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RISE OF VAR MODELLING APPROACH*

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Abstract. This paper surveys the rise of the Vector AutoRegressive (VAR) approach from a historical perspective. It shows that the VAR approach arises from a fusion of the Cowles Commission tradition and time series statistical methods, catalysed by the rational expectations (RE) movement, that the approach offers a systematic solution to the issue of 'model choice' bypassed by Cowles researchers, hence essentially inheriting and enhancing the Cowles legacy rather than abandoning or opposing it. By tackling model choice, however, the VAR approach helps reform econometrics by shifting the research focus from measurement of given theories to identification/verification of data-coherent theories.

Keywords. History of econometrics; Methodology; Rational expectations; Structural model; VAR.

1. Introduction

This is a retrospective survey of the rise of the Vector AutoRegressive (VAR) approach mainly during the two decades of the 1970s and 1980s. The further refinements of the approach from the 1990s onwards, such as various identification issues in structural VARs, are beyond the scope of this survey. Different from what is commonly expected of a survey, this paper is focused on making a historical assessment of the rise via describing how the VAR approach came about, what issues it endeavoured to resolve and what methodological position it assumed, particularly in relation to the structural approach of the Cowles Commission (hereafter simply referred to as Cowles) tradition.[1]

It must be noted that the use of VAR models long precedes the rise of the VAR approach. The model was designated as the 'reduced form' of a structural model in its most general form in the Cowles tradition (e.g. see Mann and Wald, 1943; Koopmans, 1950). Empirical studies of the dynamic properties of macroeconometric models by means of a VAR could be traced back to Orcutt's (1948) work on the famous Tinbergen model (1939). Theoretical pursuit of efficient estimators specifically for the dynamic side of simultaneous-equation models (SEM) was explored by Sargan (1959). Early promotion of VARs as the dynamic representation of structural models was advocated by H. Wold under the banner

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of 'causal chain models' as opposed to the Cowles SEM approach (e.g. see Wold, 1954, 1960, 1964). However, it was not until the joint work of Sargent and Sims (1977) that the VAR approach emerged as an alternative methodology to the Cowles tradition based mainstream econometrics (e.g. see Pagan, 1987).

A major impetus of this paper comes from the marked disparity between the 'atheoretical' attribute of the VAR approach popularly held among the econometrics profession and the devotion of many VAR modellers to identification, causality test and structural modelling to support policy analysis, issues close to the heart of the Cowles tradition. The historical investigation reveals that the 'atheoretical' attribute is a partial and somewhat extreme label. The VAR approach has actually resulted from a fusion of the Cowles tradition and time series statistical methods, catalysed by the rational expectations (RE) movement. It has arisen from as well as been nourished by extensive interplay between macroeconomics and econometrics.[2] It offers a systematic way of resolving the issue of model choice with respect to the dynamic side, an issue left aside by the Cowles group.

The rest of the paper is organized as follows. The next two sections give a prelude to the VAR approach; Section 2 mainly describes the early econometric activities of C. Sims, the acknowledged leader of the VAR approach; Section 3 traces the RE movement with particular emphasis on the use of VARs. Section 4 is focused on the Sargent–Sims joint work (1977), which effectively launches the VAR approach. The well-known Sims's (1980a) manifesto of the VAR approach forms the subject of Section 5. Section 6 describes the emergence of the structural VAR (SVAR) approach. The concluding section gives methodological assessment of the rise of the VAR approach.

2. Dynamic Specification Gap: From Theory to Data

The 1960s saw increasing efforts in dynamic and stochastic modelling of agents' behaviour. Exemplary works include models for inventory control (e.g. see the joint research by Holt, Modigliani, Muth and Simon, 1960), studies emulating Koyck model (1954) in the area of production and investment (e.g. see Jorgenson, 1963; Griliches, 1967), and studies on the dynamics of demand (e.g. see Houthakker and Taylor, 1966). It was in this milieu that Sims undertook the mission to bridge 'the big gap between economic theory and econometric theory' (Hansen, 2004) when he started his econometrics career.

Sims's initial work was to study the effects of dynamic specification errors under the assumption that a theoretical model was known and given. Using a continuous time distributed-lag model as the given theoretical model, he demonstrated two dynamic specification gaps in applying the model to data – one was the approximation of the continuous-time model by a discrete-time model (1971) and the other the approximation of an infinite lag distribution by a finite lag one (1972a). The two studies led him to the view that 'the usual approach . . . to proceeding to "efficient" estimation and inference as if the [empirical] model were exact, can lead to serious errors' (1972a). These studies are reminiscent of Haavelmo's discovery (1943) of the OLS 'bias' in the context of an SEM.

