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Construction Elasticities and Land Availability: A Two-stage Least-squares Model of Housing Supply Using the Variable Elasticity Approach

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Summary. This paper uses data at English local authority district level to construct a simultaneous equation model of housing construction that compares elasticities of supply between two cross-sectional periods—1988 (boom) and 1992 (slump)—using the variable elasticity approach. Econometric issues raised by earlier supply studies are discussed and tested for. The paper also discusses the rationale for, and tests the existence of, a backward-bending supply relationship, and finds that supply is concave in both periods, and 'bends backwards' during the boom. Evidence of a structural break between boom and bust is found, producing average price elasticities of supply noticeably smaller in the boom (0.58) than in the slump (1.03), with considerable variation across disticts. Land supply elasticities are found to be more stable over time, and marginally greater in the boom (0.75) than in the slump (0.71). The paper also calculates second partial derivatives based on the whole demand–supply system to obtain estimates of the impact of land release on new house prices.

1. Introduction

One of the most underresearched aspects of the UK housing system is the analysis of housing supply and its responsiveness to changes in prices and inputs. Certainly the modest volume of research does not reflect its importance in the economic system. In particular, the responsiveness of supply to price changes will be a key factor in influencing the effect of demand shifts on price. A rise in price following a shift of demand should provoke a positive response from suppliers, resulting in a subsequent fall in price. The extent of this price adjustment will depend on the magnitude of the price elasticity of supply, which in turn depends (*inter alia*) upon the price and availability of inputs, factor substitutability, future expectations of housing demand, construction lags, ease of entry and exit, and the size and structure of the building industry. If the elasticity of supply over the relevant range of the supply curve is high, then prices will return to previous values over a relatively short time-frame. If supply is inelastic, this adjustment period may be so long that supply never responds adequately within the given policy and cyclical time-frame, and the result is that prices are largely demand-driven and highly cyclical. This has implications for the macroeconomy via the impact of house price

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booms and equity withdrawal on the consumption function (see Carruth and Henley, 1990).

Estimates of new housing construction supply elasticities that have been computed for the UK (Whitehead, 1974; Mayes, 1979; Meen, 1996) have tended to be considerably lower than the estimates from US studies (Muth, 1969; Follain, 1979). One commonly suggested explanation is that housing supply in the UK is particularly constrained by land availability problems, and this is due in part to a sluggish planning system.

This paper aims to consider some of the econometric issues raised by earlier supply studies, and to use the unique data set compiled by Bramley (1993a, 1993b) to construct an alternative, more parsimonious model which produces more rigorous estimates of construction elasticities, and to simulate the effect of changes in the quantity of land supply on prices using the outstanding planning permissions variable. In particular, the problem of simultaneity and how it has been handled in models of housing supply is examined, along with the issue of over-identification, which occurs when a large numbers of exogenous variables are used in a simultaneous equation system. The paper is also the first attempt in the UK context to test for the existence of backward-bending supply in the market for new houses using a variable elasticity (VE) estimation approach. Department of the Environment data on private house-starts are used to construct a housing supply system with endogenous prices, estimated by two-stage least squares on cross-sectional samples for 1988 and 1992. Evidence is found to support the view that supply was backward-bending during the boom, and concave in prices both in 1988 and 1992, and in the pooled regression model. Land availability is found to be the most statistically significant explanatory variable throughout. The paper also calculates variable elasticities of supply for both years.

The remainder of the paper is structured as follows. Section 2 considers the theoretical rationale for backward-bending supply. Section 3 discusses the problems associated with simultaneity and evaluates the methods that have been adopted in the housing supply literature. Other problems surrounding specification of housing supply functions are discussed in section 4 including: the use of input prices, pros and cons of cross-sectional analysis, and heteroscedasticity issues. Section 5 describes the data set, and section 6 outlines the econometric methods used, along with the procedure for calculating elasticities. The main regression results are presented in section 7, and alternative regressions for the purpose of comparing OLS and 2SLS, and the effect of including construction costs, are discussed in section 8. Section 9 concludes.

2. Backward-bending Supply

Mayo and Sheppard (1991) provide theoretical justification for the feasibility of a backward-bending supply curve. They show that stochastic ‘development control’ (i.e. planning restrictions) can cause large increases in demand to

> generate large increases in price but with very little change in the quantity of housing constructed. The apparent low elasticity of supply will, however, not give a reliable prediction of the response of the market to a more modest increase in demand (Mayo and Sheppard, 1991, p. 16).

The rationale for this phenomenon is based upon an extension of Titman’s (1985) model which showed that vacant land can be viewed as an option to buy one of a range of housing units in the future. Holding land vacant is valuable because it permits the developer to wait until some of the uncertainty regarding future states of the world is resolved, and this is particularly valuable in the construction industry where, once a firm has committed itself to a programme of development, it is very difficult to reverse direction. Development controls increase the uncertainty surrounding future courses of action, and this reinforces the value of holding land vacant, to the extent that it may actually exceed the value of developed land. This has the important corollary that "housing will not be supplied if the value of the land exceeds the value if developed" (p. 6). Thus,

> an increase in the variance of planning delay, holding the expected duration of delay constant, will increase the value of vacant land and decrease the supply of housing in the current period (Mayo and Sheppard, 1991, p. 12).

Moreover, a rise in the price of housing, P, increases both the profit from immediate development π_0 and the value of vacant land V_0. Given that housing is only supplied when $\pi_0 > V_0$, if the increase in V_0 from the house price rise is greater than the increase in π_0 (i.e. $\partial V_0/\partial P > \partial\pi_0/\partial P$) to the point where $\pi_0 > V_0$, then no housing is supplied, resulting in a backward-bending supply curve for the industry. The greater the level of uncertainty due to factors such as development controls, the lower the cut-off price at which supply becomes backward-bending.

Uncertainty about future events may produce a negative relationship between price and output through a more straightforward mechanism, if price and output decisions are seen in a time-series context. Assume that suppliers base their beliefs about future prices on (local) past price behaviour, and that past (local) prices have followed a strong cyclical pattern. Assume also that there is a delay δ between the start and completion of a house structure, then it is conceivable that there will be some cut-off price P_t^* beyond which future prices will be expected to fall. So, the number of starts may become negatively related to current prices during a boom because output decisions will be based on prices expected in period $t + \delta$. This is essentially Evans' point when he says that,

> Housebuilders, even if allocated more land to build on, would be likely to hold back if they could foresee that the prices of land and of housing were likely to fall (Evans, 1996, p. 583).

If expectations are unbiased, so that on average firms correctly predict $P_{t+\delta}$ then starts will be negatively correlated with price towards the peak of the boom and during most of the downswing—depending on the frequency of the cycle compared with δ—and positively related towards the bottom of the slump and most of the upswing; but completions will be positively related to price throughout. If, however, there is a prolonged boom, as during the 1980s, then construction firms may find that they have been unnecessarily pessimistic at P^*_t, resulting in completions falling at time $t + \delta$ while prices are still rising.

A third rationale for supply failing to follow its traditional neoclassical upward-sloping pattern arises from the Sraffian critique of Marshallian supply analysis (additional explanations are surveyed in Shea, 1993). Neoclassical theory usually assumes that commodities can be identified either as outputs or inputs, or as intermediate goods, defined as "partly finished goods that form inputs to the production process of another firm or industry" (Ozanne, 1996, p. 749). If, however, an intermediate product constitutes an input to the production process of the *same* firm or industry (i.e. a 'produced input'), then it has been shown that perverse supply responses to price increases may result (see Ozanne, 1996). Although the empirical relevance of this anomaly has been confirmed by Ozanne (1996) in the context of the agricultural sector, it is not so obvious how the result may hold in the housing construction context.[1] One possibility is that factory-produced components produced by construction firms, such as windows and doors, are sold as finished products to consumers, as well as constituting important inputs to the construction industry. A rise in the price of the produced inputs—windows and doors—may adversely affect the supply of the compound output—housing. A similar effect may result over a longer time-period with respect to use of premises by construction firms, although this is likely to be a less marked effect given the low 'business-premises intensity' of property construction. Also, the durable nature of real estate gives rise to large secondhand markets in commercial premises.

It is beyond the scope of this paper and the data available to construct a complete econometric model along the lines of Mayo and Sheppard's theory of supply under planning uncertainty, or to develop a time-series system to analyse whether local starts lead local prices during the peak of a boom, or indeed to develop a Sraffian model of produced inputs along the lines of Ozanne (1996). Nevertheless, the necessary conditions for the existence of a backward-bending supply curve can be tested simply by including a squared term for price in the regressions and making a simple application of calculus. Assuming price is plotted on the horizontal axis, a zero coefficient on the squared term implies that the supply curve is a straight line; a negative coefficient indicates that the supply curve is concave (a necessary condition for backward-bending supply); and a positive coefficient points to a convex curvature. If the curve is indeed concave, then the turning-point of the curve can be identified where the first partial derivative with respect to price is zero. And so supply becomes backward-bending if the local maximum occurs within the sample range of price values. (For 1988, the maximum price in the sample was 128.3, and for 1992, 84.49. Thus if the price at which $\partial Q/\partial P = 0$ is less than 128.3 for the 1988 OLS regression, then supply is backward-bending; similarly for 1992.)

