Economics Doctoral School

RÉSUMÉ OF THE DISSERTATION

Viktor Várpalotai

Modern Bayesian econometric analyses

Using smoothness prior to measure business cycle synchronization and to forecast inflation

Supervisor:

József Móczár, Ph.D.
professor

Budapest, 2008

Department of Mathematical Economics and Economic Analyses

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Contents

1 Introduction and motivation

Bayesian econometrics has become popular since last decades. There are several reason for this increasing popularity. The first and the probably most important reason is that any Bayesian analysis is based on a simple probability rule, namely on the Bayes-rule. With some exaggeration it can be said that one has to know only the Bayes-rule for conducting Bayesian econometric analysis, and the rest is pure aritmethic. However, the powerful arithmetic techniques have been developed recently only. Namely, if the distribution of a posterior is unknown then the moments of the posterior distribution cannot be deducted analytically. Simulation techniques developed recently has revolutionized the Bayesian econometrics, as using proper simulations one can calculate any moments of any type of distribution.

A further reason of the increasing popularity of the Bayesian analysis is that the statistic properties of Bayesian estimators are exacts even in small sample case, therefore contrary to classical econometric approach one does not have to rely on asymptotic results which are often used in classical econometrics. As a last reason, large-sized econometric models cannot be estimated with classical econometric methods due to scarce information contents of the data.[1] In Bayesian econometric frameworks these missing pieces of information can be replaced easily by priors which incorporate economic knowledge origins from previous results or are simply based on analysts' own belief.

The increasing popularity of Bayesian methods all over the world is reflected in the growing number of publications using Bayes methods both in absolute and relative term. However, I found only few papers written by Hungarian authors which refer to[2] and even fewer which carry out[3] Bayesian analysis. Thus the first aim this

[1] Relatively new SDGE models are estimated with Bayesian techniques exclusively. See for example Smets–Vouters (2003) or Beyer–Mestre (2005).

[2] See Szatmáry (1996), Valentinyi (2005), Darvas–Szapáry (2004a), Komáromi (2002), Kristóf–Virág (2005). Econometric textbooks also lack Bayesian analysis except for Kőrösi–Mátyás–Székely (1990) dealing with Bayesian econometrics briefly and Hunyadi (2001) which contains a whole chapter devoted to Bayesian analysis.

[3] See Theiss (1971), Hunyadi (1980, 1985), Gál (1998), Horváth (2001a, 2001b) and papers written by myself Várpalotai (2002, 2003a, 2003b, 2003c, 2003d, 2006a, 2006b, 2006c).

thesis is that it tries to fill this gap with supplying an overview about the modern Bayesian techniques which, I believe, would inspire many of Hungarian researchers to carry out Bayesian econometric analysis.

1.1 Investigated issues and the structure of the thesis

The thesis has three chapters. In the first chapter, I review the modern tools of Bayesian analysis supplemented by several illustrative examples. This chapter has two aims. First, it serves as a short handbook of modern Bayesian analysis written in Hungarian which tries to encourage Hungarian econometrist to use Bayesian analysis in their empirical research. Second, it summarizes the Bayesian techniques, definitions, tricks, etc. which are extensively used in the second and third chapters of the thesis. The second and third chapters of the thesis are based on this introduction.

Any Bayesian analysis takes similar more or less mechanical steps. First, one has to specified the prior and the model, then she must apply the Bayes-rule to derive the posterior density, and finally, one has to condense the information content of posterior into a more digestable forms, i.e. one should calculate the posterior moments of the parameters. Again, this universal procedure reveals the main advantages of Bayesian analysis: complex estimation problems can be treated with a relatively few, easily learnable tools and the calculated statistics (distribution, moments, etc.) of estimates are always exact, i.e. one does not need any asymptotic result which is often used in classical econometrics.

In the second chapter, I introduce the concept of time varying fractional lag which is proved to be a very flexible time series transformation with which time series can be shifted, 'stretched out' or 'compressed' arbitrary. Using time varying fractional lag, I setup a simple model which separately measures the time varying degree of comovement and phase shift between two time series. I apply Bayesian framework to obtain estimates from this model. The superiority of models containing time varying fractional lag compared to other models and estimation strategies is demonstrated on both artificial and real data set..