However, Sims soon switched his research angle. He began to investigate the dynamic specification gap from data to theory, instead of starting from a given theoretical model. An important impetus appeared to be Granger's (1969) introduction of what is now known as Granger causality test.[3] The test was designed to detect sequential causality between time-series variables and the design was inspired by mathematician, N. Wiener. The test rules out one variable causing another if the past of the former exerts no impact on the latter in a dynamic bivariate relationship, which is effectively a VAR. More precisely, the test decides that y does not cause z if all the parameters $\pi_{21,i}$ are shown to satisfy $\pi_{21,i} = 0$ in the following bivariate VAR:

$$\begin{aligned} y_t &= \sum_{i=1}^{p} \pi_{11,i} y_{t-i} + \sum_{i=1}^{p} \pi_{12,i} z_{t-i} + u_{1,t} \\ z_t &= \sum_{i=1}^{p} \pi_{21,i} y_{t-i} + \sum_{i=1}^{p} \pi_{22,i} z_{t-i} + u_{2,t} \end{aligned} \tag{1}$$

where u_1 and u_2 are white-noise errors.

The significance of Granger's (1969) paper was recognized almost immediately by Sims for its intimate link to Wold's causal chain model, since Granger's notion of causality departed from the traditional static notion built upon SEMs. Sims applied Granger causality test to the money–income dynamic relationship (1972b) in order to show how time-series information could help differentiate a 'unidirectional causality' concerning rival theories on the relationship between money and income. Sims's application was immediately followed by Sargent. He adopted Granger causality test as the means to empirically assess the RE hypothesis (e.g. see Sargent, 1973; Sargent and Wallace, 1973; and also Qin, 2010a). Subsequently, Granger causality test became a core tool used by macroeconomists (see the next section and also Sent, 1998; chapter 3).

Sims's (1972b) paper elicited a great deal of interest 'because it came out in the peak of the monetarists-Keynesian controversy' (Hansen, 2004) and also because it touched the methodologically controversial issue as to what extent econometric models were capable of verifying behaviourally causal hypotheses. In response, Sims put forward a substantive clarification on 'exogeneity and causal ordering in macroeconomic models' (1977a).[4] Here, Sims related Granger causality to the 'strictly exogenous' concept and presented Granger causality as an augmentation of Wold's causal ordering by making the ordering testable.

Interestingly, Sims (1977a) also discussed the position of Granger causality with respect to the Cowles SEM approach. In his view, 'numerous maintained hypotheses of exogeneity' were needed for the implementation of an SEM, hypotheses which could easily lead to Granger causal ordering. Sims realized that the choice between an SEM and Wold's causal chain model would invoke inevitably the issue of identifiability of structural models. He tried to define 'structural' relations by two key attributes, following closely Hurwicz's (1962) definition. The first states that 'being "structural" is a property of the way we interpret the system as applying to the real world, not of the system's form'; and the second states that 'being behavioural is neither necessary nor sufficient to make a relation structural relative to an interesting class of possible interventions'. The latter was made in particular pertinence to Lucas' critique (1976) (see the next section). Sims maintained that the essence of econometric modelling was to search for a data-coherent causal model 'to buttress a claim that the model is behavioural or structural relative to variations in the path of x [the forcing variable in the model] as identifying interventions' and that Granger causality test was a useful tool in that connection, even though there lacked sufficient ground to verify a model displaying Granger causality being indeed a 'structural' model.

Sims's (1977a) paper paved the way for the VAR approach. It manifested his research interest in methodological matters with particular attention on filling the model specification gap between data and economic theory. Unfortunately, the manifestation has not been recognized widely in the econometric circle, probably because Sims (1977a) paper has largely been overshadowed by his (1980a) critique.[5]

3. RE Hypothesis and VAR

The early 1970s witnessed a major reform in macroeconomics. Widely known now as the RE movement,[6] the reform set to configuring macro theories into both dynamically testable and behaviourally optimizable models. In the eyes of key RE proponents, macroeconomics was weak both technically and methodologically, especially in comparison with the Cowles structural econometrics, and the weakness lay mainly in the lack of micro foundation in the Keynesian methodology; empirically, the weakness had led to poor forecasts and misguiding policy simulations by existing macroeconometric models (e.g. see Lucas and Sargent, 1978; Sargent, 1980).

