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ESTIMATION OF PARAMETERS OF STRUCTURAL CHANGE UNDER SMALL SIGMA APPR0XIMATION THEORY

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ABSTRACT

In this paper, the structural change in a linear regression model over two different periods of time is estimated. The ordinary least squares and Stein-rule estimators are employed to estimate the structural change. Their efficiency properties are derived using the small sigma theory and dominance conditions are derived.

KEYWORDS

Structural change, ordinary least squares, Stein-rule estimators.

1 INTRODUCTION

In regression analysis it is generally assumed that the regression coefficients do not change over the period of study. However, in practice, there may arise many situations in which some or al the regression coefficients change.

In econometrics, it is often necessary to estimate model with structural change since economic relationships are usually unstable. Thus it is necessary to estimate the model under structural change. Suppose there exists a structural change in a linear regression model so that the model has two regimes. An important question in the regression analysis is whether sets of coefficients for different samples are identical. Once it is known that when models change and which coefficient change, estimation can be simply handed by the ordinary least square method.

Small disturbance asymptotic methods have been used previously on by many authors, e.g., Kadane [1] found the distribution to test of the over-identifying restrictions, Ramage [2] studied the specification error, Brown [3] studied the reduced form estimation and forecasting, Klein[4] studied the effect of choosing a particular normalization rule, Peck [5]studied estimators in the presence of pooled time-series and cross-sectional data, Srivastava [6] and Brown, Ramage and Srivastava [7] studied the disturbance variance estimators, Sawa [8] studied the small sigma (σ) asymptotically unbiased estimator whose finite sample moments exists. Thus small asymptotic can by thought of as reasonably good approximation. Small sigma asymptotic has the important advantage over large sample theory of being able to "correct" the sample size. Therefore, whenever an econometrician is prepared to trust large sample theory, he should be willing to trust small σ theory as well. Small disturbance approximation will be good or poor in any application depending on whether σ is small or not in context.

In this paper the estimation change in coefficients of a linear regression model over two different periods of time. For these ordinary least squares estimator and estimators arising from the family of stein-rule are employed to study the efficiency properties o difference estimator by employing small sigma approximation theory.

2 MODEL SPECIFICATION AND ESTIMATORS

Consider the linear regression model under the structural change as

$$y^{*} = X^{*}\beta^{*} + \sigma u^{*} \qquad (1)$$

$$y^{**} = X^{**}\beta^{**} + \sigma u^{**} \qquad (2)$$

where y^{*} and y^{**} are the $T^{*} \times 1$ and $T^{**} \times 1$ vectors of observations on the study variable respectively, X^{*} and X^{**} are the $T^{*} \times p$ and $T^{**} \times p$ full column rank matrices of observations on p explanatory variables respectively, β^{*} and β^{**} are the $p \times 1$ vectors of regression coefficients, u^{*} and u^{**} are the $T^{*}\times 1$ and $T^{**} \times 1$ vectors of disturbances respectively and σ is a scalar. These disturbance vectors are assumed to the stochastically independent following a multivariate normal distribution with mean vector null and variance covariance matrix identity. Thus it follows that

$$E(u^{*}) = E(u^{**}) = 0$$

$$E(u^{*}u^{*\prime}) = I_{T*}$$

$$E(u^{**}u^{**\prime}) = I_{T**}$$

$$E(u^{*}u^{**\prime}) = 0.$$

Here we are interested in the estimation of structural change in regression coefficients, which is measured by

$$\Delta = (\beta^{*} - \beta^{**}). \qquad (3)$$

If we employ the ordinary least squares method to estimate β^{*} and β^{**}, then Δ can be estimated by

$$D_{OLS} = (b^{*}_{OLS} - b^{**}_{OLS}) \qquad (4)$$

Where

$$b^{*}_{OLS} = (X^{*\prime} X^{*})^{-1} X^{*} y^{*}$$

$$b^{**}_{OLS} = (X^{**\prime} X^{**})^{-1} X^{**} y^{**}.$$

It is well known that the ordinary least squares procedure provides the best estimators of regression coefficient in the class of linear and unbiased estimators. In practice, sometimes the introduction of non- linearity and bias may lead to gain in efficiency considerably such as the estimators arising from Stein-rule procedure, see, e.g., Judge and Bock [9]. If we employ the Stein-rule procedure, then Δ can be estimated by