I use model containing time varying fractional lag to investigate how synchro-

nized are the business cycles of European Union member states and of some other countries with that of the Economic and Monetary Union aggragtes. The theoretical background of this investigation stems from the optimal currency area (OCA) literature. According to OCA concept, the introduction of common currency might yield welfare gain if the member countries' business cycles are synchronized enough.[4]

Investigating business cycle synchronization in European Union member states has been especially important since the birth of Economic and Monetary Union (EMU). From one part, it is worth investigating whether the business cycles synchronization of the EMU member countries has increased since the introduction of the common currency. This issue is related to proposition of Frankel – Rose (1998) who argue that there might be a self-fulfilling effect of an optimal currency area, i.e. the comovement of business cycle might become more synchronized after adopting a single currency.

On the second part, the new European Union member countries engaged themselves to join the EMU, therefore, it is important to investigate whether the comovement of business cycle of the new EU members with that of the EMU aggregate is strong enough, as in the future, the welfare effect of joining to the EMU might depend on the extent of synchronization. These investigations entail some policy recommendation for the non-EMU-member EU-member states on joining to or refraining from the EMU membership. If these countries' cycles do not move strongly along with the EMU cycle then it is worth considering not to join to the EMU. However, if estimates deliver some evidence on growing synchronization after adopting the Euro, then it might be encouraging for the non EMU members to adopt the common currency even if they do not exhibit strong synchronization with the EMU currently.

On the third part, I also included some non European Union member countries' data in the investigation by which I can test the existence of world business cycle which was tested also by Kose – Otrok – Whiteman (1999) and Canova – Ciccarelli – Ortega (2004).

[4]However, this is a necessary but not sufficient condition of presence of welfare gain.

In the third chapter, I present a model designated to forecast inflation in Hungary. As Hungary adopts an inflation targeting monetary regime in which the monetary policy is mainly influenced by the forecasted path of inflation, it is crucial to have reliable forecasts at the central bank. The model is disaggregated and assumes that the consumer prices are ultimately determined by costs.

2 Methods used in the thesis

2.1 Summary of modern Bayesian techniques

Regarding the fact that the Bayesian econometric analysis is not so wide-spread in Hungary and to give a methodological introduction to the second ant third chapters of the thesis, in the first chapter I review the modern Bayesian econometric techniques supplemented by several illustrative examples. In the review of the modern Bayesian econometrics, I followed presentation of Paap (2005) and Koop (2003).

2.2 Time varying fractional lag operator and its application to investigate the synchronization of business cycles

Analyzing economic time series data researcher aims to fulfill several possibly contradictory requirements: the empirical framework must be flexible enough to describe relations, the sample in use must be homogenous, moreover the conclusions drawn from the analysis must be as reliable as possible. In practice, the first requirement can be fulfilled by using many parameters, however, it undermines the reliability of the result due to the decreased degree of freedom of the estimates. The second requirement can be satisfied by using reduced sample, in which the relations remains presumably unchanged, but it may dramatically reduce the degree of freedom of the estimates decreasing the reliability of the results. The last requirement encourages analyst to use the entire sample, which may compensate the increased uncertainty induced by a more flexible framework, but it inconsistent with the requirement of using homogenous sample.

Harmonizing these contradictory requirements, those newly developed econometric tools became popular in the past two decades which are able to model the change

in relation among economic variable over time. The demand for these econometric tools is natural: in the case of analyzing several decades of data it is obvious to assume that the relations among economic variable might have changed. In fact, assuming unchanged relation for long period is unrealistic. Why should they remain unchanged, if the underlying economy is in permanent change: the economies are characterized by accommodation to new policies, technologies, innovations, undulant market of factor, intermediate and final goods, demographical change, or different shocks.

