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Introduction: P.A.V.B. Swamy's contribution to Econometrics

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ABSTRACT

This paper introduces this special issue of Economic Modelling which marks the significant contribution made by P.A.V.B Swamy to econometrics. His work spans almost 50 years and has been both innovative and challenging. The many distinguished authors who have contributed to this volume attests to the high regard in which he is held in the profession.

1. Introduction

This special issue of *Economic Modelling* has been compiled to commemorate the contributions of P.A.V.B Swamy, one of the most original thinkers in econometrics during the past forty years. It is also our way of expressing our appreciation to Swamy (as he is almost universally known) for being our friend and colleague.

Swamy received a B.A. in economics from Andhra University, India, in 1956, both an M.A. in economics and a M.S. in statistics from the same university in 1958 and a Ph.D. in economics from the University of Wisconsin, Madison, in 1968. He wrote his Ph.D. dissertation under the supervision of Arthur Goldberger. The other members of the dissertation committee were Edward Feige and Arnold Zellner. The title of his thesis was "Statistical Inference in a Random Coefficient Regression Model." The idea of developing a random coefficient model originated from Klein's depiction of a model with random coefficients in his 1953 textbook on econometrics and Zellner (1969) on aggregation.[1] Swamy's work on his Ph.D. thesis in many ways sets the tone for much of all his subsequent work, which includes 106 articles published in refereed journals (including thirteen papers in *Journal of Econometrics*, seven papers in *Journal of the American Statistical Association,* and three papers in *Econometrica*). His Ph.D. thesis led to a book, *Statistical Inference in Random Coefficient Regression Models* (1970), which quickly became a classic in the econometrics literature.

Initially, Swamy's career followed a conventional academic path leading from Assistant Professor at the State University of New York at Buffalo in 1967 to Professor at Ohio State University in 1972. His career then took a turn as he joined Board of Governors of the Federal Reserve System, where, from 1974 until 1995, he worked, first as an Economist, and then as a Senior Economist, in the Division of Research and Statistics. In 1995 he became a Financial Economist at the U.S. Office of the Comptroller of the Currency, where he remained until 2001. From 2001 through 2008 he worked as a Mathematical Statistician at the Statistical Methods Division of the Office of Employment and Unemployment Statistics, at the U.S. Bureau of Labor Statistics. In addition to the above appointments, Swamy held a number of part-time and visiting positions. Among the part-time positions, he had been an Adjunct Professor at the George Washington University and among the visiting positions, he had been a Visiting Scholar at the International Monetary Fund. He had also served on the editorial boards of the *Journal of Econometrics* and *Communications in Statistics*.

Swamy's scientific philosophy is based on the correct use of observed data to enhance understanding of the real world. As an econometrician faced with the problems of working with data in a policy environment, a good deal of Swamy's thinking has centred around the inadequacies of the conventional econometric paradigm. In this connection, Swamy has focused on the problems arising from the simultaneous presence of measurement error, misspecified functional forms, and omitted variables. His thinking on these problems has led him well outside the conventional paradigm, resulting in a unique research agenda and econometric methodology. In what follows, we provide an overview of his contributions to econometrics.

2. Fundamental Problems of Econometrics

Standard econometric modelling is plagued by the following four problems. (i) The correct functional forms of economic relationships are rarely, if ever, known. (ii) The error terms of econometric models indicate that data pertaining to some of the explanatory variables that belong in these models are not available. This situation, of course,

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[1] Swamy's dissertation was financed by a research assistantship under an NSF grant awarded to Zellner. J. N. K. Rao and T.R. Rao played pivotal roles in helping shape the initial stages of Swamy's career.

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leads to omitted-variable biases. (iii) It is difficult to obtain accurate estimates of the coefficients of models if their error terms and explanatory variables are correlated with each other. (iv) The use of data with measurement errors to estimate models introduces measurement-error biases into the coefficients. Because of these difficulties, a valid *joint solution* to the fundamental problems of unknown functional forms, omitted variables, measurement errors, and correlations between error terms and explanatory variables is needed. In collaboration with a number of co-authors, Swamy has made a singular contribution to econometrics by originating and developing an estimation procedure that deals with all of these fundamental problems simultaneously.

This procedure had its beginnings in Swamy's 1971 book, *Statistical Inference in Random Coefficient Regression Models*, his 1970 paper, "Efficient Inference in a Random Coefficient Regression Model", published in *Econometrica*, and his Chapter 5, "Linear Models with Random Coefficients", published in the book entitled, Frontiers in Econometrics, edited by Zarembka. Subsequent extensions led to this procedure's full development and its applications in a series of articles.[2] In those and other early contributions, Swamy pioneered the econometric method known as random coefficient estimation, and the extension of this procedure to random effects estimation. Under the random coefficient method, the coefficients of a regression model are allowed to fluctuate freely, with respect to both time and cross section, so that the empirical specification passes through each data point. Subsequently, Swamy extended and generalised this technique so that it deals simultaneously with the four major problems of econometrics mentioned above.

