CHUNG-HUA INSTITUTION FOR ECONOMIC RESEARCH

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AN-LOH LIN

DISCUSSION PAPER SERIES No. 9601

January 1996

Discussion Paper Series No. 9601

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by
An-loh Lin

Research Fellow
Chung-Hua Institution for Economic Research

January 1996

CHIER
Chung-Hua Institution for Economic Research

75 Chang-Hsing St., Taipei, Taiwan 106
Republic of China

AN-LOH LIN*

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Abstract

This paper examines a specification error which might have been committed by numerous authors in using a dummy variable in the AR(1) model. Theoretical and simulation results are obtained for the misspecified model, which omits a relevant lagged dummy variable.

Keywords: Dummy Variables, Dummy Functions, Distributed Lag Models, Specification Errors, Lagged Dependent Variables.

I. Introduction

This paper examines a specification error which might have been committed by numerous authors in using a dummy variable in the AR(1) model. A simple example is

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*The author is a research fellow at Chung-Hua Institution for Economic Research, Taipei, Taiwan. He is thankful to Ping-Wen Chiu for research assistance, Nancy Zigmund for editorial improvements, and Chi Chow of Chung-Hua for comments.

$Y_t=a+bX_t+cY_{t-1}+dD_t+v_t,$ (

where v_t is an error term and D_t, a dummy variable, may assume the val 1 for $t=t_1$ (type A), $t_2 \le t \le t_3$ (type B), or $t \ge t_4$ (type C), and 0 otherwis Some actual examples using this type of equation are Margo (1984), Bo and Giannini (1985), Bernanke (1986), Blecker (1989), Garman a Richards (1992), and Ramirez (1994).

However Equation (1) will not be appropriate if the effect of t dummy variable added does not decline exponentially as implied by t model. In particular, if its effect is limited totally to the current period, many outliers or unusual events will be, the following equation shou apply:

$Y_t=a+bX_t+cY_{t-1}+dD_t-cdD_{t-1}+w_t,$ (

which has an additional term for the lagged dummy variable. Equation (is thus misspecified if Equation (2) is the correct model. It is shown this paper the OLS estimate of the coefficient d based on the misspecifi model will be inconsistent if the dummy variable is of type B or C.

The purpose of this paper is to examine the misspecification proble and compare the simulation results of (1) and (2).

II. Specification

The dynamic impact of a dummy variable can be expressed by a dumn function $f(D_t)$ for D_t as defined above. The function, following Jorgens (1966) and Box and Tiao (1975), can generally assume a ratior distributed lag form of

$f(D_t)=[N(L)/D(L)]D_t$ (

with N and D being two polynomial functions of the lag operator L. F our purpose, we let N(L)=d and D(L)=1 or 1-cL. Thus we examine or two cases: dD_t and $[d/(1-cL)]D_t$. The effect of the dummy variable la only one period for the first case while it diminishes exponentially for t second case.

We consider the Koyck distributed-lag model for demonstration. The model can be specified as:

$$Y_t=a^*+[b/(1\text{-}cL)]X_t+f(D_t)+u_t. \tag{4}$$

A substitution of $[d/(1\text{-}cL)]D_t$ into (4) for $f(D_t)$ yields Equation (1), with $a=a^*(1\text{-}c)$ and $v_t=u_t\text{-}cu_{t-1}$, by making the rates of decline (c) for both X_t and D_t identical in order to stay with the AR(1) model. Likewise, substituting dD_t into (4) then yields Equation (2), a similar version of which was used by Gregory and MacKinnon (1980) in their estimation of the demand for money in Canada. These two equations thus imply two different courses of dynamic impact for the dummy variable D_t.

III. Estimation

It is well known that in the presence of Y_{t-1} the OLS estimates for (1) or the restricted LS estimates for (2), assuming each to be correctly specified, cannot be said to be unbiased but will be consistent if v_t or w_t is well-behaved. However, it can be shown that the OLS estimate of the coefficient d for (1), as a misspecified model of (2), will be inconsistent if the dummy variable is of type B or C.