The RE movement stems from the RE hypothesis originally formalized by Muth (1961) in a microeconomic context. Essentially, a RE model can arise from augmenting a simple static model, say a bivariate one

$$y_t = \beta z_t + \varepsilon_t \tag{2}$$

by an expectation term, y^e, of the endogenous variables y_t

$$y_t = \beta z_t + \lambda y^e_{t+k} + u_t \tag{3}$$

When $k = 0$, forward expectations are absent.[7] The RE hypothesis models the latent y^e_t on all the available information set $\{I_{t-1}\}$, i.e. the history of y_t and z_t in the present case

$$\begin{aligned} y^e_t &= E(y_t \mid \{I_{t-1}\}) = E(y_t \mid \{y_{t-1}\}, \{z_{t-1}\}) \\ &\Rightarrow \quad y_t - y^e_t = \nu_t \quad \Rightarrow \quad E(\nu_t \mid \{I_{t-1}\}) = 0 \quad \mathrm{Var}(\nu_t \mid \{I_{t-1}\}) = \mathrm{Var}(\nu_t) \end{aligned} \tag{4}$$

As a result, the expectation error, ν_t, should follow an innovative process, as shown in (4). Taking conditional expectation of equation (3), we get:

$$E(y_t \mid \{I_{t-1}\}) = (1-\lambda)^{-1}\beta E(z_{t-j} \mid \{I_{t-1}\}) = (1-\lambda)^{-1}\beta z_t^e \tag{5}$$

Equation (5) transforms the RE hypothesis into a model where the explanatory variable becomes the latent expectations of the original exogenous variable. The consequent need to model z_t^e becomes referred to as the requirement of 'completing' the model (e.g. see Wallis, 1980). For example:

$$z_t^e = E(z_t \mid \{I_{t-1}\}) = \sum_{i=1}^{p} \pi_{21,i}\, y_{t-i} + \sum_{i=1}^{p} \pi_{22,i}\, z_{t-i} \tag{6}$$

Combining (5) into (4) results in a closed VAR of the same form as (1).[8] This VAR is 'reduced' from the structural model (3) combined with the RE hypothesis in (5).

The RE movement thus foreshadows the VAR approach in two key and interrelated respects. It highlights the need of formulating a closed model in the sense that all the variables considered in a model should be regarded as potentially endogenous; and it rationalizes a general dynamic specification by the RE hypothesis.

At the time, the first aspect gave rise to a powerful critique by Lucas (1976) on the use of macroeconometric models.[9] Essentially, Lucas' critique questioned the legitimacy of using constant parameter macroeconometric models for policy simulations because shifts in policy would affect the constancy of certain structural parameters. In terms of the simple RE model given above, policy shifts amount to value changes in π_{22} when z represents the policy instrument; the changes would affect obviously π_{12} of the first equation of VAR (1) (see footnote 8), thus destroying the constancy of that equation.[10] Lucas' critique has invoked a great deal of rethinking about the practice of *a priori* categorization of endogenous versus exogenous variables. Attempts to make the categorization testable led to further popularization of Granger causality test (see Sargent, 1976a, 1978).

Meanwhile, an important demonstration of the second respect was Sargent's discovery of the 'observational equivalence' problem (1976b). In an effort to make it empirically possible to differentiate the impacts of Keynesian policy shocks versus shocks based on classical theories, Sargent stripped down what he considered as a general structural model into a Wold representation

$$\begin{aligned} y_t &= \sum_{i=0}^{\infty} \delta_{11,i} u_{1,t-i} + \sum_{i=0}^{\infty} \delta_{12,i} u_{2,t-i} \\ z_t &= \sum_{i=0}^{\infty} \delta_{22,i} u_{2,t-i} \end{aligned} \tag{7}$$

which was effectively an inversion of VAR (1) into a moving average (MA) model. Conceptually, Sargent assumed (7) as the 'structural' model by regarding the innovation errors of the RE hypothesis as policy shocks. In other words, if policy shocks are defined as un-anticipated deviations of the policy variable from its expected path, equation (5) can become

$$E(y_t \mid \{I_{t-1}\}) = \sum_{i=0}^{\infty} \delta_{11,i}\left(z_{t-i} - z^{e}_{t-1}\right) + \sum_{i=1}^{p} \pi_{11,i}\, y_{t-i} \tag{8}$$

which is equivalent to the y equation in (7). Note, the structural status of (7) has departed substantially from the Cowles' structural model framework and resonated the Slutsky–Frisch impulse-propagation scheme (see Frisch, 1933; Slutsky, 1937). Nevertheless, it is obvious that (7) can be transformed into a VAR, so that the 'reduced-form' status of the VAR remained intact. Since the first equation in (7) embraces theories of both RE and non-RE types depending on how the shock variables are formulated, the corresponding reduced-form VARs set the empirical limit to the testability of economic hypotheses concerned.[11]

For econometricians at the time, the RE movement essentially endorsed the VAR a central position in bridging time-series econometrics with macroeconomics. Moreover, it turned their attention from estimation and identification of structural parameters of *a priori* formulated models towards testing and searching for data-coherent models. The VAR approach emerged effectively from the starting point of such searches.

