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TESTING DYNAMIC SPECIFICATION IN SMALL SIMULTANEOUS SYSTEMS:
AN APPLICATION TO A MODEL OF BUILDING SOCIETY BEHAVIOR IN THE UNITED KINGDOM

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TESTING DYNAMIC SPECIFICATION IN SMALL SIMULTANEOUS SYSTEMS:
AN APPLICATION TO A MODEL OF BUILDING SOCIETY BEHAVIOR IN THE UNITED KINGDOM

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I. Introduction

The literature on estimating economic models from time-series data has revealed a considerable state of ferment in recent years. Conventional econometric approaches have been sharply questioned (see e.g. Granger and Newbold (1974)) and the forecasting ability of systems estimated by such methods has been criticized (see Cooper (1972)). Conversely, the main alternatives advocated, namely fitting Autoregressive Integrated Moving Average (ARIMA) equations (see Box and Jenkins (1970)) or the closely related "control theoretic" methods (see Astrom (1970)) are far from having unqualified support from practitioners (see Chatfield and Prothero (1973) and Wall and Westcott (1974)). As argued by the last authors and by Nerlove (1972) a crucial function is left to the "Mutually supportive roles of theory and measurement."

The criteria which determine the selection of an ARIMA representation are roughly: maximize the likelihood of the model transformed to be stationary and invertible, basing the initial specification on autocorrelation analysis of the data such that the chosen form is the most parsimonious which does not violate diagnostic checks on the residuals being "white noise." For a multiple input process, considerable judgment is required.

These criteria are basically sensible but minimal. Slight problems are that some economic variables are not well represented by ARIMA models (e.g. tax rates) and there are other ways to achieve stationarity than blanket differencing. More importantly, emphasizing single output models distracts attention from the joint dependence of economic variables and by allowing almost no weight to theory or prior information accrued from other studies (relevant variables, signs and magnitudes of parameters, orders of lags, etc.) it exacerbates the difficulty of using short data series. Indeed, by placing
all the initial emphasis on the (albeit important) dynamics-autocorrelation interaction it may underplay the multivariate aspect which remains of primary concern to the economist. On the other hand, initially examining only the multivariate relationship is equally unhelpful and it seems imperative to consider both \textit{ab initio} (see Hendry (1974) and Zellner and Palm (1974)). Even then it is essential that the analysis be conducted in the context of an appropriate economic theory.

Unfortunately, although interdependence and dynamics have been accorded equal importance in general theoretical analysis (see e.g. Hicks (1946)) the latter has not been successfully developed for operational use. Economic theories remain for the most part of the long run equilibrium-comparative statics variety and their practical value has also been queried (see Nerlove (1972)). In any case, this is precisely the component which differencing (to achieve stationarity) will remove!

Nevertheless this paper is an attempt to integrate a "long run equilibrium" theory of the behavior of Building Societies with a short-run control-theoretic model of their dynamic disequilibrium adjustment deliberately designed such that the equilibrium solution of the latter reproduces the former. The theory also suggests which data transformations may be useful (e.g. differencing, ratios, etc.). While simple, it is based on established institutional evidence and I have shown elsewhere that it includes three other extant models of Building Societies as special cases (see Hendry (1975b)).

Finally a sequential procedure for statistically testing the dynamics, autocorrelation and economic theory restrictions is developed and we jointly apply these to the model of O'Herlihy and Spencer (1972) to investigate whether the economic theory predicts any mis-specifications of variables or
dynamics, whether the statistical approach reveals any in practice (their system was estimated by two-stage least squares) and if so, how closely these coincide with our anticipations from the theory.

II. **Building Societies**

These non-profit making co-operative institutions (denoted **BS**) dominate the UK mortgage market with their 70% share, and they also hold 25% of private financial assets. Most are members of the Building Societies Association and they meet monthly to agree mortgage and deposit interest rates and act essentially as a cartel by quoting (for the most part) homogeneous figures. Mortgages have a standard life of 20-25 years while deposits can be withdrawn on demand. Changes in either interest rate affects the complete stock immediately. Since the availability and price of mortgages have been important politically **BS** have been subjected to considerable indirect government pressure and/or help at various times. Revell (1973) provides an excellent discussion of their structure and functioning.

Clayton *et al.* (1974) investigated the objectives Building Societies claim to set themselves, Ghosh and Parkin (1972) and Ghosh (1974) considered their Portfolio and Debt Behavior, O'Herlihy and Spencer (1972) built a formal econometric model of their behavior and estimated the existence and extent of credit rationing, the London Business School model of the U.K. economy contains a sub-model of **BS** behavior (see Ch. 1 in Renton (1975)) and Riley (1974) has developed a model for the Treasury based on time-series analysis methods (see Astrom (1970)). As discussed in Hendry (1975b), none of these studies are fully satisfactory although all aid our understanding in different respects.

Since **BS** constitute a homogeneous sector, problems of aggregation and
measurement errors are likely to be of relatively less importance than usual. Conversely, the Credit Rationing for which these institutions are infamous is a serious additional complication, as it seems to be chronic (rather than a transient "switching of regimes" type) and endogenous to the system. Thus there may be no observations on the demand for mortgages schedule which need not preclude estimating the effects of changes in demand but does rule out using the conventional market clearing equation to close the system for observability. Further, as BS act as a group the equally conventional "Walrasian" equation of prices adjusting in response to excess demand is not valid either. Clearly "chronic" rationing entails an ability to control both price and quantity (although "transient" rationing could be a slowly evolving disequilibrium), and as an operational criterion we used: if an increase in the mortgage interest rate induces a non-decrease in advances ceteris paribus then rationing was previously present.