To demonstrate this, let w_t be white noise and let the relevant lagged dummy term be omitted from (2) so that: $v_t=w_t\text{-}cdD_{t-1}$ and $E(v_t)=\text{-}cdD_{t-1}$ for (1). The OLS estimator of (1) is then given by

$$\hat{\beta}=(Z'Z)^{-1}Z'Y=\beta+(Z'Z)^{-1}Z'w\text{-}cd(Z'Z)^{-1}Z'D_{-1}, \tag{5}$$

where $\hat{\beta}=(\hat{h}\ \hat{d})'$, $h=(\hat{a}\ \hat{b}\ \hat{c})'$, Y, Z=(H D), H=(1 X Y_{-1}), and w are all in vector or matrix form.

Since both Y_{-1} and w are stochastic, the multiplicative terms in (5) cannot be separated out when the mathematical expectation of $\hat{\beta}$ is taken. Thus $\hat{\beta}$ cannot be said to be unbiased and will probably be biased for small sample sizes, as the last two terms of (5) will not be likely to vanish or cancel out.

To obtain the probability limit (plim) of $\hat{\beta}$, we first evaluate the inverse of $Z'Z$ by partitioning before seeking any plim because plim $(1/n)(Z'Z$ which involves a dummy variable, is a singular matrix and hen $[\text{plim}(1/n)(Z'Z)]^{-1}$ does not exist. Let $B=H'H-H'D(D'D)^{-1}D'H=H'M$ and $M=[I-D(D'D)^{-1}D']$, M being a symmetric idempotent matrix f $M'M=M$. Since MH is a nx3 matrix whose ith column consists of estimated residuals from the regression of the ith variable of H on t dummy variable D, $B=(MH)'(MH)$ is a 3x3 matrix of squared a cross-product sums of the estimated residuals and $\text{plim}[(1/n)(B)]^{-1}=\Sigma_{hh}^{-1}$ assumed to exist. Thus

$$(Z'Z)^{-1}(Z'w) = \begin{bmatrix} H'H & H'D \\ D'H & D'D \end{bmatrix}^{-1} \begin{bmatrix} H'w \\ D'w \end{bmatrix}$$

$$= \begin{bmatrix} B^{-1} & -B^{-1}H'D(D'D)^{-1} \\ -(D'D)^{-1}D'HB^{-1} & (D'D)^{-1}+(D'D)^{-1}D'HB^{-1}H'D(D'D)^{-1} \end{bmatrix} \begin{bmatrix} H'w \\ D'w \end{bmatrix}$$

$$= \begin{bmatrix} B^{-1}(MH)'w \\ -(D'D)^{-1}D'HB^{-1}(MH)'w+(D'D)^{-1}D'w \end{bmatrix}$$

and,

$$\text{plim}[(Z'Z)^{-1}(Z'w)] = \begin{bmatrix} \text{plim}[(1/n)B]^{-1}\text{plim}(1/n)[(MH)'w] \\ \{-\text{plim}[(1/n)(D'D)^{-1}]\text{plim}[(1/n)(D'H)] \\ \text{plim}[(1/n)B]^{-1}\text{plim}(1/n)[(MH)'w] \\ +\text{plim}[(1/n)(D'D)]^{-1}\text{plim}[(1/n)(D'w)]\} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

since MH and w are uncorrelated as assumed and so are D and w. By same token, we have:

$$\text{plim}[(Z'Z)^{-1}(Z'D_{-1})] = \begin{bmatrix} \text{plim}[(1/n)B]^{-1}\text{plim}(1/n)[(MH)'D_{-1}] \\ \{-\text{plim}[(1/n)(D'D)^{-1}]\text{plim}[(1/n)(D'H)] \\ \text{plim}[(1/n)B]^{-1}\text{plim}(1/n)[(MH)'D_{-1}] \\ +\text{plim}[(D'D)^{-1}(D'D_{-1})]\} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1-1 \end{bmatrix}$$

where m is the duration of the dummy, with m=1 for type A, m=m type B, and m=∞ for type C, since $\text{plim}[(D'D)^{-1}(D'D_{-1})]=\text{plim}[(1/m)(m-$

=plim[1-(1/m)]=1-(1/m) for finite duration and 1 for infinite duration as n tends to infinity. Also, $\text{plim}(1/n)[(MH)'D_{-1}]=0$ for MH is a matrix consisting of the estimated OLS residuals.

