Bayesian Multivariate Time Series Methods for Empirical Macroeconomics

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Abstract

Macroeconomic practitioners frequently work with multivariate time series models such as VARs, factor augmented VARs as well as time-varying parameter versions of these models (including variants with multivariate stochastic volatility). These models have a large number of parameters and, thus, over-parameterization problems may arise. Bayesian methods have become increasingly popular as a way of overcoming these problems. In this monograph, we discuss VARs, factor augmented VARs and time-varying parameter extensions and show how Bayesian inference proceeds. Apart from the simplest of VARs, Bayesian inference requires the use of Markov chain Monte Carlo methods developed for state space models and we describe these algorithms. The focus is on the empirical macroeconomist and we offer advice on how to use these models and methods in practice and include empirical illustrations. A website provides Matlab code for carrying out Bayesian inference in these models.

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1

Introduction

The purpose of this monograph is to offer a survey of the Bayesian methods used with many of the models used in modern empirical macroeconomics. These models have been developed to address the fact that most questions of interest to empirical macroeconomists involve several variables and, thus, must be addressed using multivariate time series methods. Many different multivariate time series models have been used in macroeconomics, but since the pioneering work of Sims (1980), Vector Autoregressive (VAR) models have been among the most popular. It soon became apparent that, in many applications, the assumption that the VAR coefficients were constant over time might be a poor one. For instance, in practice, it is often found that the macroeconomy of the 1960s and 1970s was different from the 1980s and 1990s. This led to an interest in models which allowed for time variation in the VAR coefficients and time-varying parameter VARs (TVP–VARs) arose. In addition, in the 1980s many industrialized economies experienced a reduction in the volatility of many macroeconomic variables. This Great Moderation of the business cycle led to an increasing focus on appropriate modelling of the error covariance matrix in multivariate time series models and this led to the incorporation of multivariate

stochastic volatility in many empirical papers. In 2008 many economies went into recession and many of the associated policy discussions suggest that the parameters in VARs may be changing again.

Macroeconomic data sets typically involve monthly, quarterly or annual observations and, thus are only of moderate size. But VARs have a great number of parameters to estimate. This is particularly true if the number of dependent variables is more than two or three (as is required for an appropriate modelling of many macroeconomic relationships). Allowing for time-variation in VAR coefficients causes the number of parameters to proliferate. Allowing for the error covariance matrix to change over time only increases worries about over-parameterization. The research challenge facing macroeconomists is how to build models that are flexible enough to be empirically relevant, capturing key data features such as the Great Moderation, but not so flexible as to be seriously over-parameterized. Many approaches have been suggested, but a common theme in most of these is shrinkage. Whether for forecasting or estimation, it has been found that shrinkage can be of great benefit in reducing over-parameterization problems. This shrinkage can take the form of imposing restrictions on parameters or shrinking them towards zero. This has initiated a large increase in the use of Bayesian methods since prior information provides a logical and formally consistent way of introducing shrinkage.[1] Furthermore, the computational tools necessary to carry out Bayesian estimation of high dimensional multivariate time series models have become well-developed and, thus, models which may have been difficult or impossible to estimate 10 or 20 years ago can now be routinely used by macroeconomic practitioners.

A related class of models, and associated worries about over-parameterization, has arisen due to the increase in data availability. Macroeconomists are able to work with hundreds of different time series variables collected by government statistical agencies and other

[1] Prior information can be purely subjective. However, as will be discussed below, often empirical Bayesian or hierarchical priors are used by macroeconomists. For instance, the state equation in a state space model can be interpreted as a hierarchical prior. But, when we have limited data information relative to the number of parameters, the role of the prior becomes increasingly influential. In such cases, great care must to taken with prior elicitation.

policy institutes. Building a model with hundreds of time series variables (with at most a few hundred observations on each) is a daunting task, raising the issue of a potential proliferation of parameters and a need for shrinkage or other methods for reducing the dimensionality of the model. Factor methods, where the information in the hundreds of variables is distilled into a few factors, are a popular way of dealing with this problem. Combining factor methods with VARs results in Factor-augmented VARs or FAVARs. However, just as with VARs, there is a need to allow for time-variation in parameters, which leads to an interest in TVP-FAVARs. Here, too, Bayesian methods are popular and for the same reason as with TVP–VARs: Bayesian priors provide a sensible way of avoiding over-parameterization problems and Bayesian computational tools are well-designed for dealing with such models.

In this monograph, we survey, discuss and extend the Bayesian literature on VARs, TVP–VARs and TVP-FAVARs with a focus on the practitioner. That is, we go beyond simply defining each model, but specify how to use them in practice, discuss the advantages and disadvantages of each and offer some tips on when and why each model can be used. In addition to this, we discuss some new modelling approaches for TVP–VARs. A website contains Matlab code which allows for Bayesian estimation of the models discussed in this monograph. Bayesian inference often involves the use of Markov chain Monte Carlo (MCMC) posterior simulation methods such as the Gibbs sampler. For many of the models, we provide complete details in this monograph. However, in some cases we only provide an outline of the MCMC algorithm. Complete details of all algorithms are given in a manual on the website.

Empirical macroeconomics is a very wide field and VARs, TVP–VARs and factor models, although important, are only some of the tools used in the field. It is worthwhile briefly mentioning what we are not covering in this monograph. There is virtually nothing in this monograph about macroeconomic theory and how it might infuse econometric modelling. For instance, Bayesian estimation of dynamic stochastic general equilibrium (DSGE) models is very popular. There will be no discussion of DSGE models in this monograph (see An and Schorfheide, 2007 or Del Negro and Schorfheide, 2010 for excellent treatments of

Bayesian DSGE methods with Chib and Ramamurthy, 2010 providing a recent important advance in computation). Also, macroeconomic theory is often used to provide identifying restrictions to turn reduced form VARs into structural VARs suitable for policy analysis. We will not discuss structural VARs, although some of our empirical examples will provide impulse responses from structural VARs using standard identifying assumptions.

There is also a large literature on what might, in general, be called regime-switching models. Examples include Markov switching VARs, threshold VARs, smooth transition VARs, floor and ceiling VARs, etc. These, although important, are not discussed here.

The remainder of this monograph is organized as follows. Section 2 provides discussion of VARs to develop some basic insights into the sorts of shrinkage priors (e.g., the Minnesota prior) and methods of finding empirically-sensible restrictions (e.g., stochastic search variable selection, or SSVS) that are used in empirical macroeconomics. Our goal is to extend these basic methods and priors used with VARs, to TVP variants. However, before considering these extensions, Section 3 discusses Bayesian inference in state space models using MCMC methods. We do this since TVP–VARs (including variants with multivariate stochastic volatility) are state space models and it is important that the practitioner knows the Bayesian tools associated with state space models before proceeding to TVP–VARs. Section 4 discusses Bayesian inference in TVP–VARs, including variants which combine the Minnesota prior or SSVS with the standard TVP–VAR. Section 5 discusses factor methods, beginning with the dynamic factor model, before proceeding to the factor augmented VAR (FAVAR) and TVP-FAVAR. Empirical illustrations are used throughout and Matlab code for implementing these illustrations (or, more generally, doing Bayesian inference in VARs, TVP–VARs and TVP-FAVARs) is available on the website associated with this monograph.[2]

[2] The website address is: http://personal.strath.ac.uk/gary.koop/bayes_matlab_code_by_koop_and_korobilis.html.

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