As well as being a means for testing the backward-bending hypothesis, concavity of the output–price relationship may also be an important specification issue. If the relationship between new construction and price is indeed non-linear, then previous supply models have effectively fitted linear regressions to a concave relationship, producing results that are potentially spurious. There is no apparent rationale for supply being convex in prices, and so regressions which indicate this result are also likely to be misspecified.

3. Dealing with Simultaneity

One of the innovations of Bramley's (1993a, 1993b) work was to develop a 'lagged response model' in an attempt to provide an alternative way of overcoming the econometric problems related to the simultaneous determination of price and quantity. Bramley notes that,

> The preferred 'lagged response' model ... is one where current demand factors along with current output determine price [equation [B1]], while output is determined by lagged values of price, land availability, construction costs and so on [equation [B3]]. The assumption of lags on the supply side is both plausible and convenient, since it avoids recourse to the special econometric procedures associated with simultaneous equation systems (e.g. instrumental variables). The simultaneous equation approach has also been explored, but demand-side models for quantity work much less well than demand-side models for price (Bramley, 1993a, p. 13).

However, this approach may be open to criticism because simply lagging the price effect only pushes the simultaneity problem back to the previous period, and so does not genuinely deal with the simultaneity problem. The basic version of his supply equation [B3][2] is as follows:

$$Q = b_0 + b_1P_{t-1} - b_1C_{t-1} + b_2L_{St-1} + b_3L_{Ct-1} + b_4L_{Pt-1} + \varepsilon_S$$

where, variable definitions are given in Table 1 and in the Appendix. (Note that, in using price net of costs in the supply function, this approach implicitly assumes that the coefficient on price is the exact negative of the coefficient on costs, which is a restriction which should be tested for.)

In order for the lagged response model to bypass the simultaneity problem, one has to effectively assume P_{t-1} to be exogenous, which is an unrealistic assumption, particularly if price is modelled as a demand relationship [B1] of the form:

$$P = a_0 + a_1Q + a_2D_S + a_3D_L + \varepsilon_D$$

(again, variable definitions are given in Table 1 and in the Appendix). Even substituting

Table 1. Data definitions and sources

Variable name	Definition/Source
P	Real house prices for a standard new house, £000s, at 1987 values (NHBC)
Q	Private house-starts (LHS)
L	Land stock with outstanding planning permissions (for private/general housing)
Z	Percentage economically active in social classes I and II (Census)
U	Rates of unemployment as a percentage of the total resident economically active population (NOMIS)
D	Percentage of residential development on land in former urban uses (predicted by Bramley)
C	Estimated cost of rebuilding standard house (Bramley 1993a, 1993b)

once for the lagged endogenous variable, reveals substantial underlying problems.

Substituting [B1] in [B3] yields:

$$\begin{aligned} Q = {} & b_0 + b_1(a_0 + a_1 Q_{t-1} + a_2 D_{St-1} + a_3 D_{Lt-1} \\ & + \varepsilon_{Dt-1}) - b_1 C_{t-1} + b_2 L_{St-1} \\ & + b_3 L_{Ct-1} + b_4 L_{Pt-1} + \varepsilon_S \\ = {} & b_0 + b_1 a_0 + b_1 a_1 Q_{t-1} + b_1 a_2 D_{St-1} \\ & + b_1 a_3 D_{Lt-1} - b_1 C_{t-1} + b_2 L_{St-1} \\ & + b_3 L_{Ct-1} + b_4 L_{Pt-1} + v_1 \end{aligned}$$

where, $v_1 = \varepsilon_S + b_1 \varepsilon_{Dt-1}$

Thus the error term in the reduced form equation for Q contains b_1 and so the error term is not independent of the explanatory variables. This leads to OLS providing inconsistent estimates of the structural parameters. One could quite legitimately substitute for Q_{t-1} last periods supply function, to yield:

$$\begin{aligned} Q = {} & b_0 + b_1 a_0 \\ & + b_1 a_1 (b_0 + b_1 P_{t-2} - b_1 C_{t-2} + b_2 L_{St-2} \\ & + b_3 L_{Ct-2} + b_4 L_{Pt-2} \\ & + \varepsilon_{St-1}) + b_1 a_2 D_{St-1} + b_1 a_3 D_{Lt-1} \\ & - b_1 C_{t-1} + b_2 L_{St-1} + b_3 L_{Ct-1} + \\ & b_4 L_{Pt-1} + v_1 \\ = {} & b_0 + b_1 a_0 + b_1 a_1 b_0 + b_1 a_1 b_1 P_{t-2} \\ & - b_1 a_1 b_1 C_{t-2} + b_1 a_1 b_2 L_{St-2} \\ & + b_1 a_1 b_3 L_{Ct-2} + b_1 a_1 b_4 L_{Pt-2} + \\ & b_1 a_2 D_{St-1} \\ & + b_1 a_3 D_{Lt-1} - b_1 C_{t-1} + \\ & b_2 L_{St-1} + b_3 L_{Ct-1} + b_4 L_{Pt-1} + v_2 \\ v_2 = {} & \varepsilon_S + b_1 a_1 \varepsilon_{St-1} + b_1 \varepsilon_{Dt-1} \end{aligned}$$

which further compounds the simultaneity problem. Thus the endogeneity of output and price is not removed when a lagged response is introduced, but merely results in a domino effect originating in the infinite past. To assume that this process had its definitive start in the recent past, such as 1986/87, would be a rather heroic assumption. Supply estimates based on this approach are likely to be inconsistent due to simultaneity (see Maddala, 1992, ch. 9, and Greene, 1993, ch. 20).

3.1 Identification Problems

Even if assumptions regarding the exogeneity of lagged endogenous variables hold, the construction of complex systems of equations is vulnerable to overidentification problems. An example of this is given in the Appendix, where a system of seven simultaneous equations with lagged endogenous variables (based on Bramley, 1993a) is shown to suffer from considerable overidentification in each equation. Overidentification implies that it is possible to arrive at multiple estimates of the same parameter from the estimated system of equations, and there is no assurance that these will be the same; neither is there any method of determining which estimate is the most accurate. Consequently, one of the aims of the modelling strategy adopted below is to ensure that the equation of most interest (in this case, the supply function) is exactly identified, even if periphery equations are overidentified (such as the demand function).[3]

3.2 *Indirect Least Squares vs Two-stage Least Squares*

The most common method of dealing with the simultaneous determination of housing supply/demand and price in the housing supply literature has been to use indirect least squares (ILS). Authors such as Follain (1979) have constructed simultaneous equation models of demand and supply and then employed previously computed estimates of the elasticity of demand to derive supply elasticities from the estimated reduced form parameters. ILS has a number of drawbacks, however. First, it soon becomes very cumbersome if there are more than a few regressors; and, secondly, it implies strict limitations on the values of coefficients.

A more flexible and less cumbersome approach is to use two-stage least squares, not often applied in the housing supply elasticity literature (a UK exception is Whitehead, 1974), but the dominant method in the non-housing-supply econometric literature for dealing with simultaneity. This effectively takes the best possible combination of available instruments by regressing all right-hand side endogenous variables on all exogenous variables in the system; the predicted values of which are used to replace the endogenous variable in the original structural equation, which is then estimated by OLS. It has been shown that the error term is not correlated with the composite instrument, and so the two-stage least-squares estimator is consistent.[4]

4. Other Theoretical and Specification Issues

4.1 *Construction Costs and Misspecification*

A criticism that has been levelled at a number of housing supply studies (studies such as de Leeuw and Ekanem, 1971; Follain, 1979; Bramley, 1993a, 1993b; Mayo and Sheppard, 1996) is the common practice of including input costs in the supply equation. It is argued that factor price terms should not be included in the estimated supply equation on the basis that the same exogenous factors which drive demand shifts will also influence factor prices, producing simultaneity bias. Employing a rather different argument, but arriving at what is essentially the same conclusion, Olsen (1987, p. 1018) notes that, because long-run supply price will equal minimum long-run average costs,

> a properly specified relationship explaining long-run supply price will contain either the quantity of the good, or input prices, but not both.