4. Emergence of VAR Approach

The blueprint of the VAR approach was first presented at a conference on business cycle research in November 1975 sponsored by the Federal Reserve Bank of Minneapolis. It came out as a joint work of Sargent and Sims (1977),[12] entitled 'Business cycle modelling without pretending to have too much *a priori* economic theory'. The title emphasized their opposition to the common practice of assuming that structural models were *a priori* set and well formulated. Sargent and Sims pointed out that many of those models lacked theoretical foundation and empirical support, thus reducing the practice to 'measurement without theory', a famous criticism with which Koopmans (1947) had charged the National Bureau of Economic Research (NBER) thirty years earlier (see Qin, 1993; chapter 6). Having rejected the common practice, Sargent and Sims groped for a new, alternative modelling route in order to improve the credibility of the theoretical content of macroeconometric models.

Broadly, the Sargent–Sims alternative contained the following steps. First, they compared the NBER method of deriving a 'reference cycle' indicator of business cycles from a selected group of variables with the conventional macroeconometric model approach of explaining business cycles by modelling key macro variables, and decided to follow the latter.[13] Next, they showed VARs as the general form of conventional macro models. They then proceeded to estimating the VAR and sought data-coherent ways of simplifying the VAR in order to identify and compare data-based model features with what had been postulated *a priori* in the form of a particular macro model nested in the VAR.[14] Finally, the simplified VAR is transformed into an MA model to enable the application of impulse response analysis for further assessment of the dynamic properties of the model and also for policy simulations.

To compare the Sargent–Sims route with the Cowles tradition, a closer examination is needed. Their choice in the first step appears in line with the Cowles procedure, i.e. to start econometric modelling from known theory. However, the structural model they choose is not an SEM but a distributed-lag model, i.e. a special case of the first equation in (1) or a dynamic augmentation of (2)

$$y_t = \sum_{i=0} \beta_i z_{t-i} + \varepsilon_t \tag{9}$$

The model thus shifts discussion from simultaneity to exogeneity and dynamics, a shift virtually mirrors the RE movement in macroeconomics. Although its link to VARs comes natural and apparently stays on par with the step of SEMs → reduced-form VARs in the Cowles tradition, the motivation is distinctly different. Instead of utilizing reduced-form models to facilitate estimation, Sargent and Sims use the link to justify Liu's (1960) argument to start empirical modelling from unrestricted VARs. They find Liu's strategy very useful for abandoning the incredible assumption of *a priori* known structural models. But different from Liu's intention to produce better forecasts, their primary goal is to make theory testable, which inherits and enhances the Cowles tradition. The goal renders crucial the third step of VAR simplification. Here, particular attention is given to testing exogenous variables so as to identify data-coherent causal ordering of the equations in the VAR. However, the concept of identification is no longer equivalent to that in the Cowles procedure. It has blended in the Box-Jenkins (1970) time-series notion of identification. Another source of VAR simplification discussed is cross-equation linkages/restrictions postulated in various theories, restrictions which form a natural ground for testing the theories concerned. Finally, the utilization of the simplified VAR to conduct impulse response analysis via its MA representation shares the Cowles conviction of producing models for policy purposes.

The Sargent–Sims joint venture attracted more criticisms than approval (see the comments in the conference proceedings). In defence, Sims emphasized that the new approach was developed more for hypothesis testing and evaluation than forecasting, see (Sims 1977b), whereas Sargent acknowledged that the VAR approach was more for prediction than policy evaluation (1979). Their apparently contradictory interpretations reflect the essential spirit of the Sargent–Sims joint venture. For a macro theorist, it is an opportunity to seek a systematic route of producing empirically operational theories, whereas for an econometrician, it is one to strengthen the theoretical underpinning of empirical models. The synergy adheres to the broad Cowles principle, but it was hidden almost completely by the rebellious veneer of their undertaking.

5. Manifesto to the VAR Approach

A fuller methodological exposition of the Sargent–Sims joint venture is given by Sims entitled 'Macroeconomics and Reality' (1980a). This article has been widely regarded as the manifesto of the VAR approach as an open departure from the Cowles structural modelling tradition.

The opening discussion of the manifesto was focused on the issue of identification, as implied by the title 'Macroeconomics and Reality'. The discussion resonated what had been argued in Sims's joint paper with Sargent (1977). It drew its main inspirations from the then recent RE movement; its specific attack was on those ad hoc dynamic restrictions used frequently for the conventional identification purposes; it defined the research interest within the domain of business cycle modelling and stressed the importance of adopting a fully dynamic and closed model so as to capture the possible impact of the changing time paths of any policy variables; and more fundamentally, it anchored its methodology on building models for the purposes of theory testing and policy analysis, rather than merely forecasting, although it regarded its position as comparable to Liu's (1960) critique.