$$D_{SR} = (b^{*}_{SR} - b^{**}_{SR}) \qquad (5)$$

Where

$$b^{*}_{SR} = \left[1 - \frac{k}{T^{*} - p + 2} \frac{(y^{*} - X^{*} b^{*}_{oLs})'(y^{*} - X^{*} b^{*}_{oLs})}{b^{*\prime}_{oLs} X^{*} X^{*} b^{*}_{oLs}}\right] b^{*}_{oLs}$$

$$b_{SR}^{**} = \left[1 - \frac{k}{T^{**} - p + 2}\frac{(y^{**} - X^{**}b_{oLs}^{**})'(y^{**} - X^{**}b_{oLs}^{**})}{b_{oLs}^{**\prime}X^{**\prime}X^{**}b_{oLs}^{**}}\right]b_{oLs}^{**}$$

With k as positive characterizing scalar.

Another estimator of Δ can be formulated by writing the equations (1) and (2) compactly as

$$\begin{bmatrix} y^{*} \\ y^{**} \end{bmatrix} = \begin{bmatrix} X^{*} & 0 \\ 0 & X^{**} \end{bmatrix}\begin{bmatrix} \beta^{*} \\ \beta^{**} \end{bmatrix} + \sigma\begin{bmatrix} u^{*} \\ u^{**} \end{bmatrix}$$

$$y = X\beta + \sigma u. \qquad (6)$$

Now we can estimate the whole vector β by applying the Stein-rule procedure. This leads to the following estimator of Δ.

$$\hat{\Delta}_{SR} = \left(\hat{\beta}^{*} - \hat{\beta}^{**}\right) \qquad (7)$$

Where

$$\hat{\beta}^{*} = \left[1 - \frac{k}{T - p + 2}\frac{S}{b_{oLs}^{*\prime}X^{*\prime}X^{*}b_{oLs}^{*} + b_{oLS}^{**\prime}X^{**\prime}X^{**}b_{oLS}^{**}}\right]b_{oLS}^{*}$$

$$\hat{\beta}^{**} = \left[1 - \frac{k}{T - p + 2}\frac{S}{b_{oLs}^{*\prime}X^{*\prime}X^{*}b_{oLs}^{*} + b_{oLS}^{**\prime}X^{**\prime}X^{**}b_{oLS}^{**}}\right]b_{oLS}^{**}$$

With

$$S = \left[y^{*} - X^{*}b_{0LS}^{*}\right]'\left[y^{*} - X^{*}b_{0LS}^{*}\right] + \left[y^{**} - X^{**}b_{0LS}^{**}\right]'\left[y^{**} - X^{**}b_{0LS}^{**}\right]$$

is the residual sum of squares in the combined model and $T = T^{*} + T^{**}$.

3 PROPERTIES OF ESTIMATORS

In order to study the properties of D_{OLS}, D_{SR} and $\hat{\Delta}_{SR}$, we observe that

$$(D_{OLS} - \Delta) = (b_{oLS}^{*} - \beta^{*}) - (b_{oLS}^{**} - \beta^{**})$$
$$= \sigma\,[(X^{*\prime}X^{*})^{-1}X^{*\prime}u^{*} - (X^{**\prime}X^{**})^{-1}X^{**\prime}u^{**}],$$

Whence it is easy to see that

$$E(D_{OLS} - \Delta) = 0 \qquad (8)$$

$$Var(D_{OLS}) = \sigma^{2}[[X^{*\prime}X^{*}]^{-1} + [X^{**\prime}X^{**}]^{-1}]. \qquad (9)$$

Thus D_{OLS} is an unbiased estimator of Δ. However, if we consider D_{SR} and $\hat{\Delta}_{SR}$, it can be easily verified that both are biased estimators of Δ. The exact expressions for the bias vectors and mean squared error matrices of D_{SR} and $\hat{\Delta}_{SR}$ can be derived following judge and Bock [9] but these expressions will be quite intricate and may not shed any light on the efficiency properties as well as the gain arising from the use of one estimator over the other. We have therefore employed the small disturbance asymptotic theory to derive the efficiency properties. The properties of the estimators are given in the following theorems.