The lack of identification of mortgage demand was solved by O'Herlihy and Spencer using "prior" subjective information (primarily based on newspaper reports) formulated in dummy variables to proxy "mild" D(1) and "strict" D(2) rationing. See Figure 1 (r_m = Mortgage Interest Rate, M = Mortgage Lending, M^d = Demand for Mortgages Perceived by BS). Criticisms of this
approach are its subjective nature, that it implies constant absolute magnitude effects of rationing, that the dummies are really endogenous and are not an "explanation" of rationing, hence being difficult to use for forecasting and that the method is highly specific to the BS sector. Our "guideline" theory suggests that rationing is potentially present due to the inherent nature of how BS take their decisions. Specifically, it seems to be generated by the efforts of Building Societies to reconcile conflicting objectives rather than achieve a sole target such as (e.g.) profit maximization (compare Ghosh (1974)). To model this we adopt a "Managerial" type of theory based on the optimization of an objective function comprising several goals and subject to several (cost) constraints on the variability of the instruments to attain the targets. This is an explicitly dynamic "control theory" approach but only partly circumvents the awkward dilemma of postulating "desired" variables separately determined outside of the optimization framework. (See Theil (1964).)

We do not consider the overall portfolio allocation problem however, (see e.g. Ghosh and Parkin (1972)), but treat Other Assets as a single entity. A simple linear expository model of their long run behavior can be developed as follows.

**Capital Account**

(1) \[ A = LA + OA + M = D + R = L \]

where the symbols respectively denote Assets, Liquid Assets, Other Assets, Mortgages, Deposits, Reserves and Liabilities. We postulate that BS plan to relend a constant proportion \( \theta_1 \) of Deposits as Mortgages (this being their primary function as co-operative institutions),

(2) \[ M^g = \theta_1 D \]
and hold a constant proportion $\theta_2$ of their assets in liquid form,

(3) $LA = \theta_2 A$

accept all deposits offered,

(4) $D = D^g$

maintain a constant ratio $\theta_3$ of reserves to assets,

(5) $R = \theta_3 A$

and in equilibrium they realize their plans. From (1)-(5) we have

(6) $OA = (1 - \theta_2 - \theta_1 (1 - \theta_3)) A = \theta_4 A$

and

(7) $D = (1 - \theta_3) A$

Finally, the private sector's equations for Mortgage Demand and Deposit Supply are

(8) $M^d = f(y, r_m, PH) \quad \frac{\partial f}{\partial y} > 0, \quad \frac{\partial f}{\partial r_m} < 0$

(9) $D^g = h(y, r_d, T, r_c, P) \quad \frac{\partial h}{\partial y} > 0, \quad \frac{\partial h}{\partial r_d} > 0, \quad \frac{\partial h}{\partial T} < 0, \quad \frac{\partial h}{\partial r_c} < 0, \quad \frac{\partial h}{\partial P} < 0$

where $y$ is income, $r_m$, $r_d$, $r_c$ are pre-tax mortgage, deposit and competitive interest rates, $PH$ and $P$ are price indices for housing and all goods and $T$ is the tax rate. (BS pay tax on interest earnings for depositors at a rate which differs slightly from the standard tax rate and they generally quote after tax deposit interest rates: $r = r_d (1-T)$.)
Current Account

\[(10) \quad r_m + r_c^{OA} = E + r_d D + S\]

where \( E = \theta_5 \) are management expenses (including overheads does not materially affect the analysis) and \( S \) is the "surplus" planned to equilibrate the reserve ratio. Dividing by \( A \) and re-arranging:

\[(11) \quad r_d = \frac{\theta_4}{5} r_c + \frac{\theta_1}{1} r_m - \frac{\theta_3}{4} r_c + \frac{\theta_6}{6} S/A\]

where \( \theta_6 = 1/(\theta_3 - 1) < 0 \). Let \( K_t = (R/A)_t \) then if \( A_t \approx (1+g)A_{t-1} \) (say), \( S/A = K_t - (1/1+g)K_{t-1} \) (zero in stationary equilibrium) and if BS do plan to have \( K_t = \theta_3 \), then for given \( g \), \( r_c \), \( K_{t-1} \) and \( \theta_4 \) (11) determines \( r_d \) as a function of \( r_m \) (the "mark-up") or \textit{vice versa} on re-normalizing on \( r_m \). Note that \( \Delta(S/A)_t = -(1/1+g)\Delta K_{t-1} \) if \( K_t = \theta_3 \).

This leaves (e.g.) \( r_m \) to be determined and in the absence of a profit maximization motive, some other objective function must be postulated. The crucial point is that if BS do not equilibrate \( M^g \) and \( M^d \) then as a near monopoly which believes in keeping interest rates low (or is ordered to do so by the government), which does not seek to maximize \( S \) and which plans to achieve its balance sheet goals then they will ration credit to control both price and quantity. Two extreme possibilities are (i) the government dictates \( r_m \) on political grounds, (ii) BS do equilibrate \( M^g \) and \( M^d \) and so choose \( r_m \) as the implicit solution of

\[(12) \quad f(y, r_m, PH) = \theta_1 h(y, \{\theta_4 r_c + \theta_3 r_m = \theta_3 r_c + \theta_6 S/A\}, T, r_c) \]

Either way, given \( r_m \), (11) determines \( r_d \), (9) gives \( D \), (2) gives \( M \) and so on. Figure 2 summarizes the behavior of the model for an arbitrarily
given low value \( r_m \), and fixed \( y, r_c, PH, P, T \). By abstracting from the dynamics we have implicitly taken

\[ \Delta D = ND = 0 = NA = \Delta M \quad (g = 0) \]

where \( ND \) and \( NA \) are Net Deposits and Net Advances and

(13) \[ GD = WD, \ GA = PR \]

where the symbols respectively denote Gross Deposits, Withdrawals, Gross Advances and Principal Repayments. Out of stationary equilibrium, to obtain

(14) \[ ND = GD - WD \quad \text{and} \quad NA = GA - PR \]

the four components in (13) must be modelled. Note, however, that in equilibrium
(15) \( PR = \frac{1}{n^M} \) if the Mortgage Life is \( n \) years.