Indeed, if the function relating input prices and supply price is specified correctly, Olsen (1987, p. 1018) reasons that

> the coefficient of quantity in their relationship is zero regardless of whether the long-run supply curve is upward sloping or completely elastic. Therefore, the estimated coefficient of the quantity of housing service tells us nothing about the elasticity of the long-run supply curve for this good.

Consequently, construction costs are omitted from the main regression equations listed below (regressions 1–6), and misspecification from including costs is tested for by comparing these results with equations with costs included (regressions 16–27). Introduction of an instrument for costs did not alleviate the problems encountered.

4.2 *Cross-sectional Ambiguities*

Most empirical estimates of supply functions have concentrated on long-run functions, because

> there are infinitely many short-runs and there is no reason to believe that any two markets (or the same market at two points in time) have the same short-run supply curve (Olsen, 1987, p. 1018).

Thus, researchers using cross-sectional methods, such as de Leeuw and Ekanem (1971, p. 806), have argued that data from cross-sections of residential areas yield the required long-run supply elasticity since

> studying differences among cities amounts to studying how housing markets behave

> in the long run, in the sense of having had ample time to adjust to basic market forces. The reason is that differences among cities in size, costs, tax rates, real income and so on tend to persist for years or even decades.

They adopt the ILS approach to obtain supply elasticities ranging from 0.3 to 0.7, which is considerably lower than other ranges estimated in the US using time-series methods. Bartlett (1989, p. 39) argues that the inelastic supply estimates may be due to the cross-section method failing to capture 'long-run' values of the variables:

> It is rather implausible that all agents are operating at long run equilibrium values, and so the estimated equation is likely to be a hybrid measure of an unknown combination of short and long-run effects.

Assuming that the elasticity of supply in response to a (positive) demand shock is monotonically increasing over time, however, and that there are no exogenous supply shocks, then one would expect the elasticity of supply at a particular point in time to be greater the longer the time-interval since the shock occurred. Elasticities at the peak of a boom are thus likely to be smaller than during a downswing, *ceterus paribus*, with recession estimates offering a more 'long-run' picture of supply elasticities. Indeed, in practice the true long-run elasticity is ambiguous, since it may never be reached within a given cyclical or policy time-frame, and so long-run estimates may have no practicable purpose. Thus it could be argued that estimates of intermediate elasticities would be more relevant to policy-makers if the above assumptions are realistic. If it is assumed further that, at the given level of disaggregation, each observational unit experiences similar major shocks contemporaneously,[5] then cross-sectional estimates are interesting if comparisons can be made between years, as they reveal how quickly each region is responding to the shock. Nevertheless, cross-sectional estimates based on averages in one year should be treated with caution given the heterogeneity between regions and the ignorance of the adjustment time-frame, and the current position of a region within it.

A particular advantage of the cross-sectional approach is that it allows the researcher to test one of the predictions of the Muth (1964) model that elasticities of supply will vary across locations, a hypothesis tested in detail in Bradbury *et al.* (1977). Elasticities in this paper are thus interpreted as being a weighted average of long- and short-run elasticities, which are still of interest if one is examining differences between regions, although ideally a time-series or panel model should be constructed to distinguish between long- and short-run effects.[6]

4.3 Heteroscedasticity Issues

A problem associated with most cross-section research is that the Gauss–Markov assumption that variance is constant across the sample may not hold ('heteroscedasticity'). Although this in itself does not result in biased or inconsistent estimates, White (1980) has shown that heteroscedasticity can cause inefficient estimates of the standard errors producing unreliable *t*-statistics. Most cross-section studies in the housing supply field have not tested or corrected for heteroscedasticity, but still use *t*-statistics to guide model construction choices. Housing supply models constructed in this fashion may thus be misspecified and liable to produce biased parameter estimates. It should be noted that in almost all the regressions run on data used in this paper, we found heteroscedasticity to be a problem.

5. Data

The available data are at English LA district level pre-reorganisation (sample of 162 out of 366 English local authority districts) for the years 1987, 1988, 1991 and 1992, most of which were collected and compiled by Glen Bramley from a variety of sources including *inter alia*: County Planning Department Questionnaire Survey results on land availability and planning variables; Department of the Environment Local Housing Statistics for information on private housing-starts; Building Cost Information Service data on construction costs; and Census data on social economic groups and economic activity. Only data for 1988 and before were used in Bramley (1993a, 1993b) and so we take advantage of the more recent acquisitions to compare two years when the housing market (and macroeconomy) were at opposite phases of the business cycle: 1988 (boom) and 1992 (bust). For most regressions, the sample reduces to 130 due to missing values. All prices are in 1987 values.

5.1 Land Availability and Planning Restrictions

The model developed below follows Bramley (1993a, 1993b) in using a measure of total land available for development based on local authority land stock with outstanding planning permissions for private/general housing. However, even though this is probably as good a measure as is available for the UK, it is acknowledged that the true relationship between land supply and construction is likely to be as much influenced by the quality and location of site, as it is the total stock of available land. The quality of location will be determined by a host of factors (such as infrastructure, environment and access to schools, shopping centres and work), requiring the construction of a hedonic price variable for land, which is beyond the scope of the data available. Moreover, as we discuss below, inclusion of land prices in supply regressions would lead to misspecification and unreliable estimates. Consequently, the econometric model in this paper uses only land stock with outstanding planning permissions for private housing, as obtained by Bramley (1993a, 1993b). However, Evans (1996, p. 583) argues that the use of the 'structure plan provision' variable as the measure of land supply in Bramley's simulations "damps down changes in output following an increase in the supply of land available for development". A more substantial relationship between housing output and land supply is recognised to exist if the supply of land is measured using 'land with outstanding planning permission' rather than structure plan provision (see also Bramley, 1996). This is because much of the land provided under planned provision never receives actual planning permissions, due to what Bramley calls the 'implementation gap'. Consequently, it is argued that from a policy point of view, land with outstanding planning permissions is a more appropriate variable to use in simulations.

We also diverge from Bramley's analysis by not using completions as a measure of housing output, because it could be argued that this is not the best measure of output to use when examining the link between construction and land supply. An increase in land supply will not have any direct effect on current completions, which are more likely to be influenced by current demand. (It is a well-known strategy of construction companies to hold the construction of a housing unit at an unfinished stage until known buyers become available. This avoids holding large stocks of completed housing which are susceptible to vandalism and squatting. Concentrated stocks of vacant property may also give a negative signal to potential buyers regarding the desirability of the location.) Lagging completions to proxy starts (as per Bramley, 1993a) is an unnecessarily cumbersome way of linking output to land supply. Consequently, private starts data from LHS are used below as the dependent variable. A complete list of the variables used in the reported regressions is given in Table 1, and descriptive statistics of those variables is given in Table 2.

6. Econometric Methods

6.1 Basic Model and Expected Signs

The basic structure of the demand and supply equations focused on below are as follows:

$$Q^S = \alpha_1 + \alpha_2 P + \alpha_3 P^2 + \alpha_4 L + \alpha_5 D + \alpha_6 U + \alpha_7 U^2 + \varepsilon_S$$

$$\mathrm{Q}^{\mathrm{D}} = \beta_1 + \beta_2 P + \beta_3 U + \beta_4 Z + \varepsilon_D$$

Table 2. Descriptive statistics

Variable	Mean	Standard deviation	Minimum	Maximum	Cases
Z	39.895	8.4878	20.11	60.98	130
D	50.611	18.846	17.50	93.75	130
t = 1988					
P_t	56.863	19.640	27.64	128.3	130
$\tilde{P}_t$	56.863	14.397	32.16	93.19	130
L_t	1909.5	1168.8	227.2	5786.0	130
U_{t-1}	7.0362	3.1544	2.300	16.30	130
C_{t-1}	41.249	6.1972	31.07	56.35	130
t = 1992					
P_t	42.605	10.159	26.40	84.49	130
$\tilde{P}_t$	42.605	7.2523	27.45	63.52	130
L_t	2233.1	1480.8	139.5	9334.0	130
U_{t-1}	6.9264	2.0654	3.668	14.25	130
C_{t-1}	39.133	5.8252	31.03	53.52	130

where, Q_S and Q_D are quantity supplied and quantity demanded respectively. It can be seen that both the demand and supply equations are *identified* (rank condition), with the supply equation being exactly identified, and the demand equation overidentified (order condition). However, solving the system for either price or quantity shows that $\mathrm{Cov}[P, \varepsilon_S] = f(\beta_2, \alpha_2)$ and $\mathrm{Cov}[P, \varepsilon_D] = g(\beta_2 — \alpha_2)$, indicating that in both structural equations the error term is not independent of the endogenous variables. Consequently, least-squares estimates of the parameters of all equations with endogenous variables on the right-hand side (i.e. both the demand equation and the supply equation) will be inconsistent.