In this connection, Swamy showed the way misinterpretations of model coefficients and error terms in the presence of model misspecifications can be avoided using a coefficient-decomposition approach. A key aspect of this approach involves the use of what are called "coefficient drivers." Intuitively, coefficient drivers may be thought of as variables, which, though not part of the explanatory variables in a relationship, serve two important purposes. First, they deal with the correlations between the included explanatory variables and their coefficients.[3] In other words, even though it can be shown that the included explanatory variables are not unconditionally independent of their coefficients, they can be conditionally independent of their coefficients given the coefficient drivers. Second, the coefficient drivers allow the coefficient on a regressor to be decomposed into three components, such that one of these components representing the specification-bias-free component, is identified separately from the other two components, which represent specification biases. In one sense the coefficient drivers may be seen as a dual (and a generalization) of instrumental variables. A good instrument is correlated with the explanatory variable measured with error while being uncorrelated with the model's error term. A good coefficient driver is correlated with the parts of coefficients that arise from the econometric misspecification, and, therefore, provides information that allows the correction of the biases in the coefficients.

In what follows, we provide a more-detailed description of Swamy's contributions, including his unique methodological approach.

1. Golberger (1987) raised a crucial question about parameterization: Which features of a complete set of demand functions, derivable from maximization of a consumer utility function, ought to be treated as constant parameters if the utility function itself is not specified? His answer was: Any particular choice of constant parameters might be questioned, since the parameters of the demand functions are related to those of the utility function, which are unknown. Goldberger's answer may apply to other economic relationships as well. As a general procedure, the unknown functional form of a relationship suggested by economic theories can be embedded in an infinite class of functional forms defined by a linear-in-variables model, with the same variables as the theoretical relationship, but with freely-varying coefficients. We consider this idea so fundamental that we refer to it as the *Swamy Theorem*. The relationship coincides with the linear-in-variables model (or, what is the same thing, the linear-in-variables model will have the correct functional form) if the cross-sectional and time profiles of the coefficients of the linear-in-variables model are determined by the true functional form of the relationship.[4] This is an impervious method of avoiding incorrect functional forms in practice.[5] Another name for linear-in-variables models is the observation equations in state-space models, such as those employed — in Durbin and Koopman (2001). The true functional form of a linear-in-variables model with freely-varying coefficients can be found by equating each of these coefficients to a linear function of certain observable variables, called coefficient drivers, plus an error term.
2. Pratt and Schlaifer (1984, 1988, p. 34) proved that, in the absence of measurement errors, the error term of any econometric model cannot be independent of its explanatory variables unless the error term represents a certain "sufficient set" of relevant explanatory variables excluded from the model. The reasoning underlying the idea of a sufficient set of relevant explanatory variables runs as follows. (i) By construction, the error term of a model captures the net effect of omitted variables (since some of the effects are captured in the coefficients of the included explanatory variables). (ii) In the presence of such *net* indirect effects, it is not correct to assume that the omitted explanatory variables are independent of the included variables. (iii) To obtain independence, it is necessary to account for omitted-variables bias in each coefficient of the included variables. (iv) When such bias is eliminated, the error term will be the remainder after taking account of the effects of the excluded variables on the included variables. (v) It is these remainders that constitute a sufficient set of excluded variables.[6]
3. The explanatory variables of the observation equation in any state-space model cannot be uncorrelated with its coefficients if the explanatory variables are measured with error.[7] To deal with the lack of independence, Swamy has shown that, by making the coefficients functions of appropriate coefficient drivers, the explanatory variables can be assumed to be *conditionally* independent of the coefficients, given the coefficient drivers.[8]
4. Without further assumptions, the time-varying coefficients of the observation equation in any state-space model are unidentified in the sense they cannot be used to identify the true underlying structural parameters of interest.[9] Lehmann and Casella (1998, p. 24) showed that unidentified parameters are statistically "meaningless" (*i.e.*, they cannot be consistently estimated). To make the structural parameters partially identifiable and statistically meaningful, each coefficient of the observation equation

[2] See, [7,9,10,12,14,17,21,24,25,27,30,32,34,37,38,40,46,48,49,51,54,56–70,72,73,75,77,79–101,103–116]. The numbers correspond to those in the Annex. Jatinder Singh Mehta has been a co-author of forty eight of the papers listed in the Annex and George S. Tavlas has been a co-author of forty two of the papers listed in the Annex.

[3] A formal definition of coefficient drivers is provided in Swamy and Tavlas (2006) [106].

[4] Swamy and Tavlas [106] define a true fuctional form as follows: a relationship, has the true functional form if the forecasts of the dependent variable from the relationship given the values of its explanatory variables without measurement errors, are perfect for all time periods.

[5] See, [77,80–82,86,101,103–116,127–134,136].

[6] How such a "sufficient set" can be derived using the correct solution to the unknown functional-form problem is explained in [128,130].

[7] See, [73,81,82,87,88,91,93,94,100,104,106,107,108,111–114,116,130].

[8] See, [73,81,82,87,88,100,104,106,107,108,111,112,114,116,128,130,131,133,136].

[9] See, [130].