In disequilibrium, \( r_m \) and \( CA \) will not be constant and there will be premature terminations as well as routine repayments.

Given this "long-run" framework we can formulate the objective function of \( BS \) and introduce dynamics at the same time. As argued above, their prime objective is to achieve the long-run aim of relending a relatively constant fraction of their expected total Deposits \( \hat{D}_t \) as Mortgages, but now \( \hat{D}_t \neq D_t \) due to the stochastic nature of cash flows, unforeseen changes in \( y, r_c \), etc. At the same time they pay some attention to satisfying "reasonable" mortgage applications and maintaining their long run reserve ratio while attaching adjustment costs to changes in their instruments (if only to avoid "Bang-Bang" control). Four other objectives/costs which do not affect the formal specification of the control rules but do alter the precise parameterization are: maximizing the growth rate of assets, minimizing lending rates, adjusting faster the more they are out of equilibrium and equilibrating interest rate differentials with the money market.

To facilitate comparison with existing models we take the objective function to be quadratic in the variables and to be one-period only. This is because \( BS \) do act as if they were myopic, but introducing \( t^* > 1 \) in (16) "simply" creates leads in the analysis and first-period Certainty Equivalence applies (see Hay and Holt (1975)). However, the control is also equivalent to ignoring terminal conditions and the stability properties of this are well known!

(1) We measure the "Disutility" of "Disequilibrium" by \( (M_t - \theta_1 \hat{D}_t)^2 \), even though such costs are probably asymmetric away from equilibrium.
(II) Since $M_t - M_t^d = NA_t - NA_t^d$ and $NA_t = \text{Min}(NA_t^s, NA_t^d)$ we take the disutility of not supplying the required volume of housing finance to be 
$\alpha_1 (NA_t - NA_t^d)^2$.

(III) To achieve the desired reserve ratio requires the appropriate surplus, and if $\theta_3$ is constant, to model the BS making marginal adjustments rather than re-evaluating the entire basis of the mark-up each period we have; 
$\alpha_2 (\Delta r_{mt} - \frac{1}{\theta_1} \Delta r_{ct} - \theta_7 \Delta (S/A)_t)^2$, on normalizing with respect to $r_m$ in (11), with $\theta_7 = 1/\theta_1 (1 - \theta_3)$. This could also be interpreted as a cost of adjusting the differential.

(IV) Inertia to avoid high frequency oscillations in $NA_t$ and $r_{dt}$ seems desirable, but there are adjustment costs in any event arising from processing costs and destabilizing influences on the housing market for the former, and administrative costs (perhaps less so with computers) and the creation of uncertainty for depositors concerning the latter.

Thus we use $\lambda_1(\Delta NA_t)^2 + \lambda_2(\Delta r_{dt})^2$.

The objective function which results to determine BS behavior is

$$c_t = \sum_{t=1}^{t^*} (1 + r_c)^{-t} \left[ (M_t - \theta_3 N_t)^2 + \alpha_1 (NA_t - NA_t^d)^2 + \lambda_1 (\Delta NA_t)^2 + \lambda_2 (\Delta r_{dt})^2 + \alpha_2 (\Delta r_{mt} - \frac{1}{\theta_1} \Delta r_{ct} - \theta_4 \theta_7 \Delta r_{ct} + \theta_8 \Delta K_t - 1)^2 \right] \quad (\theta_8 = \theta_7 / (1 + g))$$

and BS seek to minimize this as a function of $NA_t$, $r_{mt}$ and $r_{dt}$. Completely independent empirical support exists for formulating a myopic objective function (in which $t^*$ denotes six-months) with conflicting aims and emphasizing the goals of stable flows of funds, reserves in line with assets, relending the maximum subject to achieving the desired liquidity ratio, attempting to satisfy the demand for housing finance and NOT maximizing profits.
This is provided by Clayton et al. (1974) who conducted a questionnaire survey of how the Building Societies Association perceived the role of BS in the housing market and they reached the conclusions noted in the previous sentence.

While \( c_t \) is not "homogeneous" in its arguments and it would be preferable to deflate \( M_t, D_t, \) and \( NA \) by \( A \) (say), we retain (16) for simplicity, with \( t^* = 1 \).