Theorem 1: When disturbance are small, the bias vector upto $0(\sigma^{2})$ and mean squared error matrix upto $0(\sigma^{4})$ are

$$B(D_{SR}) = E(D_{SR} - \Delta)$$
$$= -\sigma^{2}k\left[\frac{T^{*} - p}{(T^{*} - p + 2)\theta^{*}}\beta^{*} - \frac{T^{**} - p}{(T^{**} - p + 2)\theta^{**}}\beta^{**}\right]. \qquad (10)$$

$$MSE(D_{SR}) = E(D_{SR} - \Delta)(D_{SR} - \Delta)'$$
$$= V(D_{OLS}) - \sigma^{4}k\left[\frac{T^{*} - p}{(T^{*} - p + 2)\theta^{*}}C^{*} + \frac{T^{**} - p}{(T^{**} - p + 2)\theta^{**}}C^{**}\right]. \qquad (11)$$

whence

$$\theta^{*} = \beta^{*\prime}X^{*\prime}X^{*}\beta^{*}$$
$$\theta^{**} = \beta^{**\prime}X^{**\prime}X^{**}\beta^{**}$$

The proof of theorem 1 is given in Section 4.

Theorem 2: When disturbances are small, the bias vector upto $0(\sigma^{2})$ and mean squared error matrix upto $0(\sigma^{4})$ are

$$B(\hat{\Delta}_{SR}) = E(\hat{\Delta}_{SR} - \Delta)$$
$$= -\sigma^{2}k\,\frac{T - 2p}{(T - p + 2)(\theta^{*} + \theta^{**})}\Delta \qquad (12)$$

$$\mathrm{MSE}(\hat{\Delta}_{SR}) = E(\hat{\Delta}_{SR} - \Delta)(\hat{\Delta}_{SR} - \Delta)'$$

$$= V(D_{OLS}) - \sigma^4 k \frac{(T-2p)}{(T-p+2)(\theta^* + \theta^{**})} C \qquad (13)$$

Where $C^* = 2(X^{*\prime} X^*)^{-1} - \left[\frac{4+k}{\theta^*}\right] \beta^* \beta^{*\prime}$

$C^{**} = 2(X^{**\prime} X^{**})^{-1} - \left[\frac{4+k}{\theta^{**}}\right] \beta^{**} \beta^{**\prime}$

$C = 2(X^{*\prime} X^*)^{-1} + 2(X^{**\prime} X^{**})^{-1}$

$$- \frac{1}{(\theta^* + \theta^{**})} + \left[4 + k\frac{T-2p+2}{T-p+2}\right] \Delta\Delta'.$$

The proof of Theorem 2 is given in Section 4. From equations (8), (9) and (12), it is observed that the estimator D_{OLS} estimates Δ unbiased while the other two estimators D_{SR} and $\hat{\Delta}_{SR}$ do not so. However it is, difficult to draw any clear inference regarding the relative magnitude of biases.

Next, let us compare the estimators with respect to the criterion of the trace of mean squared error matrix. From (9) and (11), we observe that

$$\mathrm{tr}\, \mathrm{Var}(D_{OLS}) - \mathrm{tr}\, \mathrm{MSE}(D_{SR}) \qquad (14)$$

$$= \sigma^4 k \left[2tr[X^{*\prime} X^*]^{-1} + 2tr[X^{**\prime} X^{**}]^{-1} - (4+k)\left(\frac{\beta^{*\prime}\beta^*}{\theta^*} + \frac{\beta^{**\prime}\beta^{**}}{\theta^{**}} \right) \right]$$

Which is positive if

$$0 < k < 2a : a > 0 \qquad (15)$$

Where

$$a = \frac{\frac{\theta^*}{\beta^{*\prime}\beta^*} tr\left(X^{*\prime} X^*\right)^{-1} - 2}{1 + \frac{\theta^*}{\theta^{*\prime}} \frac{\beta^{**\prime}\beta^{**}}{\beta^{*\prime}\beta^*}} + \frac{\frac{\theta^{**}}{\beta^{**\prime}\beta^{**}} tr\left(X^{**\prime} X^{**}\right)^{-1} - 2}{1 + \frac{\theta^{**}}{\theta^*} \frac{\beta^{*\prime}\beta^*}{\beta^{**\prime}\beta^{**}}}.$$