As a result, the probability limit of $\hat{\beta}$ is given by

$$\text{plim}(\hat{\beta})=\beta+\text{plim}[(Z'Z)^{-1}(Z'w)]-cd\,\text{plim}[(Z'Z)^{-1}(Z'D_{-1})]$$

$$=\begin{bmatrix} a \\ b \\ c \\ d[1-(1-1/m)c] \end{bmatrix} \tag{6}$$

Thus consistency of the OLS estimates of a, b, and c is not affected by the omission of the lagged dummy variable irrespective of the type of the dummy variable used. However the estimated coefficient of the dummy variable is consistent only for type A (or any similar type such that $D'D_{-1}=0$) but not for type B or C. As shown, $\text{plim}(\hat{d})=d[1-(1-1/m)c]$ for type B and $\text{plim}(\hat{d})=d(1-c)$ for type C, both of which are smaller than d in absolute value since $0<c<1$ is assumed.

IV. Simulation

To examine the issues of bias and consistency for the models (1) and (2), a simulation experiment is performed. We first generate Y^*_t, without a dummy variable, using the following two equations:

$$Y^*_t=2+X_t+cY^*_{t-1}+v_t, \tag{7}$$

$$Y^*_0=[7/(1-c)]+[1/\sqrt{(1-c^2)}]v_0, \tag{8}$$

where X_t and v_t are normal random variables and independently, identically distributed, with means equal to 5 and 0, respectively, and both having a unit standard deviation. As specified, Y^*_0 (initial value) has the same normal distribution as Y^*_t with the mean given by 7/(1-c) and the variance by $1/(1-c^2)$. We let c (rate of decline) take three different values, 0.8, 0.5 and 0.2, to examine their effect on estimation.

Next, three types of dummies are created: $D_t=1$ for t=6 (type A), $6\leq t\leq 8$

(type B), or $t \geq 6$ (type C), and 0 otherwise. Each Y_t, with a dummy, is the given by

$$Y_t = Y^*_t + 8D_t. \quad (9$$

where Y^*_t is dummy-free. Thus the impact of the dummy in each perio is assumed to last only one period. The assumed coefficient of the dumm in (9) is about 23% of the mean of Y_t for c=0.8 (or 57% if c=0.5, or 91% if c=0.2).

We let n (sample size) be: 25, 100, 400, 800, and 3,000. In all, 4 cases are considered depending on n, c, and D. To examine the samplin properties of (1) and (2), 500 samples are taken in each case. For a give n, values of X are fixed irrespective of c, the type of D, and samples, bu v_t changes with each sample, though not with c and the type of D Equation (1) is estimated by the ordinary least squares method (OLS) an Equation (2) by the restricted or nonlinear least squares method (RLS).

V. Results

We first compare the size of bias for (1) and (2). The bias, if it exists, i caused by the presence of Y_{t-1} for (2), but it is also caused by the missin lagged dummy for (1) as well. Table 1 presents the average and standar deviation (in parentheses) of 500 estimates of each parameter for the thre types of dummies (A, B, and C) under each c (0.8, 0.5, and 0.2), for n=2

The results indicate, first, that the intercept (a=2) is grossly overstatec particularly for (1), when the adjustment is slow (c=0.8). Take dummy for example, the averaged estimate of a is 18.8 for (1) and 5.3 for (2), a compared with the assumed value of 2. The true value is three standar deviations below 18.8 but only 0.65 of a standard deviation below 5.3 Thus the misspecification causes the bias to increase greatly. The bia however is sizably reduced for a small c (0.2) and does not seem to diffe very much among the three types of dummies. Second, the bias for c downward for both equations and is extremely large for (1). Moreover, appears to increase relatively when c is small. Third, the estimated b i essentially unbiased for (2) regardless of c and D. This is also true for (1 with the exception of type A with c=0.8 or 0.5. Finally, the estimated is seen to be unbiased for (2). But it is biased downward for (1), with the bias increasing for lengthier dummy and decreasing with smaller c.