Minimizing \( c_t \) with respect to \( NA_t, r_{mt}, \) and \( r_{dt} \) yields the basic system (25), (27), and (28) closed by (23), (26), and (29)-(32), as follows.

\[
\frac{1}{2} \frac{\partial c_t}{\partial NA_t} = \epsilon_{1t} = (M_t - \theta_1 D_t) + \alpha_1 (NA_t - NA^d_t) + \lambda_1 \Delta NA_t
\]

\[
\frac{1}{2} \frac{\partial c_t}{\partial r_{mt}} = \epsilon_{2t} = -\alpha_1 \left( \frac{\partial NA}{\partial r_{mt}} \right) (NA_t - NA^d_t) + \alpha_2 (\Delta r_{mt} - \frac{1}{\theta_1} \Delta r_{dt} - \theta_4 \theta_7 \Delta r_{ct} + \theta_5 \Delta K_{t-1})
\]

\[
\frac{1}{2} \frac{\partial c_t}{\partial r_{dt}} = \epsilon_{3t} = -\theta_1 \left( \frac{\partial D_t}{\partial r_{dt}} \right) (M_t - \theta_1 D_t) - \frac{\alpha_2}{\theta_1} (\Delta r_{mt} - \frac{1}{\theta_1} \Delta r_{dt} - \theta_4 \theta_7 \Delta r_{ct} + \theta_5 \Delta K_{t-1}) + \lambda_2 \Delta r_{dt}
\]

Further

\[
\Delta M_t = NA_t
\]

\[
\Delta D_t = ND_t
\]

and

\[
\Delta D_t = D_{t-1} + ND_t,
\]

where

\[
\Delta D_t = \beta_1 + \beta_2(B)ND_t + \beta_3 \Delta r_{dt} + \beta_4 \Delta r_{ct} + \beta_5 \Delta y_t \quad (0 < \beta_2 \leq 1, \ 0 < \beta_3, \ \beta_4 < 0, \ \beta_5 > 0)
\]

and \( \beta_2(B) \) is a polynomial in the lag operator \( B \). Note that (23) includes both rational expectations and ARMA models as special cases depending on what
values the BS use for the B_j. We obtain from these and (17),

\begin{equation}
NA_t' = -\frac{1}{1+\lambda_1}(M_{t-1} - b_1 D_{t-1}) + \frac{\lambda_1}{1+\lambda_1}NA_t - 1 + \frac{\alpha_1}{1+\lambda_1}(NA_t - NA_t') + \frac{\theta_1}{1+\lambda_1}ND_t + \frac{\varepsilon_{lt}}{1+\lambda_1}
\end{equation}

or

\begin{equation}
NA_t' = -\frac{1}{1+\lambda_1 + \alpha_1}(M_{t-1} - b_1 D_{t-1}) + \frac{\lambda_1}{1+\lambda_1 + \alpha_1}NA_t - 1 + \frac{\alpha_1}{1+\lambda_1 + \alpha_1}NA_t'
\end{equation}

\[ + \frac{\theta_1}{1+\lambda_1 + \alpha_1}ND_t + \varepsilon_{lt}.\]

As required, in equilibrium (25) reproduces (2). From (16) we have

\[0 < \lambda_1, \lambda_2, \alpha_1, \alpha_2 < 1\] if the first objective is the major one, and hence

\[
\left(0 < \frac{1}{1+\lambda_1 + \alpha_1}, \frac{\lambda_1}{1+\lambda_1 + \alpha_1}, \frac{\alpha_1}{1+\lambda_1 + \alpha_1}, \frac{\theta_1}{1+\lambda_1 + \alpha_1} < 1\right).
\]

From (18), assuming (possibly with additional lags)

\begin{equation}
NA_t' = \delta_1 y_t + \delta_2 (r_{mt} (1 - T_t) - b_t) + \delta_3 PH_t + \delta_4 M_{t-1} + \nu_{lt}
\end{equation}

\[0 < \delta_1, \delta_2 < 0, \delta_3, -1 < \delta_4 < 0\]

we obtain (neglecting variations in \(T_t\))

\begin{equation}
\Delta r_{mt} = \frac{1}{\theta_1} \Delta r_{dt} + \delta_4 \gamma \Delta r_{ct} - \theta_7 \Delta K_{t-1} + \frac{\alpha_1 \delta_2}{\alpha_2} (NA_t - NA_t') + \varepsilon_{2t}
\end{equation}

\[1 < \frac{1}{\theta_1}, \frac{\delta_4 \gamma}{\alpha_2} < 0, \theta_4 \theta_7 > 0, 0 < \theta_8\]

Finally, from (19) and (23), and using (27) to eliminate \(\Delta r_{mt}\)
\( \Delta x_{dt} = \frac{\theta_1 \beta_3}{\lambda_2} (M_t - \theta_1 r_t) + \frac{\alpha_1 \beta_2}{\lambda_2 \theta_1} (N_{A_t} - N_{A_t}^d) + e_{3t} \quad (0 < \frac{\theta_1 \beta_3}{\lambda_2}, \frac{\alpha_1 \beta_2}{\lambda_2 \theta_1} < 0) \)

Note that all three control equations depend on the excess demand for Mortgages.

To close the system, an equation is required for \( D^e \), which need not be (23), as the ES could be using an incorrect model. To allow for different lag responses between Deposits and Withdrawals, we used

\( D^e_t = D_{t-1} + (GD^e_t - WD^e_t) + \text{interest credited (I}_t) \)

with \( GD_t = GD^e_t \) and \( WD_t = WD^e_t \), so that \( ND^e_t = I_t + GD^e_t - WD^e_t = ND_t \).

\( GD_t = \gamma_1 (B) y_t + \gamma_2 (B) r_{dt} + \gamma_3 (B) x_{ct} + \gamma_4 (B) p_t + v_{2t} \quad (0 < \gamma_1 < 1, 0 < \gamma_2, \gamma_3 < 0, \gamma_4 < 0) \)

and similarly for \( WD_t \). Finally, empirically

\[ I_t \sim \mu \left( \frac{r_{dt} + r_{dt-1}}{2} \right) \left( \frac{D_t + D_{t-1}}{2} \right). \]

Equivalently we have

\( GA_t = N_{A_t} + PR_t \)

where \( PR_t \) is composed of routine repayments and premature terminations.

