A STABILITY TEST FOR SIMULTANEOUS EQUATION MODELS

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Abstract

This paper presents a stability test for simultaneous equation models based on the predictive ability of the model. The test is given as a function of the values of the likelihood over two subsamples and so, it is readily available with existing software. The usefulness of the test is illustrated with an application to the analysis of investment in Spain.

Resumen

Este trabajo presenta un contraste de estabilidad para modelos de ecuaciones simultáneas, basado en la capacidad predictiva del modelo. El contraste se deriva como función de los valores de la función de verosimilitud en dos submuestras y por tanto, se puede calcular fácilmente con los programas econométricos existentes.

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1. Introduction

Stability testing is important in applied research for at least two reasons: 1) it is a way of detecting structural breaks, 2) it mitigates the problem of 'data mining', almost unavoidable in applied research. Stability tests for single equation models have been developed by Chow (1960). where their close relationship to the predictive ability of the model is shown. This paper presents a stability test for simultaneous equations models based on the predictive ability of the model. The test is presented in a way that can be easily evaluated with most existing econometric software. An application to the analysis of investment in capital goods in Spain is analysed. Section 2 gives the test and discusses some related problems. The application is presented in section 3.

2. A stability test for simultaneous equation models

This section discusses several aspects related to the problem of stability testing in simultaneous equations models. More specifically a stability test based on predictive ability is obtained in a form that can be easily implemented with existing econometric software.

We need first some notation. Let us define a simultaneous equation model by,

$$BY_t + C\,Z_t = \varepsilon_t, \qquad \varepsilon_t \sim N(0, \Sigma), \qquad E(\varepsilon_t\,\varepsilon_s') = 0, \; t \neq s \qquad (1)$$

where B is squared of order 'n' and there are 'k' predetermined variables, Z. The reduced form is given by

$$\begin{aligned} Y_t &= -B^{-1}\,C\,Z_t + B^{-1}\,\varepsilon_t \\ &= \pi\,Z_t + v_t, \qquad V(v_t) = \Omega \end{aligned} \qquad (2)$$

I define also $Z' = (Z_1, \ldots, Z_t)$ and similarly for other matrices (The notation is basically that of Hendry (1976). The superscripts (~), (^), will denote maximum likelihood estimators with the whole sample and the first T_1, observations respectively. The subindex $(\ )_1$ will denote the set of the first T_1, observations, and $(\ )_2$ the last $T_2(T_1+T_2 = T)$. The vectorization of a matrix is defined as the vector obtained stacking its rows, and is indicated by vec (A):

We can define the forecast error for the second period as

$$\bar{v}_f' = Y'_2 - Z'_2\,\hat{\pi} \qquad (3)$$

where $\hat{\pi}$ is the maximum likelihood estimator of π, based on the first T_1, observations. We immediately have

$$\mathrm{tr}\ \hat{\Omega}\ (\bar{v}'_f\ \bar{v}_f)\ \underset{A}{\sim}\ \chi^2_{nT_2} \qquad (4)$$

and this is a stability test based on predictive ability. Now (4) can be written as follows,

$$\begin{aligned} \mathrm{tr}\ \hat{\Omega}\ (\bar{v}'_f\ \bar{v}_f) + O(T_1^{-1}) &= \mathrm{tr}\ \hat{\Omega}^{-1}\ (\tilde{v}'\ \tilde{v} - \hat{v}'_1\ \hat{v}_1) \\ &= (\mathrm{vec}\ \tilde{v}')'\ (\hat{\Omega}^{-1} \otimes I)\ (\mathrm{vec}\ \tilde{v}') \\ &\quad - (\mathrm{vec}\ \hat{v}'_1)'(\hat{\Omega}^{-1} \otimes I)(\mathrm{vec}\ \hat{v}'_1) \qquad (5) \end{aligned}$$

since $\hat{\pi} - \tilde{\pi} = O(T^{-1})$, and this last expression is the equivalent of the Chow test for simultaneous equations models.