Usually, in econometrics the changes are captured by dummies, trends, use of different subsamples and time varying parameter methods. The common feature of these solutions is that they try to describe the change in the size of relation over time. However, there exists a different aspect of the change in relations: the change of the timing of the relations that in general these methods can not handle explicitly. To illustrate this, it might be that a variable affected an other one with one year lag in the past, but now, it affects with one quarter or one month lag only. In the thesis, I introduce a new *time varying parameter and time varying fractional lag model* (henceforth TVFL) which is capable to capture not only the first dimension of a change but also changes in timing. This model relies on a real number generalization of the standard (integer) lag operator and it is estimated with a Bayesian technique using a smoothness prior inspired by Shiller (1973). The superiority of this new model is illustrated on both artificial and real data set. I find that model incorporating TVFL provides an excellent in sample fit and the goodness of out of sample forecasts outrangs those of the alternative models

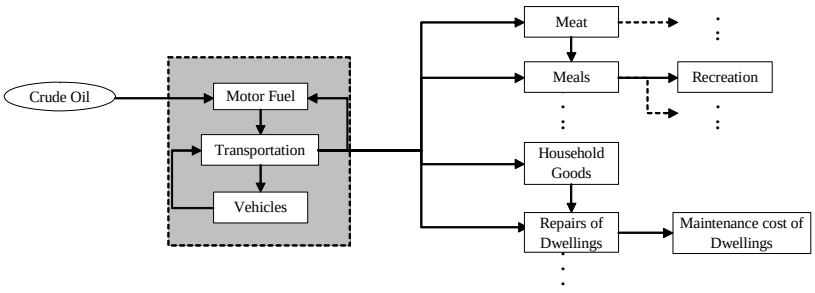
2.3 Disaggregated cost pass-through based Bayesian econometric model to forecast inflation in Hungary

The third chapter presents a new model for forecasting inflation in Hungary. The model is disaggregated, based on econometric estimates accompanied by expert judgments. The disaggregation helps to trace individual price movements. The model structure, the involved explanatory cost variables, the prior parameterization are

based on experts' information. Estimation helps to amalgamate information inherited in data with experts' information.

Model treats prices as being ultimately determined by costs. This cost pass-through based approach is applicable within the set of marketed goods of the consumer basket, which has competitive market structure ensuring a close relationships among prices and costs over both short and long term causing only temporary changes in mark-up on factor costs. However, there exists other set of goods and services in the CPI basket, whose administered prices are determined by discretionary decisions approved by the central government or local authorities (non-marketed goods).[5] For completely different way of price setting, this cost pass–through based approach rules out the non-marketed goods from the modeling.

Cost pass–through approach means that the model focuses on short and medium term price adjustment process, in which changes in costs infiltrate slowly in the consumer prices. However, the model takes into consideration spill over effects as well, i.e. price changes which are induced by changes in prices of other consumer goods. Figure 2.3 gives some partial insight about how costs pass-through and what kind of spillover effects are present in the model. The grey area represents the set of



goods whose prices are determined simultaneously. The arrows denote the directions of cost pass-through and spill over.

[5]There are 17 goods and services corresponding to 19% of CPI basket approximately: sewage disposal, meals at kindergartens, meals at schools, natural and manufactured gas, pharmaceutical products, local transport, rent, travel to work and school, miscellaneous travels, postal services, refuse disposal, gambling, purchased heat, telephone, TV fee, electricity and water charges.

The novelty of this model from econometric point of view is that it estimates slow, several year lasting cost pass-through process in a Bayesian framework applying and enhancing the concept of smoothness priors developed by Shiller (1973).

2.3.1 Framework of the model

The model explains the developments of consumer prices by changes in their cost factors. I modeled the temporary changes in mark-up on factor cost of the marketed goods with an error correction approach distinguishing short-run price adjustment proces from that of long term price equilibrium using monthly data. According to the standard two stages method, I separated the problem of identifying the long-term equilibrium cost structures from that of identifying the short-term dynamics of cost pass-though adjustment toward the equilibrium.