If monthly payments are held constant, an increase in \( r_{mt} \) will reduce \( PR_t \); but for recently effected loans, this effect will hold even if the length of life of the mortgage is held constant. Increased income and/or house prices will probably increase premature repayments. Thus, allowing for (15), and with linearity, to explain changes in \( PR_t \) we propose (subject to additional lags).
\[ \Delta PR_t = \varphi_1 N_t - 1 + \varphi_2 \Delta y_t + \varphi_3 \Delta m_t + \varphi_4 \Delta PH_t + \varphi_5 (\text{PR}_t - 1)^{-1} n_{t-1} + \nu_3 t \]

\[ (0 < \varphi_1 < 1, 0 < \varphi_2, 0 > \varphi_3, 0 < \varphi_4, \varphi_5 < 0) \]

In equilibrium this reproduces (15). As argued in Hendry (1975b) however, dimensionless analysis, homoscedasticity and stationarity all argue for logarithmic or ratio forms for all of these equations but we keep linearity for comparison with O'Herlihy and Spencer.

III. The Model of O'Herlihy and Spencer

The formulation of this is shown in Table IA (see Table II for four one-period ahead forecasts). The Gross Deposits equation is similar to (9) as is that for Withdrawals (compare (23)) and the Principal Repayments equation is (very roughly) \[ \Delta PR_t = \varphi_1 AGA_t . \] Given (31) and (15) we can expect very considerable simultaneity between these and this is supported by the extremely large coefficient on \( GA_t \).

The Gross Advances equation can be interpreted as (24) with

\[ (GA_t - GA^d_t) = \xi(D(1), D(2)) \text{ (see Figure 1), } \hat{N}_t = a(y/P)_t \text{ and with } 
\]

\[ (M_{t-1} - \theta_1 D_{t-1}) \] omitted. Note that if this last term is reformulated in a stationary way as \[ [(M/D)_{t-1} - \theta_1] \text{ this is approximately equal to } \]

\[ (1 - \theta_1(1 - \theta_3) - LQ_{t-1})/(1 - \theta_3) \text{ where } LQ = (A-M)/A \text{ which will be highly correlated with the form chosen by O'Herlihy and Spencer, namely } \]

\[ L^0_t = \frac{1}{2}(LQ_{t-1} - 15.5)/(19 - LQ_{t-1})(LQ_{t-1} - 12) \]

as the denominator is always positive. Both the Mortgage and Deposit interest rate equations are formulated in levels; the former is made a geometric distributed lag of \( r \) so (27) predicts a number of omitted variables while the
latter depends negatively on $L_t^0$ (see the previous sentence) and on $K_t^0$ (a transform of $K_t$ similar to $L_t^0$) such that the dependent variable could easily be made $\Delta r$ (compare (28)). Given these theoretical predictions of mis-specification, we next develop a statistical theory for testing the formulation of the system.

IV. **Statistical Testing of Dynamic Specification in Small Simultaneous Systems**

The determination of an appropriate lag structure in dynamic models is still primarily treated as an empirical matter, generally resolved by experimenting with a set of lagged regressors using a relevant estimator (e.g. ordinary or two-stage least squares). This can yield very misleading results in view of the well known lagged dependent variable--autocorrelated error bias, especially in simultaneous equations systems (see Hendry (1975a)). However, an econometric approach which explicitly recognizes the interaction between the equation dynamics and the stochastic specification was developed by Sargan (1964), and can be generalized as follows.

Consider a model given by

\[ By_t + Cz_t + D\mu_{t-1} = \eta_t \text{ where } \eta_t = Fu_{t-1} + \xi_t, \xi_t \sim NI(0, \Sigma) \]

with restricted reduced form

\[ \chi_t = \Pi_1 z_t + \Pi_2 \mu_{t-1} + \nu_t \]

where $\mu_t = \bar{y}y + u_t$, $\Pi_1 = -B^{-1}C$, and $\Pi_2 = -B^{-1}D$, $\bar{y} = B^{-1}FB$, and transformed reduced form (eliminating the autocorrelation)

\[ \chi_t = \Pi_1 z_t + (\Pi_2 + \bar{y})\mu_{t-1} - \bar{y}\Pi_{t-2} - \bar{y}\Pi_{t-2} + u_t \]
Equivalently, we have an unrestricted version of (35)

\[(37) \quad y_t = p_1 z_t + p_2 y_{t-1} + \nu_t \]

where \( \nu_t = G \nu_{t-1} + w_t \) and its transformation

\[(38) \quad y_t = p_1 z_t + (p_2 + G) y_{t-1} - G_{21} z_{t-1} - G_{22} y_{t-2} + w_t \]

Finally, we could ignore the autoregressive restriction in (38):

\[(39) \quad y_t = q_1 z_t + q_2 y_{t-1} + q_3 y_{t-2} + q_4 y_{t-3} + \varepsilon_t \]

where \( \varepsilon_t \) are all the non-redundant regressors in \( z_{t-1} \).