The stability test as given in (4) cannot generally be implemented with standard packages in an easy way. However, a simple transformation makes this possible. We note first that,

$$\begin{aligned} \mathrm{tr}\ \hat{\Omega}_1^{-1}(\tilde{v}'\ \tilde{v} - \hat{v}'_1\ \hat{v}_1) &= T_1 \mathrm{tr}(\tilde{v}'\ \tilde{v}(\hat{v}'_1\hat{v}_1)^{-1} - I) \\ &= T_1 \mathrm{Log}\ |\tilde{v}'\tilde{v}(\hat{v}'\ \hat{v}\ )^{-1}_1| + O(T^{-1}) \qquad (6) \end{aligned}$$

where the last step is based upon the fact

$$\mathrm{Log}\ |I + B| = \mathrm{tr}\ B + O(T^{-2}), \quad \text{if} \quad B = O(T^{-1}) \qquad (7)$$

The log of the likelihood function for the system (1) is

$$LK = -\frac{nT}{2}\,\mathrm{Log}\;2\pi - \frac{T}{2}\,\mathrm{Log}\;|\Omega| - \frac{1}{2}\,\mathrm{tr}\;\Omega^{-1}\,v'\,v \tag{8}$$

Concentrating out Ω, we get

$$LK^* = -\frac{nT}{2}\,(1 + \log\,2\pi) - \frac{T}{2}\,\log\,|\Omega| \tag{9}$$

where $\Omega = (v'v/T)$ and similarly for the first T_1 observations, LK^*_1. Simple manipulations yield

$$-2(LK^* - LK^*_1) = -\frac{2T_2}{T}\,LK^* + T_1\,\mathrm{Log}|\tilde{v}'\tilde{v}(\hat{v}_1'\hat{v}_1)^{-1}| + T_1\mathrm{Log}\left(\frac{T_1}{T}\right)^n \tag{10}$$

Since

$$T_1\;\mathrm{Log}(T_1/T)^n = -\,n\,T_2 + O\,(T^{-1}) \tag{11}$$

we get finally,

$$-2\;[(1 - (T_2/T))\;LK^* - LK^*_1] + nT_2 \underset{A}{\sim} \chi^2_{nT_2} \tag{12}$$

and this last expression can be readily evaluated with most existing econometric packages, since they generally produce the value of the likelihood as a standard result.

Let us consider now the stability tests, from a maximum likelihood point of view. If the number of observations in the second subsample is not sufficiently large, the estimated errors for that period will be identically zero. Then, the maximum likelihood ratio test for parameter constancy after concentrating out Ω is

$$-2(LK_R - LK_{UR}) = T\;\mathrm{Log}\;|\tilde{v}'\tilde{v}(\hat{v}_1'\hat{v}_1)^{-1}| + O(T^{-1}) \underset{A}{\sim} \chi^2_{nT_2} \tag{13}$$

Then, (6) is in fact a likelihood ratio test. (Note that LK_{UR} cannot be computed with standard programs since the parameters in the second sample are unidentified and the program will usually fail when attempting to estimate them). It is necessary now, to determine when T_2 is sufficiently large and therefore, (6) the appropiate test. We need some extra notation first,

$$A = (B;\ C), \qquad X = (Y;\ Z)$$

$$AX' = BY' + C\,Z' = E'$$

$$\text{vec } A = s - \int \alpha \qquad Q' = (\pi,\ I_k)$$
(14)

where the last expression is just a reparametrization of the restrictions required to identify A. Vectorizing the system we can writte,

$$Y^+ = X^+ \alpha + \varepsilon^+, \qquad Y^+ = (I \otimes X)\ s$$

$$X^+ = (I \otimes X) \int$$

$$\varepsilon^+ = \text{vec } E' \qquad (15)$$

The maximum likelihood estimator of α can be written as the solution of the following set of equations,

$$[\bar{X}^{+'} (\Sigma^{-1} \otimes I)\ X^+]\quad \alpha = \bar{X}^{+'} (\Sigma^{-1} \otimes I) Y^+ \qquad (16)$$

where $\bar{X}^+ = (I \otimes Z\ Q') \int$, or alternatively

$$\bar{X}^{+'} (\Sigma^{-1} \otimes I)\ (Y^+ - X^+ \alpha) = 0 \qquad (17)$$

Denoting by 'm_i' the number of unrestricted parameters in one equation we require,

$$\operatorname{rank}\ (\bar{X}_2^{+\prime}(\Sigma^{-1} \otimes I)\ X_2^{+}) = \sum_{i=1}^{n} m_i \tag{18}$$