Compared to Sargent and Sims (1977) paper, the identification discussion here substantially broadens the theoretical justification for the choice of the VAR route. The justification resorts to the focal attention of RE models on the dynamic interaction among macro variables, with specific reference to Lucas' (1976) critique concerning the validity of exogenous assumption of policy variables. In fact, the discussion foreshadows a broad correspondence between a VAR and the fundamental theme of dynamically general equilibrium in macroeconomics. Such a correspondence was absent in (Liu, 1960), when the reduced-form VAR model was mainly valued for its data summary and forecasting capacity.

Having laid a lengthy justification for his 'an alternative strategy', Sims proceeded to describe the VAR approach in detail. The starting point was to set up a closed and unrestricted VAR to summarize data. There were mainly two technical issues for consideration: whether the VAR would adequately summarize data information and whether any patterns or regularities could be revealed in the summary. The former was achieved via the choice of lag length and the latter via comparison of estimation results over different sub-samples. Next, possible simplification of the VAR was considered. A crucial simplification source was those 'hypotheses with economic content' which would normally limit 'the nature of cross-dependencies between variables'. While the initially unrestricted VAR facilitated hypothesis testing here, those hypotheses survived the testing would also bring in certain structural interpretation to the model. The simplified VAR was then transformed into an MA model to enable impulse response analyses. The MA representation was considered mostly useful in subjecting the model to 'reasonable economic interpretation', as well as in facilitating hypothesis testing via tracking the dynamic paths of shocks assumed of policy variables against what was implied in the hypotheses concerned. Through a detailed illustration of what possible routes a monetary innovation shock could affect a real output variable, Sims endeavoured to show how the VAR-based MA model could help empirically 'defining what battlefield positions must be' between rival theories.

Interestingly, Sims (1980a) attributes the hypothesis testing capacity of the VAR approach to the way by which the approach releases the hypothesis of interest from the 'burden of maintained hypotheses' under the conventional structural approach.

The burden is essentially a sequela of the Cowles' strategy of leaving aside the issue of 'model choice' when the group formalized econometric methods (e.g. see Qin, 1993; chapter 6). In the 1950s, Theil attempted to address this 'maintained hypothesis' problem explicitly by proposing an experimental approach of using an array of misspecification checks in a piece-meal manner, e.g. (Theil, 1957). That approach becomes generalized in the dynamic specification aspect under the general → specific procedure of the VAR strategy. Notice also how macroeconomics has evolved over the two decades. The RE movement, in particular, has turned theorists' attention from parametrizing behavioural propensities to tracing the sources of observed cyclical fluctuations and their dynamic characteristics. Sims's illustration reflects such a structural shift. It is none the less an identification attempt within the broad spirit of the Cowles enterprise, albeit it has moved away from those tightly parametrized structural models underlying the Cowles identification conditions.

However, the very act of moving away has abundantly opened the VAR approach for criticisms. Similarly to his joint work with Sargent (Sargent and Sims, 1977), Sims's (1980a) paper elicited more suspicion than appreciation among econometricians. The VAR approach was branded 'atheoretical macroeconometrics' (see e.g. Cooley and LeRoy, 1985), and described as 'dissented vigorously from the Cowles Commission tradition' (Pagan, 1987), but was 'not an adequate substitute for the Cowles programme' for drawing causal inferences (Leamer, 1985).

6. Moving Towards Structural VAR

Once the ground-breaking work was done, research in the VAR approach turned to further improvement of VAR techniques. The focal issues were however closely pertinent to the structural/causal interpretation of the VAR results. The improvement efforts led to the renovation of the VAR approach into the 'structural' VAR (SVAR) approach. The renovation can be seen as a natural defensive reaction to the criticisms. It nevertheless reinforces the commitment of VAR modellers to building models useful for policy purposes, a commitment shared by modellers following the Cowles tradition.

A vital prerequisite for the interpretability of the VAR results is model simplification, as a general VAR is known to suffer from the curse of dimensionality – the number of parameters growing with the number of variables and the maximum lag in a multiplicative manner. A primary technical issue on the VAR research agenda was to find a systematic 'shrinkage' strategy. This led to the joint work by Doan *et al.* (1984), which implemented Sims's (1980a) conjecture that the Bayesian approach might offer such a strategy.[15] Doan *et al.* (1984) imposed a number of Bayesian priors on each equation of an unrestricted VAR to help simplify mainly the lag lengths and possible time variation of the parameters. The equations were estimated one by one using the same set of priors to keep the symmetry of the VAR. A data-coherent and simplified VAR resulted from numerous experiments through the priors adjustments. Since parameter constancy was vitally important for the model applicability to simulations of policy shocks, Kalman filter and recursive estimation were used to examine the time-varying feature of their parameter estimates. To their relief, most parameter estimates revealed little time-varying feature in the experiments.[16]

