_e(P; Z_e)$	$Q_e=Q_e(P; Z_e)$
Seed Demand	$Q_d=Q_d(P; Z_d)$	$Q_d=Q_d(P; Z_d)$	$Q_d=Q_d(P; Z_d)$
Supply	$Q_s=Q_s(\Pi(P); Z_s)$	$Q_s=Q_s(\Pi(P); Z_s)$	$Q_s=Q_s(\Pi(P); Z_s)$
Market Clearing Identity	$Q_o=Q_s+Q_{h-1}$ $-(Q_e+Q_d+Q_x+Q_h)$	$Q_x=Q_s+Q_{h-1}$ $-(Q_e+Q_d+Q_x+Q_h)$	$Q_h=Q_s+Q_{h-1}$ $-(Q_e+Q_d+Q_x+Q_h)$

1. Q_s refers to quantity supplied, and Q with subscripts o,e,d,x and h refers to demands for domestic consumption, feed, seed, export, and inventory stocks respectively. P and Π refers to farm commodity price and profits, respectively. Z refers to the vector of relevant exogenous variables identified by the subscripts described above, and $Q=Q_o+Q_x+Q_d+Q_e$.

Theoretical Framework

Alternative inverse demand specifications are evaluated by their price response behavior under the condition of an exogenous shock (e.g. a supply shock). The model undergoes price and quantity changes to achieve a new market equilibrium. If the initial market clearance condition is

(5) $$Q_i = Q_s + X_k - (\Sigma_j Q_j)$$

then, after a supply shock of ΔQ_s, the resultant quantity changes should satisfy the following condition,

(6) $$\Delta Q_i + \Sigma_j \Delta Q_j = \Delta Q_s$$

where ΔQ_i is the change in the quantity of the inverse demand i,

ΔQ_s is the exogenous supply shock, and

ΔQ_j is the change in quantity of j^{th} other demand component, where j = 1, ...n.

In the inverse demand function, the price (single equation) impact can be given as

(7) $$\Delta P = ß_i \Delta Q_i \text{ and}$$

(8) $$\Delta Q_i - \frac{\Delta P}{\beta_i}$$

where ΔP is the single-equation price impact, and $ß_i$ ($= \partial P/\partial Q_i$) is the structural coefficient of quantity demand in the inverse demand function.

From equation (2), a quantity change in other demand component j can be given as

(9) $$\Delta Q_j = ß_j \Delta P.$$

where $ß_j$ ($= \partial Q_j/\partial P$) is the structural coefficient of price of the j^{th} demand function. Summing (9) over j yields

(10) $$\Sigma_j \Delta Q_j = \Delta P \, \Sigma_j \beta_j \ .$$

Substituting (8) and (10) for ΔQ_i and $\Sigma_j \Delta Q_j$ in (6) we get

(11) $$\frac{\Delta P}{\beta_i} + \Delta P \sum_j \beta_j = \Delta Q_s$$

From (11) ΔP can be written as

(12) $$\Delta P = \frac{\Delta Q_s}{\frac{1}{\beta_i} + \sum_j \beta_j}$$

where $i \neq j$, and $j = 1,\ldots,n$ and n is the number of quantity-dependent demand functions in the model.

Equation (12) shows the structural model price impact as a function of the structural coefficients of the demand functions in the model. Substituting these structural coefficients by price elasticities (ξ_j), and price flexibilities (η_i), equation (12) can be rewritten as

(13) $$\Delta P = \frac{\Delta Q_s}{K\left(\frac{w_i}{\eta_i} + \sum_j \xi_j w_j\right)}$$

where w_i and w_j are demand shares, $w_i = Q_i/Q$ for inverse demand, $w_j = Q_j/Q$ for other demands, and $K = Q/P$.