One of the aims of the paper is to distinguish between a negative coefficient on P^2 due to misspecification (notably simultaneity), and a negative coefficient due to some genuine backward-bending supply process. We attempt to do this below by comparing the results of equations with and without the squared term, for both OLS and 2SLS. It would be rational to assume that the price elasticity of supply, if different between the two periods, would be greater in the slump than in the first period since factor constraints during the heat of the boom are likely to make new construction less responsive to prices.

The unemployment rate for each local authority is included as an explanatory supply variable in order to give some measure of labour availability. Although we would expect the effect of labour availability to be stronger during a boom, this may not be reflected in the unemployment variable because this measure does not necessarily give any indication of construction-labour spare capacity. Thus some locations may have high unemployment but low quantities of construction workers, and vice versa. There is therefore a degree of ambiguity surrounding the *a priori* expected sign of the coefficient because U does not indicate levels of unemployed construction labour, but unemployment as a whole. However, in areas of very high unemployment, it is likely that this will also imply a supply of unemployed construction labour. It is expected either that the coefficient on U will be positive, or that the coefficient will be negative but have a convex shape (positive coefficient on the squared term).

Land supply is expected to have a positive effect on output, not only because it removes the direct constraint in areas where there are no spare sites on which to build, but also because the more land available for construction, the greater the choice of sites. If, for a given land supply, construction firms choose the optimum (i.e. maximum marginal profit) sites first, then as output increases, less and less profitable sites have to be employed until it is no longer optimal at the margin to produce another unit. So the injection of new land not only increases the amount of room actually available, but expands the set of profitable sites. The brownfield land variable, D, gives some measure of the overall quality of land available in an area.

Unemployment was used in the demand regression as a proxy for income. The Z variable was also included as a determinant of housing demand, as a measure of the proportion of people in an area likely to have employment status conducive to obtaining and repaying a long-term loan, and hence a measure of accessibility to owner-occupancy. Inclusion of a wider range of explanatory variables in the demand equation was precluded by the need to keep the supply equation exactly identified.

6.2 New Construction Elasticities

This section outlines the variable elasticity (VE) approach used in the calculations of elasticities of new construction, the results of which are presented in section 7.2 below. The VE approach is used because the more common log–log approach imposes rather stringent restrictions on the functional form of the supply equation—namely, that elasticities are constant across the sample (only true if all areas experience the same demand shocks and have identical adjustment mechanisms); that the supply curve passes through the origin (unlikely given fixed costs and the indivisible nature of housing construction), and that supply is monotonic—i.e. never bends backwards (a restriction not necessarily consistent with recent theory, as discussed above).

Using the VE approach thus allows us to test for the existence of backward-bending supply. Elasticities are calculated by taking the first partial derivative with respect to the relevant argument and then substituting the sample values from each observation. Elasticities can therefore be computed for each LA district, which also permits comparison of regional disparities in supply response.

6.3 Elasticity of Price with Respect to Land Release

One of the most surprising aspects of Bramley's results was the simulated response of price to land supply increases, which he found to peak at 11–12 per cent after 3 or 4 years in response to a 75 per cent increase in land supply. The precise technique used to derive these results from the estimated parameters was not made explicit, however. If the method used makes simulations by perturbing the land supply variable, assuming parameters constant at the estimated levels, then the results may be open to criticism given that the estimated coefficients in this paper where found to vary over time. Also the lag structure he adopts is exogenously constructed, and so the simulated adjustment time-scale is in effect imposed on the model *ex ante*. Just as legitimate (and considerably more explicit), would be to compute the instantaneous adjustment using differential calculus on the whole simultaneous equation system and then apply anticipated lags *ex post* if desired.[7] This offers the added advantage that elasticities can be calculated on each year's data, and also allows for the use of techniques such as 2SLS to deal properly with the simultaneity problem. Details of the implicit partial differential of price with respect to land supply for the complete equation system are given below.

The elasticity of price with respect to land was constructed as follows:

$$Q^S = \alpha_1 + \alpha_2 P + \alpha_3 P^2 + \alpha_4 L + \alpha_5 D + \alpha_6 U + \alpha_7 U^2 + \varepsilon_S \quad (1)$$

$$Q^D = \beta_1 + \beta_2 P + \beta_3 U + \beta_4 Z + \varepsilon_D \quad (2)$$

Assuming $Q^S = Q^D$, and subtracting (2) from (1) yields,

$$\alpha_1 - \beta_1(\alpha_2 - \beta_2)P + \alpha_3 P^2 + \alpha_4 L + \alpha_5\ D + (\alpha_6 - \beta_3)U + \alpha_7 U^2 - \beta_4 Z + \varepsilon_S - \varepsilon_D = 0$$

Differentiating price implicitly with respect to L yields

$$\begin{aligned}\partial P/\partial L &= -[(\partial F/\partial L)/(\partial F/\partial P)] \\ &= \alpha_4/(\beta_2 - \alpha_2 - 2\alpha_3 P)\end{aligned}$$

The elasticity of price with respect to land supply, $\eta_{P:L}$, is then given by:

$$\eta_{P:L} = \alpha_4 L/(\beta_2 P - \alpha_2 P - 2\alpha_3 P^2)$$

Although it is possible to calculate β_2 from estimating the demand equation (i.e. equation (2)), there are a number of reasons why it would be preferable to import a value from elsewhere. First, in order to maintain exact identification of the supply function, the demand equation is very parsimonious and inevitably suffers from omitted variables. In particular, there is no measure of the price and availability of substitutes such as rented housing, social housing and housing in contiguous regions. As such the estimate of β_2 from equation (2) does not control for local demand effects and so could not be used to give an accurate estimate of national demand elasticity[8]. Secondly, in order to capture as many aspects of supply as possible, the demand function was allowed to be overidentified. This means that an estimate of demand elasticity can be obtained from equation (2), but this estimate will not be unique, and there is no way of knowing which is the most appropriate estimate. Consequently, elasticities of price with respect to land release were calculated on a range of values for the national elasticity of demand, two sets of which (those based on -0.7 and -2.5) are reported in section 7 (Table 5).

For similar reasons to the above, Bramley (1993a, p. 9) assumes a price elasticity of demand of -0.7, which in the above notation implies that,

$$(\partial Q\ /\partial P)(P/Q) = -0.7$$

$$\Rightarrow\ \beta_2 = \partial Q/\partial P = -0.7Q/P$$

More generally, if the price elasticity of demand is denoted by $\eta_{QD:P}$, then,

$$\beta_2 = \partial Q/\partial P = \eta_{QD:P} Q/P$$

$$\Rightarrow\ \eta_{P:L} = \alpha_4 L/(\ \eta_{QD:P} Q - \alpha_2 P - 2\alpha_3 P^2)$$

7. Results

7.1 Preferred Regressions

Regressions were run on 1988 and 1992 allowing us to compare boom and bust. Appropriately corrected t-tests were used to determine whether exogenous variables should be lagged, logged or squared, resulting in the final equations as already described. Results are listed in Table 3. In all six regressions, all coefficients had expected signs. The Breusch–Pagan statistics show that there is evidence of heteroscedasticity in all of the equations. Although heteroscedasticity does not affect the unbiasedness or consistency of the parameter estimates, it does affect efficiency, and so the t-values reported are based on White's standard errors. Two-stage least squares calculations of the predicted values for price were based on regressions of P on all the exogenous variables in the system, the results for which are listed in Table 4.

It can be seen that in the 1988 regressions, there is clear evidence of concavity and supply being backward-bending in price for the sample range (sample maximum for $\tilde{P}_t$ is 93.19, compared with a turning-point of 67.94 in regression (2)). Moreover, in regression (1), $\tilde{P}_t$ has an insignificant t-value, which is clearly due to misspecification of the price variable as a linear relationship because when the quadratic term is included in regression (2), both P_t and $\tilde{P}_t$ have significant t-values.

There is less evidence, however, of supply being concave in prices in the slump period because even though the coefficient on $\tilde{P}_t$ in regression (4) is negative, it is 40 times smaller than the 1988 coefficient, and has a t-value suggesting that it is not possible to reject the null of $\alpha_3 = 0$. The coefficients on D and U^2 tended to be more negative in the slump.