However, the most controversial techniques were related to the impulse response analysis, which became labelled as 'innovation accounting' by Sims (1978).[17] As the MA representation of (7) was designated the structural model status, it became crucial to justify the structural interpretability of the innovation accounting. Obviously, the issue was intimately related to identification. But Sims found himself facing an apparently new identification problem – the impossibility of identifying an impulse shock with a particular structural shock if the error terms in the MA model were contemporaneously correlated across equations. Technically, he saw the solution in orthogonalizing the error terms. Conceptually, he found that solution closely linked with Wold's causal ordering, which could therefore be tested by Granger causality test. Sims thus proposed an experimental approach – use Granger causality test to simplify the cross-equation interdependence between variables, examine the degree of cross-equation correlation between the residual terms of the simplified VAR and then experiment with different Wold's causal orderings on the transformed MA; the experiment was to check either a particular theory-based ordering would generate the kind of impulse responses expected by the theory or which data-based ordering would be the most robust and to which theory such an ordering would render the best interpretation.

This experimental approach elicited immediate criticisms for two main reasons. Methodologically, it was too much data driven. Technically, it further blurred what should be considered as 'structural parameters' of the resulting model. In other words, the approach amounted to transforming those assumed 'structural shock' variables, u_{1t} and u_{2t}, in model (7) into another set of uncorrelated error terms; but it was impossible to transform the structural status to the new set unless the orthogonalizing parameters used in the transformation were established as structurally interpretable.

Efforts to slake the criticisms led VAR researchers to a significant retreat from the data-driven position. After all, development of VAR-based policy evaluation capacity was their primary research agenda (e.g. see Sims, 1986). One obvious alternative was to seek orthogonalizing ways from conventional economic theories. For instance, a 'structural' identification method for the error terms was initiated by Blanchard and Watson (1984) and extended by Bernanke (1986). The method essentially exploited the relationship between the error terms between a conventional SEM and its reduced form. Interestingly, the method moved the SVAR approach closer to the Cowles tradition. It resorted not only to an SEM for support of the structural interpretation of the shock-driven models of type (7) but also to the traditional use of *a priori* static restrictions for orthogonalization. Just as it was often difficult for modellers of conventional SEMs to find enough and adequately solid *a priori* restrictions without using certain arbitrary ones, SVAR modellers were not cleared themselves of the situation when they had to take arbitrary positions on whether certain cross-equation error correlation should totally reflect structural interdependence rather than 'passive responses' between equation disturbances (see Hansen, 2004; also Sims, 1986), because the available *a priori* restrictions from conventional structural models were often insufficient for orthogonalization.

The technical refinements were accompanied by VAR proponents' ardent defence of the usefulness of the VAR approach for theory-based policy analyses, notwithstanding the Lucas critique, e.g. see (Sims, 1982, 1986, 1987, 1989) and (Sargent, 1981). The defence was a natural reaction to the fast-rooted belief that VARs were good forecasting models but not structural models and thus incapable of structural inferences. Various VAR applications to testing rival macroeconomic hypotheses were presented by Sims (1980b; 1983), Blanchard and Watson (1984), Bernanke (1986), Litterman and Weiss (1985) and also Leeper and Sims (1994).[18] These applications demonstrated how flexible the VAR approach could be in relating empirical findings to particular dynamic theories of interest. In the late 1980s, this line of research found a new stimulus from the arrival of cointegration theory (see Granger, 1983; Engle and Granger, 1987). Since a cointegrated system could be naturally represented by a VAR (see Sims *et al.*, 1990), and cointegration theory rendered VARs a powerful link to long-run equilibrium based economic theories.

Meanwhile, research on the forecasting front came to an impasse. In preparation for a business-cycle forecasting conference organized by NBER in May 1991, Sims took over a small Bayesian VAR forecasting model from Litterman[19] and tried various experiments and technical extensions on it in order to improve its forecasts. In spite of his efforts, the nine-variable VARs failed to forecast the onset of the 1990–1991 US recessionary downturn (1993). The relatively strong forecasting performance of VARs over conventional macroeconometric models was fading away as those models became strengthened in dynamic specification. On the other hand, the limited variable coverage of VARs, due either to the modellers' allegiance to the principle of general equilibrium theory or to the technical curse of dimensionality, severely restricted VAR's forecasting competiveness with respect to other multivariate data methods such as dynamic factor analysis (see Qin, 2010b). Interestingly, the possibility of misspecification due to omitted variables has been highlighted repeatedly in the VAR literature (e.g. see Sims 1980b, 1989), in connection to changes of the causality test results due to changes in the number of variables included in the VARs.[20] But empirical VAR studies have remained on a very small scale in variable coverage nonetheless.