for (16) to have a unique solution. If there are no crossed equations restrictions, $\int$ and X^{+} will be block diagonal. Then, (18) requires $T>m_i$ for all i. Conversely, if $T<m_i$ for all i, we can make $Y^{+}-X^{+}\ \alpha = 0$ and there is no unique solution for α. Then, the estimated reduced form errors will be trivially zero too, and therefore, the appropiate stability test will be that of (6). If $T>m_i$ for all i, the parameters in the second sample are identified and the test for parameter constancy can be implemented as a maximum likelihood ratio test of a set of linear restrictions. Given the following partitioning

$$Y' = (Y_1', Y_2'), \qquad Y^{o\prime} = \begin{bmatrix} Y_1' & 0 \\ 0 & Y_2' \end{bmatrix}, \qquad B^{o} = \begin{bmatrix} B_1 & 0 \\ 0 & B_2 \end{bmatrix} \tag{19}$$

and similarly for C, Z, we can write the unrestricted system as follows

$$B^{o}\ Y^{o\prime} + C^{o}\ Z^{o\prime} = E' \tag{20}$$

and conduct a conventional test by comparison of the maximum likelihood of (20) and (1).

If for some equations $T_2>m_i$ and for others $T_2<m_i$ we are in an intermediate situation. Condition (18) is not met. Considering an equation of the first set, $Y_{2i} - X_{2i}\ \hat{\alpha}_{2i} \neq 0$ since $T_2>m_i$ and therefore, there is no way we can make the errors zero, unless the observations are dependent. The estimator for the second subsample is not uniquely defined, but the maximum likelihood ratio test does not reduce to (6) either. This situation is somewhat peculiar, and in terms of finite sample power, it may be that the test given in (6) is good enough for most practical purposes.

When testing stability by means of predictive accuracy it is implicitely assumed that the errors are normally distributed. It is therefore advisable to test for this hypotesis. This can be done easily by means of an extended test of the type suggested by Bera and Jarque (1981), for a multivariate process. First, we transform to get independence by $u_t = \Sigma^{-1/2} \varepsilon_t$, and then we have,

$$\sum_{i=1}^{n} c_i \underset{A}{\sim} \chi^2_{2n} \tag{21}$$

where

$$\hat{\gamma}_{1i} = \Sigma \hat{u}^3_{it}/T$$

$$\hat{\gamma}_{2i} = (\Sigma \hat{u}^4_{it}/T) - 3(\Sigma \hat{u}^2_{it}/T)^2$$

$$c_i = \left(\frac{\hat{\gamma}^2_{1i}}{6\sigma^6_i} + \frac{\hat{\gamma}^2_{2i}}{24\sigma^8_i}\right) T \tag{22}$$

It is easily checked that the test (4) is also valid when the parameters are subject to non linear restrictions (for example AR errors). It is also easy to see that the test can be used to check the stability of the model over several subperiods. For example, if we breakdown the sample into three periods so that $T_1+T_2+T_3 = T$, supposing that there are enough observations to estimate the model in the first two, we have

$$\operatorname{tr} \Omega^{-1} (\tilde{v}' \tilde{v} - \hat{v}'_1 \hat{v}_1 - \hat{v}'_2 \hat{v}_2) \underset{A}{\sim} \chi^2_p$$

$$p = nT_3 + \sum_{i=1}^{n} m_i \tag{23}$$

Finally, the stability of independent equations can be tested, by setting up in the obvious way, a predictive test for that particular equation.

3. An application

The usefulness of a stability test for simultaneous equations models will be illustrated in this section through its application to the study of investment in Spain. With the unemployment rate running above 20% in 1984, investment has been identified as the only possible cure. The administration who came into power in 1982, has implemented a policy addressed to increase profits restraining wages, in order to create the necessary surplus to finance investment. It is then interesting to consider the estimation of an investment function and test for stability in the last two years. Since only annual data are available, this makes simultaneity more important, and dynamics less relevant. That is, income has an impact on investment through profits, but investment is related to output in the usual IS curve. With annual data, it is usually the case that contemporaneous relationships have a heavier weight, than lagged impacts. The best way to tackle this problem is to set up and estimate a simultaneous equation model for investment and profits. More specifically, the model that has been estimated by joint maximum likelihood is the following:

$$\Delta I = \underset{(3.9)}{.016}\ \Delta U + \underset{(5.6)}{.83}\ \Delta(E + E_{-1}) + e_1$$

$$R^2 = .67, \qquad \tilde{\sigma} = .045$$

$$\Delta E = \underset{(6.8)}{.74}\ \Delta y + e_2$$

$$R^2 = .62, \qquad \tilde{\sigma} = .021$$

$$\Delta y = \underset{(4.1)}{.21}\ \Delta I - \underset{(3.5)}{.008}\ R2 + \underset{(9.5)}{.045}\ D1 + \underset{(4.0)}{.125}\ D2 + e_3$$