The differences in parameter values between boom and slump were tested for using Chow's ANOVA test[9] computed from running a pooled regression on both years and applying an F-test to compare with regressions run on each year. Both in the linear (5)

Table 3. Two-stage least-squares private starts regressions: dependent variable = QS

Variable	(1) 1988 2SLS	(2) 1988 2SLS-BB	(3) 1992 2SLS	(4) 1992 2SLS-BB	(5) Pooled 2SLS	(6) Pooled 2SLS-BB
Constant	519.21	−246.51	315.34	306.16	638.52	520.40
	(1.555)	(−0.546)	(1.606)	(0.962)	(2.305)	(1.420)
$\tilde{P}$	1.0094	26.727	3.8961	4.3261	0.025129	4.4687
	(0.216)	(2.314)	(1.518)	(0.331)	(0.006)	(0.406)
$\tilde{P}^2$	—	−0.19670)	—	−0.00480	—	−0.040
		(−2.427)		(−0.034)		(−0.428)
L_{t-1}	0.17298	0.17312	0.068351	0.06836	0.094255	0.094854
	(8.505)	(8.842)	(9.004)	(8.928)	(6.456)	(6.517)
D	−1.4463	−2.0896	−2.6769	−2.6750	−1.6354	−1.6774
	(−0.592)	(−0.859)	(−2.438)	(−2.424)	(−0.923)	(−0.948)
U_{t-1}	−72.356	−77.956	−72.943	−73.014	−85.662	−85.474
	(−2.104)	(−2.201)	(−1.522)	(−1.512)	(−2.703)	(−2.683)
U^2_{t-1}	3.4168	4.2875	5.1752	5.1792	4.2904	4.3070
	(2.152)	(2.646)	(1.586)	(1.579)	(3.095)	(3.043)
Chow's analysis of variance test for structural breaks	—	—	—	—	26.610	23.879
Adjusted R^2	0.512	0.529	0.451	0.447	0.306	0.304
$F[k-1, n-k]$	27.469	24.622	22.191	18.344	25.943	21.587
	(0.000)	(0.73E-18)	(0.44E-15)	(0.39E-14)	0.56E-15	0.86E-20
B–P $\sim \chi^2[k-1]$	19.969	21.515	50.402	53.143	52.9538	55.0843
	(5)	(6)	(5)	(6)	(5)	(6)
P^*	—	67.939*	—	450.635	—	55.859*
U^*	10.588*	9.091*	7.047*	7.049*	9.983*	9.923*

Notes: Figures in brackets under the coefficients are t-values based on White's standard errors. Figures in brackets under the F values are the probabilities. If 0.000 is returned, then the probability is smaller than 0.1E-20 which is the accuracy threshold of the statistical package used. B–P denotes the Breusch–Pagan test statistic for heteroscedasticity. Critical χ^2 values at 95 per cent and 99 per cent are respectively 7.81 and 11.30 for three variables; 9.49 and 13.3 for four variables; 11.10 and 15.1 for five variables, 12.6 and 16.8 for six, and 14.1 and 18.5 for seven, 15.5 and 20.1 for eight. P^* and U^* give the turning-points for price and unemployment respectively given the regression coefficients, calculated from setting the first partial derivative with respect to price equal to zero. Where the data are also starred, the turning-point lies within the sample range of values for the associated variable.

Table 4. Construction of the instrument for price in regressions (1) to (6)

Variable	(7) 1988	(8) 1992	(9) Pooled
Constant	33.690	-4.3574	38.555
	(1.781)	(-0.344)	(3.584)
Z	0.61949	0.74252	0.47211
	(2.591)	(5.719)	(3.015)
L_{t-1}	-0.0004	-0.0007	-0.0011
	(-0.379)	(-1.850)	(-2.021)
D	0.39498	0.16739	0.34345
	(4.663)	(4.830)	(6.053)
U_{t-1}	-3.4535	2.5781	-4.2267
	(-1.583)	(1.249)	(-3.652)
U_{t-1^2}	0.59693E-01	-0.14293	0.12676
	(0.519)	(-1.320)	(2.504)
Adjusted R^2	0.5186859E	0.4898	0.4001255
$F[k-1, n-k]$	28.803	25.769	39.287
	(0.000)	(0.67E-15)	(0.000)
B–$P[k-1]$	47.9740	23.5318	63.1357
	(5)	(5)	(5)

Notes: see Table 3

and quadratic (6) cases, the null of homogeneous coefficients was rejected at the 99 per cent confidence level, confirming the structural break over time. This explains the low adjusted R^2 in regressions (5) and (6). The preferred regressions are therefore regressions (2) and (3).

7.2 *Elasticities*

Table 5 lists summary statistics for the variable elasticities calculated for all six two-stage least-squares regressions. As the dispersion statistics show, there is considerable variation across districts of the elasticity of supply with respect to most of the arguments, and this supports the use of the variable elasticity approach (rather than the traditional constant elasticity log–log formulation). The VE approach also makes it possible to identify the elasticities of particular districts, which points the way to further research into the causes of such geographical variation. Overall, price elasticity of supply was low, but higher in 1992 (average = 1.03) than in 1988 (average = 0.58), which confirms our expectations, but is the reverse of Bramley and Watkins' (1996, p. 38) results. Note, however, that estimated price elasticities are of a similar order of magnitude (if a little smaller) to Bramley's (1993a) results for 1988 (average = 0.99). Land supply elasticities remained fairly constant over time, marginally higher in the boom (0.75) than in the slump (0.71), and again appear to be of a similar size to those of Bramley and Watkins (1996). It is also worth noting that the negative elasticities with respect to the proportion of former urban land (D) are more significant in the regressions reported here than in the Bramley studies.

Table 5 also gives the results of land elasticities of price (denoted by E_ *P*_*L*) for two values of $\eta_{QD:P}$. As the figures show, the responsiveness of prices to changes in land supply are dependent upon the price elasticity of demand. Assuming that $\eta_{QD:P} = -0.7$, as assumed by Bramley, it can be seen that—although not elastic—the responsiveness of prices to land is considerably greater than predicted by Bramley. A 75 per cent increase in land supply would result in a fall in prices

Table 5. Summary statistics of variable elasticities of housing supply

Elasticity estimated (regression number in parentheses)	Average elasticity across districts	Standard deviation of elasticity across districts	Minimum elasticity across districts	Maximum elasticity across districts
E_*P*(1)	0.17572	0.24728	0.03313	2.242
E_*L*(1)	0.75112	0.73082	0.2194	7.276
E_*D*(1)	−0.23671	0.37930	−3.444	−0.02416
E_*U*(1)	−0.34258	0.77065	−6.373	1.985
E_*P*_*L*(1) $\eta_{QD:P} = -0.7$	−0.82589	0.48849	−3.760	−0.2134
E_*P*_*L*(1) $\eta_{QD:P} = -2.5$	−0.27119	0.19263	−1.534	−0.07757
E_*P*(2)	0.58232	1.9500	−4.079	18.61
E_*L*(2)	0.75169	0.73138	0.2195	7.282
E_*D*(2)	−0.34199	0.54800	−4.975	−0.03490
E_*U*(2)	−0.13636	0.69775	−2.984	3.468
E_*P*_*L*(2) $\eta_{QD:P} = -0.7$	−0.42590	1.1181	−4.348	8.776
E_*P*_*L*(2) $\eta_{QD:P} = -2.5$	−0.24087	0.31501	−1.953	2.034
E_*P*(3)	1.0284	1.2773	0.1425	13.09
E_*L*(3)	0.70854	0.56436	0.1462	3.805
E_*D*(3)	−0.89863	1.3427	−13.45	−0.09222
E_*U*(3)	0.24110	1.2056	−1.149	8.217
E_*P*_*L*(3) $\eta_{QD:P} = -0.7$	−0.43214	0.23065	−1.283	−0.03786
E_*P*_*L*(3) $\eta_{QD:P} = -2.5$	−0.19566	0.11032	−0.6314	−0.02677
E_*P*(4)	1.0281	1.2626	0.1458	12.90
E_*L*(4)	0.70863	0.56443	0.1463	3.805
E_*D*(4)	−0.89801	1.3418	−13.44	−0.09215
E_*U*(4)	0.24065	1.2062	−1.151	8.222
E_*P*_*L*(4) $\eta_{QD:P} = -0.7$	−0.43061	0.22825	−1.276	−0.03862
E_*P*_*L*(4) $\eta_{QD:P} = -2.5$	−0.19537	0.10963	−0.6299	−0.02715
E_*P*(5)	0.0077	0.03074	0.69E-03	0.5038
E_*L*(5)	0.79298	1.6362	0.1156	25.83
E_*D*(5)	−0.60808	3.1681	−52.49	−0.02731
E_*U*(5)	−0.14142	7.2817	−10.44	120.4
E_*P*_*L*(5) $\eta_{QD:P} = -0.7$	−1.0632	1.5229	−21.45	−0.1645
E_*P*_*L*(5) $\eta_{QD:P} = -2.5$	−0.30985	0.56067	−8.598	−0.04617
E_*P*(6)	2.7265	11.371	0.2001	186.6
E_*L*(6)	0.79802	1.6466	0.1163	25.99
E_*D*(6)	−0.62372	3.2496	−53.84	−0.02802
E_*U*(6)	−0.11638	7.4400	−10.22	123.1
E_*P*_*L*(6) $\eta_{QD:P} = -0.7$	−1.2011	6.7671	−104.8	26.10
E_*P*_*L*(6) $\eta_{QD:P} = -2.5$	−0.25638	0.42764	−3.258	5.277

of 32.4 per cent even for the lowest estimate of average $\eta_{P:L}$ (−0.432), compared with a fall of 11–12 per cent estimated by Bramley (1993a, p. 25). Demand would have to be several times more price-elastic to produce such a low land elasticity of price as this, since as the table shows, even with a price elasticity of demand of −2.5, a 75 per cent increase in land still results in a fall in prices of 15 per cent. Conversely, lower price elasticities of demand would produce higher land elasticities of price.