Among other cost factors, I use the exchange rate and the foreign prices as a cost factor. Including these variables relates the investigations carried out in the thesis to exchange rate pass-through literature. Term 'exchange rate pass-through' is generally used to refer to the effects of exchange rate changes on any of the following: (1) import and export prices, (2) consumer prices, (3) investments and (4) trade volumes. The incompleteness of exchange rate pass-through into consumer prices is well documented in the literature.[6] The model gives implicit explanation of this phenomena decomposing the prices of traded good into different cost factors among which the foreign prices denominated in domestic currency represents only a part of the costs. Therefore, even if (as I assume) the exchange rate pass-through is complete at cost level, the prices of other (non-traded) cost factors lacks this adjustment yielding an incomplete pass-trough at product level.

Identifying cost structures (Long run equilibrium) The prices of marketed goods represented in the consumer basket are assumed to be determined by various costs, such as labor costs, energy, basic materials, farm crops, imports, as well as other goods and services which themselves are included in the consumer basket, such as flour in the case of bread, textiles in case of clothing, etc. Furthermore, it

[6] See for example the survey paper of Menon (1995) and Glodberg-Knetter (1997).

is assumed that each cost elasticity is constant and, therefore, over the long term prices are determined by the following Cobb-Douglas type function:

$$P_{i,t} = \Lambda_{i,t} C_{i,1,t}^{\gamma_{i,1}} C_{i,2,t}^{\gamma i,2} \cdot ... \cdot C_{i,n_i-1,t}^{\gamma_{i,n-1}} C_{i,n_i,t}^{(1-\gamma_{i,1}-\gamma_{i,2}-...-\gamma_{i,n_i-1})} \Xi_{i,t}, \tag{1}$$

where $P_{i,t}$ is the consumer price index of the i^{th} good in period t, $C_{i,j,t}$ is the price index of the j^{th} cost element of the i^{th} consumer good in period t, $\gamma_{i,j}$ is the cost elasticity of the j^{th} cost element on price of the i^{th} good, $\Lambda_{i,t}$ is the time varying scaling factor normalizing costs in terms to consumer price, capturing the changes in productivity and time varying profit margin among others, as well. $\Xi_{i,t}$ stands for the error term following lognormal distribution. It is worth noting that the cost indices are measured in 'natural units' (index of monthly average wages, price index of 1 kWh of electricity, price index of flour, etc.). That is one reason why the $\Lambda_{i,t}$ term appears in this cost function: it transforms the cost indices, expressed in various units into a (consumer) price index.

The time varying parameter $\Lambda_{i,t}$ is expected to be downward sloping, as, if there is an improvement in productivity, then the increase in consumer price index can be lower than cost indices would predict. However, increasing $\Lambda_{i,t}$ is not unexplainable either: it corresponds to a market on which one can (temporarily) earn an increasing profit margin.[7]

The sums of cost elasticities ($\sum_{j=1}^{n_i} \gamma_{i,j} = 1$) are restricted to 1 for each i, in order to ensure price homogeneity, i.e. if each cost factor prices increases by 1%, then the final price of the goods increases by 1% supposing an unchanged mark-up. A further restriction is that each parameters of cost elasticity should be positive.

For the calibration and econometric estimation, I consider the log of function (1):

$$p_{i,t} = \lambda_{i,t} + \gamma_{i,1} c_{i,1,t} + \gamma_{i,2} c_{i,2,t} + ... + \gamma_{i,n_i-1} c_{i,n_i-1,t} + (1 - \gamma_{i,1} - \gamma_{i,2} ... - \gamma_{i,n_i-1}) c_{i,n_i,t} + \varepsilon_{i,t}, \tag{2}$$

[7] Or it may reflects model misspecification, biases resulting from neglected or improperly measured cost factors.

where small case letters denote the logarithm of correspondent variables and $\varepsilon_{i,t}$ is the normaly distributed error term with zero mean.