Equation (13) reveals important behavioral aspects of inverse demand structural models in generating price impacts of exogenous shocks. The denominator of (13) has two components. The first term in the denominator represents the single equation price impact of the structural model. The second term in the denominator represents the feedback effect generated by other demand functions. In the absence of the second term of the denominator, equation (13) reduces to equation (7). Equation (7) represents the price impact of inverse demand function if Q_i is shocked by an amount equal to ΔQ_s. Thus the structural model price impact can be partitioned into: 1) a single-equation price impact which is determined by the inverse of the price flexibility weighted by the demand share of the inverse demand, and 2) a feedback effect generated by the price elasticities of other demand functions weighted by their respective demand shares.

When the price elasticities of other demands approach zero, the feedback effect disappears and the structural model solution approaches the single-equation solution. When the price flexibility of the inverse demand approaches zero, the first term in the denominator becomes large. In this case the single-equation price impact dominates the feedback effect. Under this circumstance, the single-equation price impact and the structural model price impact may not be much different. On the other hand, a large price flexibility, large price elasticities or their combinations may cause the structural model price impact to be significantly different from the single equation price impact.

Denoting single-equation price impact in equation 7 as $(\Delta P_{(i)})$, its variance is

$$(14) \qquad var(\Delta P_{(i)}) = (\Delta Q_s)^2 \, var(\beta_i)$$

where $\Delta Q_i = \Delta Q_s$ = a constant in the single equation case.

From equation (12) variance of the structural model price impact ΔP is

$$(15) \qquad var(\Delta P_{(i)}) - var\left[\frac{\Delta Q_s}{\left(\frac{1}{\beta_i} + \sum_j \beta_j\right)}\right]$$

The variance term given in (15) can be derived by using an approximation formula[1] (Wallace and Silver), i.e., using a first order Taylor Series expansion such as by Dorfman et al.

Now, it is possible to statistically test whether the single equation price impact is significantly different from the final price impact. The hypothesis of interest is

$$H_0 = \Delta P_{(i)} - \Delta P = 0$$

$$H_a = \Delta P_{(i)} - \Delta P > 0 .$$

The test statistic is

$$z = \frac{\Delta P_{(i)} - \Delta P}{\sqrt{[var(\Delta P_{(i)}) + var(\Delta P) - 2Cov(\Delta P_{(i)}, \Delta P)}} \tag{16}$$

where var($\Delta P_{(i)}$) and var(ΔP) are given by (14) and (15), respectively. The test statistic is expected to be asymptotically distributes as a N(0,1). The covariance of $\Delta P_{(i)}, \Delta P$ is given as

$$Cov(\Delta P_{(i)}, \Delta P) = \rho \sigma_{\Delta P_{(i)}} \sigma_{\Delta P} \tag{17}$$

where $\sigma_{\Delta P(i)}$ and $\sigma_{\Delta P}$ are standard errors of $\Delta P_{(i)}$ and ΔP respectively, and ρ is the correlation coefficient between $\Delta P_{(i)}$ and ΔP.

Empirical Results

For empirical analysis a complete sectoral model of wheat was used. The structural difference across the models is the maintained hypothesis on price determination. In all models wheat price is determined through a unique price-dependent demand function. The models were estimated using annual data from 1973 to 1987. The estimated models are presented in Table 2. Specification and estimated price elasticities and price flexibilities are similar to those of previous modeling work (Bailey). Statistical properties of all the demand

Table 2. Estimated Alternative Q-dependent and P-dependent Specifications.

Supply and Demand Equations

Inventory Demand

$$Q_h = \underset{(3.79)}{-801.40\, P} - \underset{(0.78)}{577.88}\, (Q_h / Q_t)^e - \underset{(4.0)}{2631.32}$$

R. Sq.=0.94 D.W. = 1.34

Domestic Demand

$$Q_o = \underset{(1.33)}{-14.63\, P} + \underset{(6.12)}{0.45\, I} - \underset{(3.18)}{280.00}$$