This leads to a sequential testing procedure for the various restrictions (see e.g. Anderson (1971), ch. 6.4). The symbol \( \mathcal{L}_z \) denotes the log likelihood value when the error on the equation is \( z \). The chosen order of testing is such that each hypothesis is investigated without conditioning on untested assumptions about a further hypothesis to be investigated i.e. from the least restricted hypothesis to the most. Despite this seeming very natural, most empirical work appears to proceed in the opposite direction and indeed investigators generally conduct tests only within (34) and for \( \mathcal{L}_z \) either zero or diagonal (the latter being required for AIV to be valid). Appropriate technology does exist for conducting the required tests (see Hendry (1971)) and is not too expensive (see Hendry and Tremayne (1973)). Our sequence is:

\( H_a \): the autoregressive restrictions on (38) is valid. If this is true then

\[(40) \quad 2(\mathcal{L}_z - \mathcal{L}_w) \sim \chi^2_m \text{ for } m \text{ regressors in } z_{t-1}^0. \]

If \( H_a \) is rejected then the system requires dynamic re-specification (go to
\( H_d \). If \( H_a \) is not rejected proceed to test:

\[ H_b : \ C = 0 \quad \text{in (38)}. \] If this is true then

\begin{equation}
(41) \quad 2(\bar{I}_w - \bar{I}_v) \sim \mathbf{\chi}_A^2 \text{ for } n \text{ equations.}
\end{equation}

If \( H_b \) is rejected use "autoregressive" estimators, otherwise use "white noise" estimators. Next we have:

\[ H_c : \ \bar{P}_1 = \bar{P}_1 \quad (i.e. \quad \bar{P}_1 = -B^{-1}C, \ \bar{P}_2 = -B^{-1}D). \] If this is true then

\begin{equation}
(42) \quad 2(\bar{I}_w - \bar{I}_v) \sim \mathbf{\chi}_N^2 \text{ if } H_b \text{ was rejected or}
\end{equation}

\begin{equation}
(43) \quad 2(\bar{I}_v - \bar{I}_v) \sim \mathbf{\chi}_N^2 \text{ if } H_b \text{ was not rejected}
\end{equation}

for \( N \) over-identifying restrictions. (Before proceeding from \( H_b \) to \( H_c \)
one could also test whether \( C \) was diagonal: \( H_a \) and \( H_b \) assumed it unrestricted. If the diagonality refers to \( E \), it could be tested after \( H_c \).

If \( H_c \) is rejected, the over-identifying restrictions are invalid, and the exclusion restrictions in (34) require modification (or the underlying theory is false). Finally if \( H_a \) is rejected one could attempt to re-specify the dynamics by testing

\[ H_d : \ Q_{31} = Q_{41} = 0. \]

This is intended to denote testing rows and/or columns of the \( Q_3, Q_4 \) matrices for significance and could be based on appropriate modifications of the methods proposed in Multivariate Analysis (see e.g. Anderson (1958), ch. 8). For the usual sample sizes and numbers of reduced form regressors in econometrics, some "degrees of freedom" adjustments seem appropriate and those used below
are of the form:

\[(T-K)^{-1} \hat{W}' \hat{W} \sim \hat{\Omega}_n \]

where \( \hat{W}' = (\hat{W}_1, \ldots, \hat{W}_T) \) and (for example)

\[(45) \quad 2(1-h/T)(\hat{E}' \hat{E} - \hat{E}' \hat{E}_o) \sim x^2_\Lambda (n^2 + nm) \]

for \( h = K_1 + \frac{1}{2}(n + K_2 + 1) \) with \( K = K_1 + K_2 \) regressors in (39), \( K_1 = n + k \), \( K_2 = n + m \), and there are \( k \) exogenous variables.

Generalizing the analysis for longer lags in \( Y_t \) in the initial formulation is straightforward; doing so for higher orders of autocorrelation is not as it raises potential non-nesting problems. However, even if \( n \) is small (3-6 say) the ARMA representations derived from (39) will have very high order lags.

Conversely, specializing the analysis to individual equations using the Autoregressive error generalization of Limited Information Maximum Likelihood, or its asymptotic equivalent Autoregressive Instrumental Variables (denoted AIV) yields the approach developed by Sargan (1964). Since this special case has already proved useful in revealing dynamic mis-specifications in empirical research (see e.g. Hendry (1974)) and is not expensive computationally, we first re-estimated O'Herlihy and Spencer by AIV to test (for each equation separately) the validity of the autoregressive restriction \( H_a \) for a structural equation), the significance of the autoregressive parameter \( H_b \) for \( n = 1 \) and also the implicit hypothesis of zero residual autocorrelation of higher order (see Pierce (1971)). Taking account of this information we produced a revised system with no residual autocorrelations other than, where required, a valid first order autoregressive error, and the results are reported in Table IB.
The re-specification brings the system closer to our theoretical form and improves its forecasting performance (other than \( r \)) but the forecast tests indicate that significant mis-specifications remain (see Table II). However, just re-estimating the original equations by AIV with a fourth order autoregressive error (compare Wallis (1972)) produced an equivalent improvement in the forecast accuracy as shown in Table II. We conclude that while there is some benefit in using AIV and its related tests relative to two-stage least squares, to yield consistent estimates all these individual equation estimators rely on the validity of the untested hypotheses that \( \Phi \) is diagonal and that both \( H_a \) and \( H_c \) are valid. The importance of this is that we cannot really \textit{a priori} expect these to hold and hence we are making the "maintained" hypothesis have less prior plausibility than many of the "null" hypotheses we are seeking to test—\textit{anticipating rejection}.

Even when all these implicit hypotheses are valid, AIV remains inefficient asymptotically compared to Full Information estimation (note the results in Rotherberg (1973), ch. 5). Both arguments emphasize the potential advantages of estimating and testing the system as a whole and although 54 observations is hardly a large sample for a six equation model it seems worth examining the practical value of the various tests applied to the original O'Herlihy and Spencer specification.