We next examine the issue of consistency and the speed of convergence in view of the simulation results. The averaged estimates and the standard deviations are given in Table 2 for four sample sizes (100, 400, 800 and 3,000) for c=0.8. The estimates for c=0.5 or 0.2 are not provided because of their similarity. Since the estimated b and d for (2) and the estimated b for (1) are unbiased as noted above, our focus will be on the rest of the estimated coefficients.

First, the estimated a and c are seen to converge to the assumed values for (2) when n=800 for the three types of dummies. But the convergence is very slow, requiring n>3,000, for the misspecified model. Second, the estimated d converges to 8 for (1) when n=800 in the case of dummy A, but it decreases as n increases for dummies B and C. Again it requires n>3,000 for the estimated d to converge to its probability limit of 3.73, as given by d[1-(2/3)c], for dummy B, or 1.6, which is equal to d(1-c), for dummy C. Thus, the estimates of d for types B and C are found to be clearly inconsistent for the misspecified model.

VI. Conclusion

This paper examines the dynamic impact of a dummy variable in the AR(1) model. It argues that the impact may not diminish exponentially as generally assumed. In many cases the impact may be short-lived, lasting for one period, and the addition of a one-period restricted lagged dummy is thus required. Failing to do this will result in a specification error which will gravely bias the estimates of the intercept and the rate of decline, and will also make the estimated coefficient of the dummy variable inconsistent unless the dummy is of the type such that $D_t' D_{t-1}=0$, where D_t is the vector of dummy values. The simulation results also indicate that the convergence of the above-mentioned parameters to their probability limits is very slow for the misspecified model. Thus consistency seems to be a virtue of cold comfort to practitioners even if it exists despite misspecification.

Table 1 Average (Standard Deviation) of 500 Estimates of Each Parameter for Equations (1) and (2) Under the Three Types of Dummies for n=25

Equation:	(1) $Y_t=a+bX_t+cY_{t-1}+dD_t+v_t$ estimated by OLS				(2) $Y_t=a+bX_t+c_{t-1}+dD_t-cdD_{t-1}+w_t$ estimated by RLS			
Dummy(D)	a=2	b=1	c	d=8	a=2	b=1	c	d=8
				c=0.8				
A	18.807	0.746	0.370	7.614	5.296	0.979	0.713	7.8
	(5.540)	(0.245)	(0.146)	(1.352)	(5.084)	(0.232)	(0.127)	(0.8
B	19.682	1.057	0.301	6.268	5.609	0.978	0.704	7.9
	(5.630)	(0.319)	(0.121)	(1.421)	(5.507)	(0.266)	(0.136)	(0.8
C	18.052	0.997	0.344	6.021	6.078	0.962	0.692	8.0
	(5.903)	(0.277)	(0.134)	(1.519)	(6.309)	(0.271)	(0.158)	(1.3
				c=0.5				
A	7.313	0.862	0.183	7.677	2.870	0.996	0.443	7.8
	(1.996)	(0.239)	(0.110)	(1.323)	(2.849)	(0.239)	(0.157)	(1.0
B	7.213	0.984	0.145	7.352	3.240	0.981	0.422	8.0
	(2.453)	(0.266)	(0.096)	(1.065)	(5.507)	(0.264)	(0.166)	(0.9
C	6.378	1.007	0.187	6.781	3.239	0.977	0.420	8.0
	(2.512)	(0.256)	(0.107)	(1.163)	(3.198)	(0.258)	(0.177)	(1.0
				c=0.2				
A	3.424	0.955	0.069	7.864	2.250	1.007	0.169	7.9
	(1.502)	(0.245)	(0.097)	(1.243)	(2.197)	(0.246)	(0.174)	(1.2
B	3.406	0.992	0.048	7.840	2.534	0.993	0.145	8.0
	(1.912)	(0.260)	(0.091)	(0.917)	(2.334)	(0.251)	(0.174)	(0.7
C	3.123	1.009	0.066	7.576	2.509	0.992	0.145	8.0
	(1.900)	(0.252)	(0.102)	(1.028)	(2.203)	(0.241)	(0.170)	(0.6