8. OLS vs 2SLS and the Exclusion of Costs

Even without the construction cost and ‘constraints’ variables used by Bramley, it can be seen that the single-year regressions have adjusted R^2 results in the 0.45–0.53 range. Comparison of R^2 figures with Bramley (1993a) thus shows that the more parsimonious specification presented here does not seriously reduce the explanatory power of the regressions, with the added advantage that overidentification and simultaneity problems have been avoided.

But does OLS and the inclusion of costs actually result in misspecification? Parallel regressions to (1)–(6) were run using OLS (Table 6), 2SLS with costs (Table 7) and OLS with costs (Table 8). To test for OLS misspecification due to simultaneity we tested the hypothesis that,

H_0: P and ε_S are independent.

against,

H_1: P and ε_S are not independent.

Hausman's (1978) test was used based on comparing $\hat{\alpha}_2$ with $\tilde{\alpha}_2$, where $\hat{\alpha}_2$ and $\tilde{\alpha}_2$ are the OLS and 2SLS estimators respectively. Under H_0, both $\hat{\alpha}_2$ and $\tilde{\alpha}_2$ are consistent, but only $\hat{\alpha}_2$ is efficient. Under H_1, $\tilde{\alpha}_2$ is consistent, but $\hat{\alpha}_2$ is not. The test statistic $m \sim \chi^2[k]$ was constructed for all OLS regressions and indicated that there is indeed a simultaneity problem associated with OLS estimates of the structural supply equations. It was found that in 8 out of 12 OLS regressions, the Hausman test rejected the null of no misspecification at the 99 per cent level of confidence; and in a further two regressions ((13) and (25)) it rejected the null at the 90 per cent level of confidence. Thus in only two OLS regressions ((10) and (22)) could the null not be rejected with confidence. Other evidence suggested misspecification under OLS. Parameter estimates were generally less stable across years and variations, with some estimates having an incorrect sign (coefficient on P in regression (12), and coefficients on P and P^2 in regression (13)). Some elasticity estimates also had incorrect signs or were implausibly large (regressions (11), (12) and (13)).

Regressions including construction costs that were run also showed signs of misspecification (incorrect signs, unstable parameter estimates), and these problems persisted even when an instrument for costs was introduced at various stages in the model construction process, which would appear to confirm the Olsen (1987) critique. In 9 out of 12 of these regressions ((16), (17), (20), (21), (22), (23), (25), (26) and (27)) supply was predicted to be positively related to costs, which seems implausible. In 6 of the regressions ((18), (19), (24), (25), (26), (27)), the cost coefficient was not significantly different from zero. The inclusion of costs also tended to have an adverse effect on the sign and significance of the price coefficients ((16), (19), (20), (22), (24), (25)).

We recognise that the model presented here has drawbacks of its own, however. In particular, limitations on the complexity of the demand function imposed by identification constraints resulted in a failure to consider the impact on demand of substitutes to new construction (such as conversions, private renting, public renting and housing supply in contiguous regions). Also, we were largely constrained to using the data collated and kindly donated by Bramley, and so the models were cross-sectional rather than time-series or (preferably) panel.

9. Conclusion

This paper has attempted to construct a more parsimonious model using similar data to Bramley (1993a), with the aim of overcoming some of the econometric problems associated with previous studies. Structural equations are specified in such a way as to ensure an exactly identified supply equation, and the two-stage least-squares procedure was implemented to overcome simultaneity problems. Following Olsen's (1987) recommendations in avoiding misspecification problems, factor prices were omitted from the supply function. This appeared to be supported by diagnostic tests on regressions which included factor prices (construction costs). The paper also discussed the rationale for, and tested the existence of, a backward-bending supply relationship, and found that

Table 6. Ordinary least squares results: without costs

Variable	(10) 1988 OLS	(11) 1988 OLS-BB	(12) 1992 OLS	(13) 1992 OLS-BB	(14) Pooled OLS	(15) Pooled OLS-BB
Constant	556.72	79.020	530.28	726.02	299.00	− 114.34
	(3.290)	(0.327)	(2.745)	(2.619)	(2.432)	(− 0.799)
P	0.44722	13.850	− 0.76698	− 8.1111	5.2447	18.441
	(0.344)	(2.824)	(− 0.579)	(− 1.208)	(4.856)	(5.953)
P^2	—	− 0.0986	—	0.0745	—	− 0.10396
		(− 3.136)		(1.263)		(− 4.928)
L_{t-1}	0.17295	0.16954	0.65380E-01	0.06588	0.099445	0.10019
	(8.505)	(8.342)	(8.871)	(8.844)	(7.311)	(7.698)
D	− 1.1872	− 0.83308	− 1.3409	− 1.2615	− 3.6817	− 3.6417
	(− 1.049)	(− 0.750)	(− 1.700)	(− 1.548)	(− 4.698)	(− 4.707)
U_{t-1}	− 75.547	− 64.229	− 84.753	− 91.643	− 53.906	− 47.067
	(− 2.834)	(− 2.523)	(− 1.690)	(− 1.779)	(− 2.724)	(− 2.560)
U^2_{t-1}	3.4815	3.1630	5.2625	5.5840	3.3868	3.2564
	(2.194)	(2.098)	(1.555)	(1.621)	(3.164)	(3.217)
Adjusted R^2	0.513	0.541	0.444	0.444	0.3739	0.4037
$F[k-1, n-k]$	27.504	25.772	21.586	18.185	34.80528	32.9327
	(0.000)	(0.16E-18)	(0.22E-14)	(0.50E-14)	(0.56E-15)	(0.71E-29)
B–P $\sim \chi^2[k-1]$	19.5497	23.9332	48.8009	51.3298	61.0899	55.2356
	(5)	(6)	(5)	(6)	(5)	(6)
E_*P*	0.084435	− 1.1374	− 0.20469	− 0.29534	0.90894	5.6368
E_*L*	0.74938	0.73458	0.67774	0.68297	0.43180	0.43504
E_*P*_*L*	− 0.92705	− 0.69073	− 6.9344	2.4748	− 0.29435	− 0.24644
Hausman test						
$m \sim \chi^2[k]$	0.218	**8.005**	**12.903**	3.572	**16.264**	**14.806**

Notes: Figures in brackets under the coefficients are *t*-values based on White's standard errors. Figures in brackets under the *F* values are the probabilities. If 0.000 is returned, then the probability is smaller than 0.1E-20 which is the accuracy threshold of the statistical package used. B–P denotes the Breusch Pagan test statistic for heteroscedasticity (see note under Table 3 for critical values). E_*P* and E_*L* are the elasticities of supply with respect to price and land. E_*P*_*L* is the elasticity of price with respect to land (assuming a price elasticity of demand of − 0.7). The Hausman test statistic has a χ^2_1 distribution, with critical values of 3.84 and 6.63 at 95 per cent and 99 per cent respectively.