The non-linearity relating GA and GA/PH precludes a direct application of our analysis to their model, but if we revise it slightly (and quite reasonably) to use PR/PH instead of PR so that all values are in real terms then the model does become linear. The results for the various test statistics are shown in Table IV.
TABLE IV

Asymptotic $\chi^2$-Statistic Values

<table>
<thead>
<tr>
<th>Equation</th>
<th>Unadjusted</th>
<th>Adjusted</th>
<th>df</th>
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<tbody>
<tr>
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<td></td>
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<tr>
<td>45</td>
<td>151</td>
<td>41</td>
<td>84</td>
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</table>

($(42)$ is adjusted using $K_1 = 4 + 6 + [22/6]$, $K_2 = K - K_1 = 9$.) Two points of note are that the small sample size means that the degrees of freedom (df) adjustment has a major impact on $(45)$, and that the validity of the overidentifying restrictions is clearly rejected ($H_c$) even if the results for $H_a$ and $H_b$ are equivocal.

Apart from the equation for $PR$, the restricted reduced form of the original model can be obtained by solution while the unrestricted reduced form can be estimated directly. We have also done this subject to a different (but similar) approximation from that used for Table IV, namely making $PR$ depend on $(GA/PH)_{t-1}$ instead of on $GA_{t-1}$ in the reduced form. These unrestricted and solved reduced form estimates (ignoring $PR_t$ in the latter and $GA_{t-1}$ in both) are presented in Table V, and there are a number of major differences between them. Most importantly, in the unrestricted the rationing dummies are not significant in $(GA/PH)$, but are in $(GD/P)$, while $L^0_t$ is significant in $(GA/PH)$. Thus the dummies appear to represent unexpected downward shifts in the supply of Deposits, and if the supply of Advances is NOT formulated as a "processing" equation, the dummies naturally proxy a fall in Advances. This conforms closely with the theory in Section II. It should be noted (when interpreting the remaining coefficients) that $r_{mt-1}$ and $r_{t-1}$ are very
collinear, but many of the other coefficients in common between the two reduced forms have markedly similar values.

Conclusion

The statistical tests of the various implicit hypotheses (and such hypotheses are often made in time-series studies) revealed a number of mis-specifications in the BS model we have examined. The new estimates suggest appropriate ways of revising the formulation of the model and despite the "pre-test" problems in doing this we believe its justification is considerably enhanced by the existence of independent predictions from a theoretical analysis that such mis-specifications would indeed occur.

To efficiently estimate our own model requires a relatively complicated computer program generalizing the method in Hendry (1971) to systems with non-linear, cross-equation restrictions on the parameters. This has now been developed and we intend to report our results from it at a later date.
TABLE I

A. **Original Model**, as reproduced\(^1\) (See O'Herlihy and Spencer (1972).)

1. \( \text{GD}/\pi^* = 39r_t - 10r_{bt} + 44T_t + .06y/P_t + .62GD/P_{t-1} - 684 \quad (s = 18.0) \)
2. \( \text{WD}/\pi^* = -23r_t + 9r_{bt} - 9T_t - .03y/P_t + .07D/P_{t-1} + 185 \quad (s = 11.5) \)
3. \( \text{GA}/\text{PH}^* = .72\text{GA}/\text{PH}_{t-1} + .02y/P_t - 16D(1) - 29D(2) - 6 \quad (s = 17.3) \)
4. \( \text{PR}^* = .20\text{GA}_t - .09\text{GA}_{t-1} + .72\text{PR}_{t-1} + 11 \quad (s = 3.9) \)
5. \( r_{mt} = .96r_t + .35r_{mt-1} + .58 \quad (s = .18) \)
6. \( r_t = -.06k^0_t - .16L^0_t + .93r_{t-1} + .31 \quad (s = .10) \)

B. **Reformulated Model.** (See Anderson (1974).)

1. \( \text{GD}/\pi^* = -11(r_b - r)_t + 105r_t - 69r_{t-1} + .08y/P_t - .04y/P_{t-1} \)  
   \[ + 33T_t + .68GD/P_{t-1} - 554 \quad (s = 18.2) \]
2. \( \text{WD}/\pi^* = 8(r_b - r)_t - .03y/P_{t-1} - 9T_t + .07D/P_{t-1} + 112 \quad (s = 9.6) \)
3. \( (\text{PR}_t - \text{PR}_{t-4}) = .17(\text{GA}_t - \text{GA}_{t-4}) - .06(\text{GA}_{t-1} - \text{GA}_{t-5}) \)  
   \[ - 3(r_{mt} - r_{mt-4}) + .57(\text{PR}_{t-1} - \text{PR}_{t-5}) + 3 \quad (s = 3.9) \]
4. \( r_{mt} = .66r_t + .55r_{mt-1} + .45 \quad [\hat{\rho}_1 = -.34] \quad (s = .17) \)
5. \( r_t = -.03k^0_t - .18L^0_t + .04(r_{bt-1} - r_{bt-2}) + .05 \)  
   \[ [\hat{\rho}_1 = -.24] \quad (s = .09) \)

\(^1\)Less four observations for forecasts. The sample size was 54 and \( s \) denotes the equation standard error. See Table III for the complete set of definitions. * denotes that seasonal dummy variables were included but are not reported. Instrumental Variable estimation was used where required. No respecification improving equation (3) was obtained, and \( \rho_1 \) denotes the first order autoregressive error parameter.
### TABLE II