Equation (1) is a misspecified model of equation (2). n=sample size. OLS=ordinary least squ RLS=restricted least squares. Values of X_t remain fixed irrespective of c, D, and samples. Fi shown are the average of 500 estimates and those in parentheses are the standard deviation o estimates. A: $D_t=1$ for $t=6$ and 0 otherwise. B: $D_t=1$ for $6\leq t\leq 8$ and 0 otherwise. C: $D_t=$ $6\leq t$ and 0 otherwise.

Table 2 Average (Standard Deviation) of 500 Estimates of Each Parameter for Equations (2) and (3) Under the Three Types of Dummies for Various Sample Sizes for c=0.8

Equation:	(1) $Y_t=a+bX_t+cY_{t-1}+dD_t+v_t$ estimated by OLS				(2) $Y_t=a+bX_t+cY_{t-1}+dD_t-cdD_{t-1}+w_t$ estimated by RLS			
n	a=2	b=1	c=.8	d=8	a=2	b=1	c=.8	d=8
			$D_t=1$ for t=6 and 0 otherwise					
100	6.887	0.920	0.669	8.223	2.717	0.995	0.780	8.011
	(2.416)	(0.103)	(0.065)	(0.975)	(1.784)	(0.101)	(0.049)	(0.748)
400	3.041	1.011	0.769	7.936	2.171	0.999	0.795	7.927
	(0.945)	(0.048)	(0.025)	(1.023)	(0.853)	(0.048)	(0.023)	(0.801)
800	2.467	0.997	0.787	8.050	2.044	1.001	0.799	8.046
	(0.652)	(0.038)	(0.017)	(1.023)	(0.617)	(0.038)	(0.016)	(0.778)
3000	2.152	0.998	0.796	8.077				
	(0.292)	(0.018)	(0.008)	(0.995)				
			$D_t=1$ for $6 \le t \le 8$ and 0 otherwise					
100	8.886	0.936	0.609	5.082	2.741	0.995	0.779	8.047
	(2.714)	(0.105)	(0.073)	(0.877)	(1.797)	(0.102)	(0.049)	(0.747)
400	3.382	1.038	0.755	4.024	2.175	0.999	0.795	7.952
	(0.985)	(0.048)	(0.026)	(0.665)	(0.854)	(0.048)	(0.023)	(0.783)
800	2.951	0.993	0.774	3.906	2.045	1.001	0.799	8.025
	(0.686)	(0.038)	(0.018)	(0.603)	(0.617)	(0.038)	(0.016)	(0.770)
3000	2.201	1.002	0.794	3.824				
	(0.297)	(0.018)	(0.008)	(0.602)				
			$D_t=1$ for $6 \le t$ and 0 otherwise					
100	6.055	1.030	0.680	2.578	2.757	0.995	0.779	8.014
	(2.496)	(0.105)	(0.068)	(0.852)	(1.837)	(0.102)	(0.050)	(1.059)
400	2.970	1.020	0.769	1.880	2.189	0.999	0.795	7.963
	(0.984)	(0.048)	(0.025)	(0.552)	(0.904)	(0.048)	(0.023)	(1.137)
800	2.498	1.013	0.783	1.787	2.028	1.000	0.799	8.096
	(0.751)	(0.038)	(0.017)	(0.493)	(0.662)	(0.038)	(0.016)	(1.112)
3000	2.085	1.001	0.798	1.652				
	(0.521)	(0.018)	(0.008)	(0.452)				

See explanations given in table 1

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財團法人 中華經濟研究院

CHUNG-HUA INSTITUTION FOR ECONOMIC RESEARCH
75 Chang-Hsing St., Taipei, Taiwan, 106
Republic of China
TEL : 886-2-735-6006
FAX : 886-2-735-6035