Table 7. Two-stage least-squares results: with costs included

Variable	(16) 1988 2SLS	(17) 1988 2SLS-BB	(18) 1992 2SLS	(19) 1992 2SLS -BB	(20) Pooled 2SLS	(21) Pooled 2SLS -BB
Constant	59.944	− 1054.8	360.47	398.66	505.79	157.05
	(0.170)	(− 2.271)	(1.677)	(1.189)	(1.734)	(0.400)
$\tilde{P}$	− 1.7139	31.752	4.7262	3.0151	− 5.6449	6.6967
	(− 0.367)	(2.966)	(1.768)	(0.233)	(− 1.256)	(0.621)
$\tilde{P}^2$	—	− 0.26052	—	0.19357E-01	—	− 0.11451
		(− 3.358)		(0.136)		(− 1.262)
L_{t-1}	0.16487	0.16327	0.69386E-01	0.69379E-01	0.85718E-01	0.86872E-01
	(8.013)	(8.324)	(8.955)	(8.925)	(6.121)	(6.257)
D	− 2.6765	− 3.7978	− 2.5132	− 2.5164	− 1.8068	− 1.9626
	(− 1.186)	(− 1.714)	(− 2.177)	(− 2.174)	(− 0.989)	(− 1.063)
U_{t-1}	− 52.567	− 55.652	− 75.583	− 75.364	− 95.805	− 95.814
	(− 1.494)	(− 1.552)	(− 1.554)	(− 1.543)	(− 2.953)	(− 2.882)
U^2_{t-1}	2.6783	3.6698	5.2785	5.2650	4.7055	4.7820
	(1.663)	(2.300)	(1.606)	(1.598)	(3.492)	(3.387)
C_{t-1}	14.460	17.626	− 1.9984	− 2.0514	12.150	12.973
	(3.800)	(4.302)	(− 0.798)	(− 0.816)	(4.236)	(4.354)
Adjusted R^2	0.542	0.574	0.448976	0.4445	0.341	0.3423
$F[k-1, n\text{-}k]$	25.88174	25.2779	18.5183	15.7469	25.3885	22.041
	(0.14E-18)	(0.000)	(0.30E-14)	(0.14E-13)	(0.56E-23)	(0.89E-15)
B–P $\sim \chi^2[k-1]$	22.4141	22.4706	50.4231	52.8569	63.1680	67.1108
	(6)	(7)	(6)	(7)	(6)	(7)
E_*P*	− 0.29837	0.13637	1.2475	1.2549	− 0.87816	2.9279
E_*L*	0.71437	0.70743	0.71927	0.71920	0.37220	0.37721
E_*P*_*L*	− 1.4968	− 0.80695	− 0.39693	− 0.40180	− 0.20418	0.74625

Notes: Figures in brackets under the coefficients are t-values based on White's standard errors. Figures in brackets under the F values are the probabilities. If 0.000 is returned, then the probability is smaller than 0.1E-20 which is the accuracy threshold of the statistical package used. B–P denotes the Breusch Pagan test statistic for heteroscedasticity (see note under Table 3 for critical values). E_*P* and E_*L* are the elasticities of supply with respect to price and land (assuming a price elasticity of demand of − 0.7). E_*P*_*L* is the elasticity of price with respect to land.

Table 8. Ordinary least squares results: costs included

Variable	(22) 1988 OLS	(23) 1988 OLS-BB	(24) 1992 OLS	(25) 1992 OLS-BB	(26) Pooled OLS	(27) Pooled OLS-BB
Constant	−58.733	−277.04	530.44	716.42	154.96	−152.71
	(−0.275)	(−1.154)	(2.417)	(2.478)	(1.015)	(−0.963)
P	−1.7553	8.4759	−0.76620	−8.3254	4.4823	17.708
	(−1.334)	(1.557)	(−0.602)	(−1.245)	(3.777)	(5.213)
P^2		−0.72E-01		0.76E-01		−0.10038
		(−2.120)		(1.293)		(−4.491)
L_{t-1}	0.16329	0.16284	0.65382E-01	0.65754E-01	0.97555E-01	0.99476E-01
	(8.060)	(8.050)	(8.852)	(8.793)	(7.265)	(7.626)
D	−3.1521	−2.4797	−1.3402	−1.3214	−4.3340	−3.8812
	(−2.943)	(−2.256)	(−1.428)	(−1.396)	(−4.616)	(−4.128)
U_{t-1}	−46.162	−44.112	−84.763	−91.004	−49.120	−45.555
	(−1.749)	(−1.713)	(−1.669)	(−1.752)	(−2.476)	(−2.424)
U^2_{t-1}	2.4900	2.4670	5.2628	5.5682	3.3045	3.2309
	(1.594)	(1.634)	(1.551)	(1.613)	(3.130)	(3.194)
C_{t-1}	17.231	13.597	−0.48889E-02	0.39625	4.7091	1.7195
	(3.986)	(2.888)	(−0.002)	(0.171)	(1.472)	(0.554)
Adjusted R^2	0.5473436	0.5592875	0.4392	0.43978	0.376	0.402
$F[k-1, n-k]$	26.39281	23.84296	17.434	15.6668	29.5291	28.913
B–P $\sim \chi^2[k-1]$	22.9382	25.6788	48.8338	51.6111	63.3727	58.1567
	(6)	(7)	(6)	(7)	(6)	(7)
E_*P*	−0.33139	−1.1340	−0.20449	−0.31404	0.77681	5.4258
E_*L*	0.70751	0.70555	0.67776	0.68162	0.42359	0.43194
E_*P*_*L*	−4.4835	−1.1288	−5.1584	−0.93535	−0.30889	−0.25160
Hausman test						
$m \sim \chi^2[k]$	0.001	**21.231**	**19.364**	2.992	**50.704**	**7.319**

Notes: Figures in brackets under the coefficients are *t*-values based on White's standard errors. B–P denotes the Breusch Pagan test statistic for heteroscedasticity (see note under Table 3 for critical values). E_*P* and E_*L* are the elasticities of supply with respect to price and land. E_*P*_*L* is the elasticity of price with respect to land (assuming a price elasticity of demand of −0.7). The Hausman test statistic has a χ^2_1 distribution, with critical values of 3.84 and 6.63 at 95 per cent and 99 per cent respectively.

supply was concave in both periods, and 'bent backwards' during the boom. Evidence of a structural break between boom and bust was found, producing average price elasticities of supply (i.e. in the preferred regressions) noticeably smaller in the boom (0.58) than in the slump (1.03)—the opposite of Bramley and Watkins (1996)—with considerable variation across districts. Land supply elasticities were found to be more stable over time, and marginally greater in the boom (0.75) than in the slump (0.71). Both sets of elasticity estimates were of a similar order of magnitude to Bramley's, whereas the brownfield land variable proved considerably more significant in the results presented here.

The paper calculated second partial derivatives based on the whole demand/supply system to obtain estimates of the impact of land release on new house prices. As expected, estimates were considerably larger than results previously reported by Bramley (1993a, 1993b) since we used the 'land with outstanding planning permissions' variable, rather than 'structure plan provision'. Bramley (1993b, p. 1045) concluded that

> Output effects [of large-scale land release] would be larger than price effects, but still on average, would be only a fifth of the size of the nominal release of land capacity

In contrast, the results presented here predict that output effects would be around four-fifths, and price effects around a half of the size of nominal land release.

These results are particularly pertinent given the forecasts from the Department of the Environment, Transport and the Regions that 4.4 million new houses will need to be built by the year 2016 due to the anticipated rise in the number of households (DETR, 1998). In response to pressure from countryside campaigners, the government has committed itself to using tax and regulatory measures to divert the bulk of new building towards brownfield sites. The danger of such restrictions, however, is that they will make the target of 4.4 million new houses all the more unattainable unless they are accompanied by substantial public works. If the results presented in this paper are correct, increasing the proportion of total residential development that occurs on urban land may actually cause a fall in private housing construction. Moreover, private-sector new construction is sufficiently sensitive to the overall amount of land available for construction (and sufficiently insensitive to prices, particularly in boom years) that any significant increase in the number of new houses is likely to require a substantial release of greenfield land.

Notes

1. In the agricultural sector, a number of commodities can be clearly identified as inputs to the same producer, such as seed, feedgrain and breeding livestock.
2. The label [B3] denotes equation (3) in Bramley (1993a). Similarly for [B1].
3. Alternatively, full information methods could have been used, such as three-stage least squares or maximum likelihood.
4. See Greene (1993, pp. 603–604) and Schmidt (1976, pp. 150–151) for explanation and proof.
5. This may be less plausible if there is a 'ripple' effect in demand and price fluctuations, as has been suggested in the UK, where the epicentre of the shock is said to start in the South East, radiating outwards with time-lags increasing as distance from London increases.
6. At present, this is not possible at a disaggregated level given current data limitations regarding land supply.
7. Lags assumed in this model, such as the lag on LS, were based on statistical tests comparing lagged versus contemporaneous versions of each variable.
8. This point was noted by Bramley in his comments on an earlier draft of the paper.
9. Often called 'Chow's First Test' from Chow (1960), although the test had previously been described in Rao (1952).

References

BARTLETT, W. (1989) *Housing supply elasticities—theory and measurement*, JRF Discussion Papers, Housing Finance Series.

BRADBURY, K., ENGLE, R., IRVINE, O. and ROTHENBURG, J. (1977) Simultaneous estimation of the supply and demand for housing location in a multizoned metropolitan area, in: G. K. INGRAM (Ed.) *Residential Location and Urban Housing Markets*, pp. 51–92. New York: NEBR.

BRAMLEY, G. (1993a) The impact of land-use planning and tax subsidies on the supply and price of housing in Britain, *Urban Studies*, 30, pp. 5–30.