R. Sq.=0.94 D.W. = 1.36

Export Demand

$$Q_x = \underset{(1.25)}{-103.92\, P} + \underset{(6.95)}{0.76\, Q_{x,-1}} + \underset{(0.54)}{267.19\, X} + \underset{(1.59)}{1.75\, P^w} + \underset{(0.24)}{92.06}$$

R. Sq.=0.80 D.W. = 2.14

Seed Demand

$$Q_d = \underset{(1.47)}{3.53\, P} + \underset{(3.56)}{1.33\, A} - \underset{(0.71)}{12.17}$$

R. Sq.=0.51 D.W. = 1.5

Supply

$$Q_s = Y \times A$$

Price Equation and Market Clearance Identity*

P-dependent Stock Demand Model

Price

$$P = \underset{(3.87)}{-0.00068\, Q_h} - \underset{(4.08)}{1.16\, (Q_h / Q_t)^e} - \underset{(21.93)}{3.16}$$

R. Sq.=0.92 D.W. = 1.79

Market Clearance

$$Q_h = Q_{h-1} + Q_s - Q_o - Q_d - Q_x$$

P-dependent Domestic Demand Model

Price

$$P = \underset{(3.82)}{-0.0113\, Q_o} + \underset{(1.74)}{0.0029\, I} + \underset{(7.07)}{0.915\, D} - \underset{(8.34)}{5.935}$$

R. Sq.=0.95 D.W. = 2.45

Market Clearance

$$Q_o = Q_{h-1} + Q_s - Q_d - Q_x - Q_h$$

P-dependent Export Demand Model

Price

$$P = \underset{(1.15)}{-0.0005\, Q_x} - \underset{(1.23)}{4.05\, X} + \underset{(3.23)}{10.82\, P^w} + \underset{(2.49)}{8.01}$$

R. Sq.=0.68 D.W. = 1.68

Market Clearance

$$Q_x = Q_{h-1} + Q_s - Q_d - Q_o - Q_h$$

t - statistic is given in parentheses. D.W. is the Durbin-Watson Statistic.
P = farm wheat price (deflated), $(Q_h / Q_t)^e$ = expected stock/demand ratio, total demand $Q = (Q_o + Q_e + Q_d + Q_x)$, I = disposable income (deflated), $Q_{x,-1}$ = lagged exports, X = exchange rate, P^w = world wheat price, A = acreage, Y = yield per acre, and D is defined as 1 if period is 1973-1975 and 0 otherwise.
* Price in Q-dependent models are implicit equations derived from the corresponding estimated demand functions given above. Price in P-dependent model is directly estimated.

functions in the model show a good fit, with high R^2 and expected signs across different specification. Most of the estimated coefficients are statistically significant at the 95% confidence level.

Supply Shock Simulation

Due to adverse weather conditions in 1988, there was a decline in yield per acre for wheat. Thus, 1988 wheat yield per acre (Y) was shocked using a normal weather condition against the actual. The normal weather yield of 38.01 bushels per acre was obtained through a trend analysis of wheat yield [1]. The supply shock induced by an increase in yield per acre (from the actual 34.1 bushels per acre to 38.04 bushels per acre) affects price in each model. While the total wheat production is projected to increase by 210 million bushels in all models, this increase generates varying price impacts across models. Price impact is highest in the P-dependent domestic demand with \$ -1.40. The next largest impact is in the P-dependent stock demand model with an impact of \$-0.47, followed by P-dependent export demand which show the smallest price impact of \$-0.29.

It is essential to show how price flexibility, price elasticities, and the demand shares cause differential price impacts between the single-equation approach and structural model approach for price determination. Several observations are important for understanding the behavior of inverse demands in structural models in generating price impacts due to exogenous shocks. The structural model impact consists of two components: 1) a single-equation price impact, and 2) a feedback effect generated by other demand functions. The

[1] The estimated trend function for wheat yield per acre with t-value in parentheses is

$$Y_a = -1299.22 + 0.673\ \text{TREND}$$
$$(-5.894) \quad (5.744)$$
$$R^2 = 0.73 \quad \text{R Bar Sq } 0.71 \quad \text{D.W.} = 1.62\,.$$

single-equation component is determined by the ratio $w_i/\acute{\eta}_i$. The smaller the value of $w_i/\acute{\eta}_i$, the larger the effect of the single-equation component. In the three models tested, price-dependent domestic demand has the smallest ratio (largest $\acute{\eta}_i$) and hence the largest single equation component of $8.07 (Table 3).