$R^2 = .87 \qquad \tilde{\sigma} = .01$ (24)

Log of the likelihood = 123.3

where all variables are in logarithms except the long term interest rate R2, I is investment in capital goods, E are profits, y denotes the GDP, D1 and D2 are step dummies for the periods (66-74) and (75-81) respectively, and 'U' is the rate of utilization of the installed capacity. The investment function is precisely that derived by E. Malinvand (1983). The equation for output is a classical IS curve where omitted variables are gathered in the dummies. The interest rate is included explicity because it is important to show that it has an indirect negative impact on investment. The interest rate in the output equation captures the negative impact that it has on other kind of investment, consumption in durable goods, and perhaps a wealth effect.

The equations of the model have been subject to several tests in order to validate then. Autocorrelation tests for each equation independently were conducted, assuming an AR(2) error process for the particular equation being tested. Inspecting the residuals, no significant outliers were found. Omitted variables were tested for significance, specially in the investment equation: a long term interest rate, output, credit availability and the cost of labour relative to that of capital $(i-p+\delta)$, 'δ' being a depretiation rate, were found to be insignificant.

Two variables tested in the profits equation have been import prices and the real wage. Although this last variable was almost significant (t = 1.9), it is was decided to drop it, given the very limited number of observations. In the output equation, the real exchange rate and an index of world trade were tried. This last variable was conventionally significant ($t = 2.4$), but it was finally dropped, again because of the limitations imposed by the available sample (with such a low T, conventional significance limits, should be considerably increased, Mauleón (1982)). In any case, the stability test conducted with the enlarged model that included these two variables, gave very similar results.

Although not a very common practice in applied research, it may be wise to test for the homogeneity of the initial observations. Estimation of the model (24) over the sample 1968-1981, yield a value of the likelihood function equal to 108. Then the test (12) takes the value,

$$-2\ ((1 - \frac{T_2}{T})\ L - L_1) + n\ T_2 = 6 \underset{A}{\sim} \chi^2\ (6) \tag{25}$$

and therefore the stability of the model over the first two observations is easily accepted. The value of the likelihood obtained estimating the model over the sample 1966-1983, was 131.6. The test ~~(12)~~ is now,

$$-2\ ((1 - \frac{T_2}{T})\ L - L_1) + n\ T_2 = 21 \underset{A}{\sim} \chi^2(6) \tag{26}$$

that strongly rejects the homogeneity of the last two observations. It may also be interesting to conduct stability tests for several subsamples in order to determine the breaking point. This type of analysis has been advocated by Dufour (1982), and although the statistical meaning attached to it is ambiguous, it may be a very helpful descriptive device. Then, the model of (24) has been estimated over five different samples, starting with observations 1966 to 79, and adding one observation at a time. This shows again that the breaking point ocurred precisely in 1982. Finally it may be interesting to check the equations individually for stability. This can be done as indicated at the end of last section. Application of this last test shows that the model is unstable because all the individual equations are.

4. Conclusions

A stability test for simultaneous equations models based on the predictive ability of the model has been presented. The test is given in a way that can be readily implemented with most existing econometric software. Therefore, it is readily available to the practicioner. Several questions related to the test are discussed, and in particular, it is shown that the test is a maximum likelihood ratio test when the number of observations in the second sample is not large enough.

An application to the analysis of investment in Spain is discussed. The test is used to detect neatly, the breaking point of the model, and to evaluate the succes of failure of certain economic policies.

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APPENDIX

Data Sources

- All data have been taken from the National Accounts published by the Spanish National Institute of Statistics and the Databank of the Bank of Spain.

- Computations have been carried out at the IBM computer of the Bank of Spain, with version 4.0 of T.S.P.

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