BRAMLEY, G. (1993b) Land-use planning and the housing-market in Britain—the impact on housebuilding and house prices, *Environment and Planning A*, 25, pp. 1021–1051.

BRAMLEY, G. (1996) Impact of land-use planning on the supply and price of housing in Britain: reply to comment by Alan W. Evans, *Urban Studies*, 33, pp. 1733–1737.

BRAMLEY, G. and WATKINS, C. (1996) *Steering the Housing Market: New Building and the Changing Planning System*. The Policy Press, Joseph Rowntree Foundation, York.

CARRUTH, A. and HENLEY, A. (1990) Can existing consumption functions forecast consumer spending in the late 1980s?, *Oxford Bulletin of Economics and Statistics*, 52, pp. 211–222.

CHOW, G. C. (1960) Tests of equality between subsets of coefficients in two linear regression models, *Econometrica*, 28, pp. 591–605.

DETR (1998) *Planning for the communities of the future*. Department of the Environment, Transport and the Regions, London.

EVANS, A. W. (1996) The impact of land-use planning and tax subsidies on the supply and price of housing In Britain, *Urban Studies*, 33, pp. 581–585.

FOLLAIN, J. R. (1979) The price elasticity of the long-run supply of new housing construction, *Land Economics*, 55, pp. 190–199.

GREENE, W. (1993) *Econometric Analysis*. New York: Macmillan Publishing Company.

LEEUW, F. DE and EKANEM, N. F. (1971) The supply of rental housing, *American Economic Review*, 61, pp. 806–817.

HAUSMAN, J. A. (1978) Specification tests in econometrics, *Econometrica*, 46, pp. 1251–1271.

MADDALA, G. S. (1992) *Introduction to Econometrics*. New York: Macmillan.

MAYES, D. (1979) *The Property Boom: The Effects of Building Society Behaviour on House Prices*. Oxford: Martin Robertson.

MAYO, S. and SHEPPARD, S. (1991) *Housing supply and the effects of stochastic development control*. Oberlin Discussion Paper in Economics, Oberlin University, USA.

MAYO, S. and SHEPPARD, S. (1996) Housing supply under rapid economic growth and varying regulatory stingency: an international comparison, *Journal of Housing Economics*, 5, pp. 274–289.

MEEN, G. (1996) Spatial aggregation, dependence and predictability in the UK housing market, *Housing Studies*, 11, pp. 345–372.

MUTH, R. (1960) The demand for non-farm housing, in: A. HARBERGER (Ed.) *The Demand for Durable Goods*, pp. 29–96. Chicago: University of Chicago Press.

MUTH, R. (1964) The derived demand for a productive factor and the industry supply curve, *Oxford Economic Papers*, 16, pp. 221–234.

MUTH, R. (1969) *Cities and Housing*. Chicago: University of Chicago Press.

MUTH, R. (1971) The derived demand for urban residential land, *Urban Studies*, 8, pp. 243–254.

OLSEN, E. O. (1987) The demand and supply of housing services, a critical survey of the empirical literature, in: E. S. MILLS (Ed.) *Handbook of Regional and Urban Economics, Vol. II*, pp. 989–1022. Amsterdam: North Holland.

OZANNE, A. (1996) Do supply curves slope up? the empirical relevance of the Sraffian critique of neoclassical production economics, *Cambridge Journal of Economics*, 20, pp. 749–762.

RAO, C. R. (1952) *Advanced Statistical Methods in Biometric Research*. New York: Wiley.

SCHMIDT, P. (1976) *Econometrics*. New York: Marcel Dekker.

SHEA, J. (1993) Do supply curves slope up? *Quarterly Journal of Economics*, 108, pp. 1–32.

TITMAN, S. (1985) Urban land prices under uncertainty, *American Economic Review*, 75, pp. 505–514.

TOPEL, R. and ROSEN, S. (1988) Housing investment in the United States, *Journal of Political Economy*, 96, pp. 718–740.

WHITE, H. (1980) A heteroskedasticity consistent covariance matrix estimator and a direct test of heteroskedasticity, *Econometrica*, 48, pp. 817–838.

WHITE, M. J. and WHITE, L.(1977) The tax subsidy to owner-occupied housing: who benefits?, *Journal of Public Economics*, 7, pp. 111–126.

WHITEHEAD, C. (1974) *The UK Housing Market*. Farnborough: Saxon House.

Appendix. Bramley's (1993a) System of Simultaneous Equations with Lagged Endogenous Variables

Bramley's (1993a) model can be represented as a series of seven simultaneous equations with lagged endogenous variables:

$$P_{t-1} = P_{t-1}(Q_{t-1}, D_{St-1}, D_{Lt-1}) \qquad [B1]$$

$$D_{St-1} = D_{St-1}(Y_{t-1}, G_{t-1}, \mathbf{Z}_{t-1}) \qquad [B1.1]$$

$$D_{Lt-1} = D_{Lt-1}(H_{t-1}, E_{t-1}, Q_{At-1}, T_{Lt-1}) \qquad [B1.2]$$

$$Q = Q(P_{t-1}, C_{t-1}, L_{St-1}, L_{Ct-1}, L_{Pt-1},) \qquad [B3]$$

$$C_{t-1} = C_{t-1}(W_{t-1}, U_{t-1}, E_{t-1}, NA_{t-1}) \quad [B3.1]$$

$$L_{Ft-1} = L_{Ft-1}(L_{Ct-1}, L_{Pt-1}, L_{St-1}, P_{t-1}, P_{t-2}) \quad [B4]$$

$$L_{St-1} = L_{St-2} + L_{Ft-1} - Q_{t-2} \quad [B5]$$

where, D_S is structural demand; D_L is locally variable demand; Y is average household income; G is geographical and locational attributes; $\mathbf{Z}$ is a vector of social characteristics; H is demographic variables; E is employment variables; Q_A is social rented housing supply; T_L is local tax bills; L_S is stock of land with outstanding planning permission; L_C is constraints on future land supply; L_P is planning policy for land release for private housing; W is wage rates relevant to construction; NA is density of population; and L_F is planning permissions flow.

Note that some of the equations have been included in the form of the previous period. For example, the price effect on supply is lagged in Bramley, and so the equation for price [B1] has been written in terms of determining P_{t-1} rather than P_t. Thus for the equations listed above to relate to Bramley's empirical results, it may be necessary in some instances to assume that the parameters are constant over time, which appears to be the assumption employed by Bramley in the production of simulation results anyway. As discussed above, these equations should not be estimated directly, but an estimation procedure able to deal with the problems of simultaneity should be employed (indirect or two-stage least squares, for example).

As Table A1 shows, every equation in Bramley's (1993a) paper is overidentified, implying that the estimated parameters are only one of a range of values theoretically possible given the equations listed.

Table A1. Overidentification of structural parameters

Equation	Variable number	B1	B1.1	B1.2	B3	B3.1	B4	B5	Endogenous variables
$\boldsymbol{Q}$	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	*
Q_{t-1}	2	1	0	0	0	0	0	0	
Q_{t-2}	3	0	0	0	0	0	0	1	
$\boldsymbol{P_{t-1}}$	**4**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	*
P_{t-2}	5	0	0	0	0	0	1	0	
$\boldsymbol{C_{t-1}}$	**6**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	*
$\boldsymbol{DS_{t-1}}$	**7**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	*
$\boldsymbol{DL_{t-1}}$	**8**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	*
$\boldsymbol{LF_{t-1}}$	**9**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	*
$\boldsymbol{LS_{t-1}}$	**10**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	*
LS_{t-2}	11	0	0	0	0	0	0	1	
LP_{t-1}	12	0	0	0	1	0	1	0	
LC_{t-1}	13	0	0	0	1	0	1	0	
Y_{t-1}	14	0	1	0	0	0	0	0	
G_{t-1}	15	0	1	0	0	0	0	0	
Z_{t-1}	16	0	1	0	0	0	0	0	
H_{t-1}	17	0	0	1	0	0	0	0	
E_{t-1}	18	0	0	1	0	1	0	0	
QA_{t-1}	19	0	0	1	0	0	0	0	
TL_{t-1}	20	0	0	1	0	0	0	0	
W_{t-1},	21	0	0	0	0	1	0	0	
U_{t-1}	22	0	0	0	0	1	0	0	
NA_{t-1}	23	0	0	0	0	1	0	0	
$g-1$	—	6	6	6	6	6	6	6	
K	—	4	4	5	6	5	6	4	
$k = 23 — K$	—	19	19	18	17	18	17	19	
Order condition	—	over	over	over	over	over	over	over	
Rank condition	—	identified	identified	identified	identified	identified	identified	identified	

Notes: g = number of exogenous variables in the system = 7. $k = 23 — K$, where 22 is the total number of variables in the system and K is the number of variables in the equation.