If $\lambda_1^* \geq \lambda_2^* \geq \ldots \geq \lambda_p^*$ denotes the characteristic roots of $(X^{*\prime} X^*)$ and $\lambda_1^{**} \geq \lambda_2^{**} \geq \ldots \geq \lambda_p^{**}$ are the characteristic roots of $(X^{**\prime} X^{**})$, then

$$\lambda_p^* \leq \frac{\theta^*}{\beta^{*\prime}\beta^*} = \frac{\beta^{*\prime} X^{*\prime} X^* \beta^*}{\beta^{*\prime}\beta^*} \leq \lambda_1^* \qquad (16)$$

$$\lambda_p^{**} \leq \frac{\theta^{**}}{\beta^{**\prime}\beta^{**}} = \frac{\beta^{**\prime} X^{**\prime} X^{**} \beta^{**}}{\beta^{**\prime}\beta^{**}} \leq \lambda_1^{**}. \qquad (17)$$

Utilizing (16) and (`17), we observe that the inequality (15) is satisfied at least as long as

$$0 < k < 2a_{min} ; a_{min} > o \qquad (18)$$

Where

$$a_{min} = \frac{\lambda_p^{**}}{\lambda_1^* + \lambda_p^{**}} \left(\sum \frac{\lambda_p^*}{\lambda_i^*} - 2 \right) + \frac{\lambda_p^*}{\lambda_1^{**} + \lambda_p^*} \left(\sum \frac{\lambda_p^{**}}{\lambda_i^{**}} - 2 \right),$$

The sufficient condition (18) has an advantage over the condition (15), that it does not involve unknown regression coefficients and therefore can be fruitfully utilized in practice.

Similarly it is observed from (9) and (13) that $\hat{\Delta}_{SR}$ is supporter to D_{OLS} with respect to the criterion of trace of mean squared error matrix to the order of our approximation when trace of mean squared error matrix is positive, i.e.,

$$0 < k < 2\alpha ; \alpha > 0 \qquad (20)$$

where

$$\alpha = \left[\frac{T-p+2}{T-2p+2}\right] \left[\frac{\theta^* + \theta^{**}}{\Delta'\Delta}\right] [tr\,(X^{*\prime}X^*)^{-1} + tr\,(X^{**\prime}X^{**})^{-1} - 2].$$

Observing

$$\frac{\theta^*}{\Delta'\Delta} = \frac{\beta^{*'} x^{*'} x^* \beta^*}{(\beta^* - \beta^{**})'(\beta^* - \beta^{**})} \geq \frac{\beta^* X^{*'} X^* \beta^*}{\beta^{*'} \beta^*} \geq \lambda_p^* \qquad (21)$$

$$\frac{\theta^{**}}{\Delta'\Delta} = \frac{\beta^{**'} X^{**'} X^{**} \beta^{**}}{(\beta^* - \beta^{**})'(\beta^* - \beta^{**})} \geq \frac{\beta^{**'} X^{**'} X^{**} \beta^{**}}{\beta^{**'} \beta^{**}} \geq \lambda_p^{**}, \qquad (22)$$

the condition (18) is satisfied so long as

$$0 < k < 2\alpha_{min} : \alpha_{min} > 0 \qquad (23)$$

where

$$\alpha_{min} = \left[\frac{T-p+2}{T-2p+2}\right]\left[\frac{\lambda_p^* + \lambda_p^{**}}{\Delta}\right]\left[\Sigma\left(\frac{1}{\lambda_i^*} + \frac{1}{\lambda_i^{**}}\right) - 2\right].$$

Next, let us compare the estimators D_{SR} and $\hat{\Delta}_{SR}$. It is seen from (11) and (13) that

$$\text{tr MSE}(\hat{\Delta}_{SR}) - \text{tr MSE}(D_{SR})$$

$$= \frac{T^* - p}{(T^* - p + 2)\theta^*} \text{tr } C^* + \frac{T^{**} - p}{(T^{**} - p + 2)\theta^{**}} \text{tr } C^{**}$$

$$- \frac{(T - 2p)}{(T - p + 2(\theta^* + \theta^{**})} \text{tr } C. \qquad (24)$$

Thus a condition on k for the superiority of one estimator over the other can be obtained. From such a condition it will, however, not be possible to deduce a neat condition.