The VAR methodology gained firm acceptance from macroeconomists in the 1990s, led by influential works such as Bernanke and Blinder (1992) and Christiano *et al.* (1996). Meantime within the econometric circle, the methodology entered a consolidatory period via more technical refinements (e.g. see Watson, 1994). But the overall trend was clear: The research was following closely the Cowles motto of building better bridges between theory and data. Only the criteria for better bridges became more explicit and specific, as best illustrated from Sims's description of an 'ideal model', i.e. one which 'contains a fully explicit formal behavioural interpretation of all parameters', 'connects to the data in detail', 'takes account of the range of uncertainty about the behavioural hypotheses invoked' and 'includes a believable probability model that can be used to evaluate the plausibility, given the data, of various behavioural interpretations' (1989).

7. Methodological Reflection

The historical investigation reveals that the VAR approach arises as a methodological revision and renovation of the Cowles tradition.[21] Stimulated by the RE movement in macroeconomics, the VAR approach offers a systematic procedure to tackle the issue of 'model choice' bypassed by the Cowles group. The procedure embodies a synergy of various preceding methods explored by prominent econometricians and statisticians alike, such as Tinbergen's 'kitchen work' (1937), Liu's appreciation of a general VAR (1960), Leamer's sinning 'in the basement' (1978), as well as Granger's time-series approach to causality (1969) and the Box-Jenkins (1970) time-series notion of identification. In spite of its imperfections, the procedure has never abandoned the Cowles tradition of theory allegiance, policy-oriented research target and technical rigour.

Why then has the VAR approach been regarded by many as 'atheoretical macroeconometrics'? On the face of it, the 'atheoretical' attribute seems to be an over-generalization of using the unrestricted VAR model as the initial step of econometric investigation. In retrospect, this initial step indeed constitutes the most drastic proposition of the VAR approach, as it advocates a reversal of the structural→reduced-form sequence, a reversal with serious methodological implication of backtracking Frisch's (1937) 'structural' method in favour of Tinbergen's (1935) 'historical' method. Moreover, the polemics employed by VAR proponents against the macroeconometric practice of the time apparently encouraged the view that they had demarcated their methodological position from the Cowles methodology. But that is insufficient to brand them with the 'atheoretical' badge. Since the Cowles methodology had been consolidated into a paradigm by the late 1960s (see Qin, 2008), any attempts to challenge it would require substantive and sometimes radical justification.

Another likely reason for the 'atheoretical' attribute is the confusion of the VAR approach with the statistical properties of VAR models. While a VAR model is known for its capacity of summarizing data regularities, the VAR approach is a strategy to develop VAR-based structural models for policy purposes on the basis of such capacity. In retrospect, the confusion appears to have stemmed from a rather confined evaluation of the VAR approach within econometrics. The evaluation conceals effectively the fact that the VAR approach has emerged in close correspondence to the RE movement in macroeconomics. As mentioned before, the RE movement has affected mainstream econometrics by changing the way macro theories were formulated. Its emphasis on dynamics and micro foundation substantially complicated the simple and static form of macroeconomic models upon which traditional econometric models and methods were built. RE models have given rise to protean connotations to 'structural' models (Sims, 1991). The moving 'structural' post makes it no longer possible for econometricians to anchor their starting position on given 'true' models. A shift of stance to treat 'structural' models as testable null hypotheses rather than maintained hypotheses seems inevitable. Empirical verification of these newly postulated theories has reoriented econometric research to dynamic specification, hypothesis testing and shock simulation. The rise of the VAR approach epitomizes the reorientation. The approach shifts the focus of econometric modelling away from measurement of given structural parameters by explicitly abandoning the assumption that applied econometricians should have true models 'about which nothing was unknown except parameter values' (Hansen, 2004, p.276); and it puts great emphasis on searching for data-permissible theories. As a result, the VAR approach incites a methodological shift in macroeconometric research – a shift from mainly confirmatory analysis towards a mixture of confirmatory and exploratory analyses.

It is only with respect to its exploratory component that the VAR approach may be seen as 'atheoretical'. But viewing it in the broad light of the reforming macroeconomics, the VAR approach is avant-garde and at the same time starkly faithful to the Cowles tradition. As shown in the previous sections, VAR modellers have devoted a great deal to mend the link between structural and reduced-form models; they have placed the issue of structural identification on top of their research agenda; they have attached far greater importance to theory testing and policy analysis than to forecasting; they have concentrated their applications within the domain of connecting macro theories with stylized facts. But more importantly, both VAR and Cowles researchers share the same fundamental conviction that macroeconometric modelling should always be formulated, specified and estimated in a system of interdependent equations. While the Cowles group emphasize simultaneity at a static level and correspond that to a Walrasian equilibrium model, VAR modellers accentuate dynamic interdependence and correspond that to a dynamic general equilibrium model. Noticeably, the latter correspondence results in an unequivocal 'structural' interpretation of the error terms, an interpretation which is absent in the Cowles modelling framework but crucially important to sustain the use of the impulse response method. In this respect, the VAR approach has actually taken a stronger structuralist position than the Cowles group. The structural shock interpretation, which underlies the impulse response analysis, assumes away the possible existence of any theoretical ignorance or omission within a specified structural model.[22] To buttress such a strong assumption, VAR modellers have to confine their reform on the dynamic side of models in which the choice of variables is largely determined *a priori* by macroeconomics. The confinement effectively delegates the possibilities of misspecification to the general equilibrium scheme and makes the VAR approach fundamentally theory-bound.