**Forecast Errors**

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<tr>
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<th>CD/P</th>
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<th></th>
<th>GA/P</th>
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<th>PR</th>
<th></th>
<th>rm</th>
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<tr>
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<td>C</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>A</td>
<td>B</td>
<td>C</td>
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<td>B</td>
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<table>
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<th></th>
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<td>1.6</td>
<td>23.4(^{+})</td>
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<td>18.6(^{+})</td>
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</tr>
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<td>(B)</td>
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<td>1.6</td>
<td>12.3(^{+})</td>
<td>5.7</td>
<td>20.4(^{+})</td>
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<td>9.6</td>
<td>1.6</td>
<td>18.0(^{+})</td>
<td>4.8</td>
<td>16.8(^{+})</td>
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</table>

(A) O'Herlihy and Spencer; (B) Anderson; (C) O'Herlihy and Spencer re-estimated allowing for

\[
    u_t = \sum_{i=1}^{4} \rho_i u_{t-i} + \epsilon_t
\]
### TABLE III

#### Definitions

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<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Source</th>
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</thead>
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<tr>
<td>GD&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Gross increase in shares and deposits outstanding net of interest credited to accounts during period t</td>
<td>Financial Statistics</td>
</tr>
<tr>
<td>WD&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Withdrawals of shares during period t</td>
<td>Financial Statistics</td>
</tr>
<tr>
<td>PR&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Repayments of mortgage principal during period t</td>
<td>Financial Statistics</td>
</tr>
<tr>
<td>NA&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Net advances of principal during period t</td>
<td>Financial Statistics</td>
</tr>
<tr>
<td>r&lt;sub&gt;mt&lt;/sub&gt;</td>
<td>Average rate of interest charged on new mortgages during period t</td>
<td>Financial Statistics</td>
</tr>
<tr>
<td>r&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Average rate of interest offered, post tax, on deposits during period t (= r_{dt}(1-T_t) )</td>
<td>Financial Statistics</td>
</tr>
<tr>
<td>ND&lt;sub&gt;t&lt;/sub&gt;</td>
<td>GD&lt;sub&gt;t&lt;/sub&gt; + Interest credited to accounts - WD&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Financial Statistics</td>
</tr>
<tr>
<td>LQ&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Liquidity ratio x 100 where the liquidity ratio is cash and &quot;non mortgage&quot; investments as a percentage of total assets at the end of period t</td>
<td>Financial Statistics</td>
</tr>
<tr>
<td>r&lt;sub&gt;bt&lt;/sub&gt;</td>
<td>Average rate of interest paid on bank deposits withdrawable at seven days notice, during period t</td>
<td>Financial Statistics</td>
</tr>
<tr>
<td>r&lt;sub&gt;At&lt;/sub&gt;</td>
<td>Average rate of interest paid by local authorities on short term loans during period t</td>
<td>Financial Statistics</td>
</tr>
<tr>
<td>T&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Standard rate of income tax expressed as a percentage payable during period t</td>
<td>Inland Revenue</td>
</tr>
<tr>
<td>y&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Personal disposable income in current money terms</td>
<td>Digest of Statistics</td>
</tr>
<tr>
<td>P&lt;sub&gt;t&lt;/sub&gt;</td>
<td>General Index of Retail Prices</td>
<td>Digest of Statistics</td>
</tr>
<tr>
<td>PH&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Index of New House Prices</td>
<td>Digest of Statistics</td>
</tr>
<tr>
<td>L&lt;sub&gt;t&lt;/sub&gt;, K&lt;sub&gt;0&lt;/sub&gt;</td>
<td>Liquidity and Reserves Constructions</td>
<td>O'Herlihy and Spencer</td>
</tr>
<tr>
<td>GA&lt;sub&gt;t&lt;/sub&gt;</td>
<td>NA&lt;sub&gt;t&lt;/sub&gt; + PR&lt;sub&gt;t&lt;/sub&gt;</td>
<td>O'Herlihy and Spencer</td>
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TABLE III, continued

<table>
<thead>
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<tr>
<td>( D_t )</td>
<td>Deposit and Shares Total at end of period ( t )</td>
<td>Financial Statistics</td>
</tr>
<tr>
<td>( M_t )</td>
<td>Mortgage total outstanding at the end of period ( t )</td>
<td>Financial Statistics</td>
</tr>
<tr>
<td>( Q_1, Q_2, Q_3 )</td>
<td>Seasonal Dummy variables</td>
<td>Construction</td>
</tr>
<tr>
<td>( D(1), D(2) )</td>
<td>Mild and Severe Rationing Dummy Variables</td>
<td>O'Herlihy and Spencer</td>
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</tbody>
</table>

The following is taken from Financial Statistics notes April 1972 with reference to Building Societies.

1. Statistics are based on returns from a sample of about 85 societies with assets amounting to 90% of total building society assets: all societies exceeding £50 million included, 2/5 of societies with assets £10m-£50m and 1/13 of societies with assets of less than £10m. Each year figures are reconciled with statutory returns made to Registrar of Friendly Societies by all building societies.

2. Pre-1965 statistics based on annual and quarterly samples smaller than the sample size now used (33 societies), together with annual statistics of Registrar.
TABLE V

Unrestricted Reduced Form Estimates

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<tr>
<th></th>
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<th>T_t</th>
<th>r_pt</th>
<th>(y/P)_t</th>
<th>(D/P)_t-1</th>
<th>L^0_t</th>
<th>K^0_t</th>
<th>(GD/P)_t-1</th>
<th>(GA/PH)_t-1</th>
<th>PR_t-1</th>
<th>r_{mt-1}</th>
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The s values (adjusted for degrees of freedom) are 15.3, 9.4, 11.9, 4.5, 0.16, .09 ('t' values in parentheses).
TABLE V, continued

Solved Reduced Form Estimates

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<th>r^t</th>
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REFERENCES