SUMMARY

In this paper, the aspect of structural change in regression analysis is considered. The estimators arising from least squares principle and Stein-rule procedure are employed to study the effect of change in structural coefficients in a linear regression model. The efficiency properties of the estimators are studied and the dominance condition of D_{SR} and $\hat{\Delta}_{SR}$ over D_{OLS} are derived by using the small sigma theory.

DERIVATION OF THE RESULTS

In order to derive small disturbance asymptotic approximations, we observe that

$$(b_{0LS}^* - \beta^*) = \sigma (X^{*'} X^*)^{-1} X^{*'} u^* \qquad (25)$$

$$(y^* - X^* b_{0LS}^*)'(y^* - X^* b_{0LS}^*) = \sigma^2 u^{*'} M^* u^* \qquad (26)$$

where

$$M^* = 1 - (X^{*'} X^*)^{-1} X^{*'}.$$

$$\overline{M}^* = (X^{*'} X^*)^{-1} X^{*'}.$$

Similarly, we get

$$\frac{1}{b_{0LS}^* X^{*'} X^* b_{0LS}^*} = \frac{1}{\beta^{*'} X^{*'} X^* \beta^*}\left[1 + 2\sigma \frac{\beta^{*'} X^{*'} u^*}{\beta^{*'} X^{*'} X^* \beta^*} + \sigma^2 \frac{u^{*'}(I - M^*)u^*}{\beta^{*'} X^{*'} X^* \beta^*}\right]^{-1}$$

$$= \frac{1}{\beta^{*'} X^{*'} X^* \beta^*} - 2\sigma \frac{\beta^{*'} X^{*'} u^*}{(\beta^{*'} X^{*'} X^* \beta^*)^2} + \ldots. \qquad (27)$$

Employing (25), (26) and (27) we find that

$$(b_{SR}^* - \beta^*) = \sigma e_1^* - \sigma^2 e_2^* - \sigma^3 e_3^* + 0_p(\sigma^4) \qquad (28)$$

where

$$e_1^* = (X^{*'} X^*)^{-1} X^{*'} u^*$$

$$e_2^* = \left[\frac{k}{T^* - p + 2}\right] \frac{u^{*'} M^* u^*}{\beta^{*'} X^{*'} X^* \beta^*} \beta^*$$

$$e_3^* = \left[\frac{k}{T^* - p + 2}\right] \frac{u^{*'} M^* u^*}{\beta^{*'} X^{*'} X^* \beta^*} A^* X^{*'} u^*$$

with

$$A^* = (X^{*\prime}X^*)^{-1} - \frac{2}{\beta^{*\prime}X^{*\prime}X^*\beta^*}\beta^{*\prime}\beta^*.$$

Similarly expressions can be obtained for the estimation error of b_{SR}^{**} as follows :

$$(b_{0LS}^{**} - \beta^{**}) = \sigma(X^{**\prime}X^{**})^{-1}X^{**\prime}u^{**} \tag{29}$$

$$(y^{**} - X^{**}b_{0LS}^{**})'(y^{**} - X^{**}b_{0LS}^{**}) = \sigma^2 u^{**\prime}M^{**}u^{**} \tag{30}$$

where

$$M^{**} = I - (X^{**\prime}X^{**})^{-1}X^{**\prime}$$

$$\overline{M}^{**} = (X^{**\prime}X^{**})^{-1}X^{**\prime}.$$

After utilizing (29) and (30) we observe that

$$\frac{1}{b_{0LS}^{**\prime}X^{**\prime}X_{0LS}^{**}b^{**}} = \frac{1}{\beta^{**\prime}X^{**\prime}X^{**}\beta^{**}}\left[1+2\sigma\frac{\beta^{**\prime}X^{**\prime}u^{**}}{\beta^{**\prime}X^{**\prime}X^{**}\beta^{**}}+\sigma^2\frac{u^{**\prime}(I-M^{**})u^{**}}{\beta^{**\prime}X^{**\prime}X^{**}\beta^{**}}\right]^{-1}$$

$$= \left(X^{**\prime}X^{**}+\frac{\sigma^{**2}}{\sigma^{*2}}X^{*\prime}X^*\right)^{-1}. \tag{31}$$