Table 3. The Relationship of Price Elasticities, Price Flexibilities, and Demand Shares to Price Impacts.

	P-dependent Domestic demand	P-dependent Export Demand	P-dependent Stock Demand
w_i	0.24	0.46	0.23
$\acute{\eta}_i$	-4.56	-0.42	-0.50
$w_i/\acute{\eta}_i$	-0.05	-1.09	-0.46
$\Sigma_j(\xi_j w_j)$	-0.30	-0.21	-0.30
$w_i/\acute{\eta} + \Sigma_j(\xi_j w_j)$	-0.34	-1.30	-0.76
$\Delta P_{(i)}$	-8.07 (0.04)	-0.36 (0.09)	-0.62 (0.62)
ΔP	-1.40 (0.06)	-0.29 (2.19)	-0.47 (0.09)
$\Delta P_{(i)} - \Delta P$	-6.67 *	-0.07	-0.15 *

Standard errors of estimates are given in parenthesis.
* indicate differences which are significant at 95% level.

The significance of the single-equation price impact in a structural model solution is twofold. First, the single-equation component of price impact sets the upper bound on the structural model price impact. As stated earlier in the paper, when price elasticities of all other demand functions approach zero, the second term in the denominator of equation (13) disappears and the structural model price impact approaches the single-equation price impact. Second, the single-equation price impact also influences the magnitude of the feedback effect. The impact of price flexibility on the feedback component is given as the derivative of $\Sigma_j(\xi_j w_j)$ with respect to $\acute{\eta}_i$ in equation (17).

$$\frac{\partial(\Sigma_j \xi_j w_j)}{\partial \eta_i} = \frac{w_i}{\eta_i^2} > 0. \tag{17}$$

Equation (17) implies that when the price flexibility of the inverse demand increases, i.e., when the single-equation price impact increases, the feedback effect also increases. In Table 3, P-dependent domestic demand and P-dependent stock demand have the same magnitudes of feedback effect ($\Sigma_j(\xi_j w_j)$) of 0.3. However, the P-dependent domestic demand has a single-equation price impact much greater than that of the P-dependent stock demand model. Accordingly, the feedback is larger in the P-dependent domestic demand model. In the P-dependent domestic demand model, the structural model price impact is only 17% of the single-equation price impact as compared to 76% in the P-dependent stock demand model.

The interrelationships have important implications in the construction and application of structural models. If the price flexibility of the inverse demand function is small or if the price elasticities of the other demand functions are small, it is possible that the structural model solution may not be significantly different from the single-equation solution. Of the three models tested, the P-dependent export demand model has the smallest single-equation price impact (largest $w_i/\acute{\eta}_i$) and the smallest feedback effect (smallest $\Sigma_j(\xi_j w_j)$).

To test the difference between single equation and structural model price impacts require knowledge of the correlation coefficient of ρ, which by theory is $-1<\rho<1$. However from equation (12) it is clear that the $\Delta P_{(i)}$ and ΔP move in the same direction. Therefore, in this case $0<\rho<1$. To perform a test we take $\rho=1$. Under this condition single equation price impact is not significantly different from the structural model price impact in P-dependent export demand (at a 95% confidence level). Clearly the true $\rho<1$, thus would draw the same conclusions on significance of price impacts of all models.