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Notes

1. For more detailed description of the Cowles tradition and its consolidation, see Christ (1952, 1994), Qin (1993, 2008) and Gilbert and Qin (2006).
2. Much of the crossbreed occurred at the University of Minnesota, where Sargent, Sims and Wallace, the key players of the VAR approach or RE models were working on the economics faculty during the 1970s, e.g. see Hansen (2004) and Evans and Honkapohja, (2005). Apart from university duty, they were also involved part-time at the Federal Reserve Bank of Minneapolis. Most of the influential papers on RE models and the VAR approach appeared first as the FRBM Working Papers, see the Bank website archive.
3. Granger was first engaged in economic time-series research at Princeton University under the directorship of Morgenstern, see (Phillips, 1997).
4. The draft of the paper was presented at a conference in 1975 sponsored by the Federal Reserve Bank of Minneapolis, see Section 3.
5. According to Sims, 'virtually nobody has read and understood' his (1977a) paper (Hansen, 2004).
6. The RM movement is commonly viewed as initiated by Lucas (1972). There are numerous studies on the history and the methodology of the RE movement (e.g. see Sheffrin (1983), Maddock (1984), Sent (1998) and see also Young and Darity (2001), Sent (1997, 2002) for the early history of RE models).
7. The assertion of forward expectations brings a new technical issue into econometrics: the need for terminal conditions to assist unique solutions (e.g. see Pesaran, 1987, chapter 5). However, this issue does not compound our methodological discussion here. For simplicity, we will only consider RE models with current expectations hereafter.
8. In the VAR, the parameters of the first equation are function of the parameters of (3) and (6), i.e.: $\pi_{11,i} = (1-\lambda)^{-1}\beta\pi_{21,i}$ and $\pi_{12,i} = (1-\lambda)^{-1}\beta\pi_{22,i}$.
9. The paper was first circulated in 1973 as a Working Paper at Carnegie–Mellon University.
10. Notice that Lucas' original presentation did not use parameter shifts as such. He analysed the policy variable in terms of its permanent and transitory components. A shift in the permanent component is equivalent to a parameter shift in the autoregressive representation of the variable.
11. From the viewpoint of some macro theorists, however, this limit implies lack of identification power of econometric models with respect to many theoretically interesting but parametrically sophisticated RE models. As a result, empirical macroeconomics branches into two directions (see e.g. Summers, 1991), one still pursuing macroeconometrics whereas the other abandoning statistical methods to develop computable dynamic general equilibrium models (e.g. see Kydland and Prescott, 1991, 1996).
12. The conference proceeding is published in 1977 under the sponsorship of Federal Reserve Bank of Minneapolis.
13. They referred to the NBER method as the 'unobservable-index model' approach and the conventional macroeconometric model approach as the 'observable-index model' approach; they also reformulated the NBER method by factor analysis (see Qin, 2010b).
14. This objective is plainly phrased by Sims as trying to 'use available data to increase our understanding of economic behaviour' (1977a, p.5).

15. Initial experiment with a Bayesian VAR approach was explored by Litterman (1979) around the time Sims was preparing his (1980a) critique. For a historical account of the rise of Bayesian econometrics, see (Qin, 1996).
16. Several interesting results emerged in the Doan *et al* (1984) experiment, including the assumption of a unit root in each variable, i.e. the prior on the own first lag taking the value of one.
17. Sims (1980a) was first distributed as a University of Minnesota Economics Discussion Paper in 1977, and a part of his (1978) paper was later published in the book edited by Kmenta and Ramsey in 1982.
18. Note that the last paper, i.e. (Leeper and Sims, 1994), examines empirically a completely specified dynamic general equilibrium model.
19. Litterman was the key VAR modeller at the Federal Reserve Bank in Minneapolis, where a 46-equation monthly forecasting VAR model of the US was built during the mid 1980s. The small model had six variables and Sims extended to nine variables.
20. The issue was highlighted later in connection with the SVAR approach by Cooley and Dwyer (1998).
21. A very similar view was actually put forward by Eichenbaum, who argued that the VAR approach 'should be viewed as a necessary complement to an important class of structural models' (1985). But his view appears to have been totally ignored.
22. The problem that the shocks might not be uniquely interpreted as structural was pointed out by Hansen and Sargent (1991), see also Qin and Gilbert (2001) for a more detailed discussion on the history of the error terms in time-series econometrics.

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