Employing (29), (30) and (31) we find that

$$(b_{SR}^{**} - \beta^{**}) = \sigma e_1^{**} - \sigma^2 e_2^{**} - \sigma^3 e_3^{**} + 0_p(\sigma^4) \tag{32}$$

where

$$e_1^{**} = (X^{**\prime}X^{**})^{-1}X^{**\prime}u^{**}$$

$$e_2^{**} = \left[\frac{k}{T^{**}-p+2}\right]\frac{u^{**\prime}M^{**}u^{**}}{\beta^{**\prime}X^{**\prime}X^{**}\beta^{**}}\beta^{**}$$

$$e_3^{**} = \left[\frac{k}{T^{**}-p+2}\right]\frac{u^{**\prime}M^{**}u^{**}}{\beta^{**\prime}X^{**\prime}X^{**}\beta^{**}}A^{**}X^{**\prime}u^{**}$$

with

$$A^{**} = (X^{**\prime}X^{**})^{-1} - \frac{2}{\beta^{**\prime}X^{**\prime}X^{**}\beta^{**}}\beta^{**\prime}\beta^{**}.$$

Using the expression we get the estimation error of D_{SR}.

$$(D_{SR} - \Delta) = \sigma(e_1^* - e_1^{**}) - \sigma^2(e_2^* - e_2^{**})$$

$$+ \sigma^3(e_3^* - e_3^{**}) + 0_p)\sigma^4). \tag{33}$$

Thus the bias vector to order $0(\sigma^2)$ is given by

$$B(D_{SR}) = \sigma\, E(e_1^* - e_1^{**}) - \sigma^2 E(e_2^* - e_2^{**}). \tag{34}$$

We find that

$$E(e_1^*) = 0$$

$$E(e_2^*) = \frac{k(T^*-p)}{(T^*-p+2)\theta^*}\beta^*.$$

$$E(e_3^*) = 0.$$

Similarly we can find

$$E(e_1^{**}) = 0$$

$$E(e_2^{**}) = \frac{k(T^{**}-p)}{(T^{**}-p+2)\theta^{**}}\beta^{**}.$$

$$E(e_3^{**}) = 0.$$

Utilizing the above expectations, we get the result stated in the Theorem.

Next, the mean squared error matrix of order $0(\sigma^4)$ is given by

$$\begin{aligned}\mathrm{MSE}(D_{SR}) = \sigma^2 E(e_1^{*} - e_1^{**})(e_1^{*} - e_1^{**})' - \sigma^2 E[(e_1^{*} - e_1^{**})(e_2^{*} - e_2^{**})' \\ + (e_2^{*} - e_2^{**})(e_1^{*} - e_1^{**})'] - \sigma^4 E[(e_1^{*} - e_1^{**})(e_3^{*} - e_3^{**})' \\ + (e_3^{*} - e_3^{**})(e_1^{*} - e_1^{**})' - (e_2^{*} - e_2^{**})(e_2^{*} - e_2^{**})']. \qquad (35)\end{aligned}$$

It can be seen that

$$E(e_1^{*} - e_1^{**})(e_1^{*} - e_1^{**})' = [(X^{*\prime} X^{*})^{-1} + (X^{**\prime} X^{**})^{-1}]$$

$$E(e_1^{*} - e_1^{**})'(e_2^{*} - e_2^{**})' = 0.$$

$$E(e_1^{*} - e_1^{**})(e_3^{*} - e_3^{**})' = k\left[\frac{T^{*} - p}{(T^{*} - p + 2)\theta^{*}} A^{*} - \frac{T^{**} - p}{(T^{**} - p + 2)\theta^{**}} A^{**}\right]$$

$$E(e_2^{*} - e_2^{**})(e_2^{*} - e_2^{**})' = k^2\left[\frac{T^{*} - p}{(T^{*} - p + 2)\theta^{*}} \beta^{*\prime}\beta^{*} - \frac{T^{**} - p}{(T^{**} - p + 2)\theta^{**}} \beta^{**\prime}\beta^{**}\right].$$

Substituting the above expectations in (35) we obtain the mean squared error of D_{SR} as stated in the Theorem. Similarly the results (12) and (13) can also be derived.

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