Appropriate Structural Model Specifications

Comparison of single-equation and structural model price impacts constitutes only one aspect of the selection of appropriate structural models. There are two additional aspects that need to be considered. If the structural model price impact is significantly different from the single-equation price outcome, the question still remains as to the acceptability of the price response to the exogenous shock (Chen and Dharmaratne). The price impact may need to be further evaluated in accordance with expert opinion, a priori experience, or by analytical methods such as a Bayesian approach. Due to the nature of this study, the issue is not elaborated. Empirical results suggest, for example, that the P-dependent domestic demand model demonstrates an unrealistically large price impact of a supply shock of 210 million bushels.

The next issue to consider is the theoretical merit of the price impacts. In a general equilibrium setting in inverse demand functions, a supply shock (i.e., a supply increase) would result in lower prices and higher quantities. However, in structural models, when a inverse demand function is used for price determination, the effect of a supply shock in the process of price determination can be traced. Increase in yield per acre first increases total supply. Total supply is an argument on the right-hand side of the market clearance identity. To satisfy market clearance, the quantity on the left-hand side of the identity should increase by the same amount as the supply shock. The quantity on the left-hand-side in the market clearance identity is always the quantity demand of the inverse demand function. Increased quantity demand thus results in a price decrease due to the negative coefficient of quantity of the inverse demand function. The final outcome is that the exogenous supply shock is transmitted into the price-dependent demand function. Therefore, for a P-dependent demand function to be theoretically valid within a structural model setting, such a quantity movement along the inverse demand function should be consistent with the theoretical expectation of price movements.

Every demand function represents the behavior of the decision maker who sets the value of a particular demand component (endogenous variable) in response to stimulus provided by their perceptions of the values of other exogenous variables (Fisher). In the inverse demand function the response variable is price while the stimuli is the quantity. For domestic consumption demand and export demand this does not constitute an acceptable cause-effect relationship.

In P-dependent stock demand, the supply shock transmission to the inverse demand function is the same as in inverse domestic and export demands. Here the increase supply increases the level of stock and decreases price. However, unlike the case of inverse domestic demand and inverse export demand specifications, in this case the cause-effect is logically meaningful. From an economic standpoint, increased supply accumulates inventory stocks. To clear the market, demand for other uses needs to increase. To increase demand for domestic use, export, feed, etc., the price level goes down, and the market clearance is achieved. Thus, increased stocks induce a price decrease.

Theoretical merit of the model along with simulation results can be utilized to determine the appropriateness of the inverse demand structural models tested. Of the three P-dependent structural model specifications, P-dependent domestic demand and P-dependent export demand do not constitute meaningful price-quantity relationships for the supply shock. On the other hand, the structural model price impact of the P-dependent export demand model is not significantly different from the single-equation price impact. For the P-dependent domestic demand model, the structural model price impact, though significantly different from the single equation price impact, appear to be unrealistically large. Thus the P-dependent stock demand model qualifies as the only valid structural model for wheat.

Conclusions

The most popular structural model specifications are P-dependent models. In P-dependent models the inverse demand function which identifies the price determination plays a key role in the performance of the model. Thus, application of P-dependent models requires careful attention to specification and solution issue to guarantee the theoretical consistency of the model, as well as to obtain desirable solution outcomes.

We decomposed the structural model price impact into a single-equation price impact and a feedback effect. When the price flexibility of the inverse demand is small and/or when the price elasticities of the demand functions are small, the single-equation solution may not be significantly different from the structural model solution. Of the three models tested, P-dependent export demand does not generate significantly different structural model price impacts compared to a single-equation solution. Using this information along with the reliability of the price impacts and their theoretical consistencies suggests that only P-dependent stock demand appears to be the credible structural model specification.

In this research, we concluded that inverse domestic and export demands are not suitable; however, more research is necessary on these demand functions as to develop theoretically valid and empirically acceptable inverse demand specifications. Further sensitivity analyses need to be performed on price elasticities and price flexibilities in relation to price impacts. This is particularly important for agricultural commodities, as elasticities and flexibilities are often expressed in ranges rather than as point estimates. Sensitivity analyses could be used as validity checks for such estimates, as price impacts are more readily observable than price elasticities and flexibilities.

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