Identifying cost pass-through (Short run dynamics) In accordance with the error correction approach, the short-run dynamics consistent with long-run equilibrium can be written as follows:

$$\begin{aligned}\triangle p_{i,t} = \mu_{i,t} + \gamma_{i,1} B_{i,1}(L) \triangle c_{i,1,t} + \gamma_{i,2} B_{i,2}(L) \triangle c_{i,2,t} + ... + \gamma_{i,n_i-1} B_{i,n_i-1}(L) \triangle c_{i,n_i-1,t} + \\ + (1 - \gamma_{i,1} - \gamma_{i,2} ... - \gamma_{i,n_i-1}) B_{n_i}(L) \triangle c_{i,n_i,t} - \phi_i \varepsilon_{i,t-1} + \xi_{i,t}, \qquad (3)\end{aligned}$$

where $\triangle$ and L are the difference and lag operators, respectively, $\varepsilon_{i,t-1}$ is the lagged residual of long-term equation (i.e. this is the error correction term), ξ_i is the error term of the short-term equation, $\mu_{i,t}$ is a time varying parameter[8], $\gamma_{i,j}$ is the estimated/calibrated cost weights of the long-term equation. The $B_{i,j}(L)$ polynomials have form $B_{i,j}(L) = b_{i,j,0} + b_{i,j,1}L + b_{i,j,2}L^2 + ... + b_{i,j,q_{i,j}}L^{q_{i,j}}$, where $q_{i,j}$ is the degree of the polynomials (lag length), and the sum of $b_{i,j,k}$ parameters is 1 for each i and j ($\sum_{k=0}^{q_i} b_{i,j,k} = 1$). $B_{i,j}(L)$ polynomials represent the dynamics of the cost pass-through of corresponding cost factors. Despite the fact, that (3) is a standard approach, the common estimation techniques, like OLS cannot be adapted in this case. The reason for this is that cost pass-through processes have (at least) four characteristics that render the standard econometric techniques inapplicable to estimate parameters in equation (3):

1. Costs pass-through into consumer prices gradually;
2. Speeds of pass-throughs differ across cost factors;
3. Coefficients of lagged cost changes ($b_{i,j,k}$) must be non negative;
4. Coefficients of lagged cost changes ($b_{i,j,k}$) are not independent from each other.

These requirements are fulfilles in a Bayesian estimation framework, in which these requirements are treated as priors. To formalize the fourth requirement I

[8] In order to have short run dynamics fully consistent with the long run equilibrium, $\mu_{i,t} = \triangle\lambda_{i,t}$ must hold.

use smoothness priors. Having defined the priors and the model's likelihood, the posterior moments of the parameters are calculated by using the so-called Gibbs-sampling technique.

3 Results of the thesis

1. In the first chapter of the thesis I present an overview about the modern Bayesian econometrics including simulation techniques which have revolutionized the Bayesian econometrics. As these techniques are less known in Hungarian econometric literature, therefore, on the one part, this chapter aims to fill the gap in this field. On the second part, this chapter serves as an introduction to the next chapters of the thesis. On the third part, the structure of this chapter is designed so that it is able serve as a handout of or a guideline for an introductionary Bayesian econometric curse. This educative role is also strengthen by several illustrative examples.

   (a) In the first chapter I show that the well known concept of HP filter (Hodrick–Prescott 1980, 1997) is based on a concept similar to Shiller's smoothness prior (Shiller, 1973). Interestingly, Hodrick–Prescott (1980, 1997) mention some precedent work, but they do not cite Shiller (1973) paper.[9] Since than the idea of smoothness prior has again been reinvented several times.[10]

2. In the second chapter I generalize the concept of the standard (integer order) lag operator introducing a time varying fractional lag operator. This new operator proves to be a very flexible tool for analyzing time series, as time series

[9] "Our method has a long history of use, particulary in the actuarial sciences. There it is called the Whittaker-Henderson Type method (Whittaker, 1923) of graduating or smoothing mortality experiences in constructing mortality tables. The method is still in use. As pointed out in Stigler's (1978) historical review paper, closely related methods were developed by the Italian astronomer Schiaparelli in 1867 and in the ballistic literature in the early forties by, among others, von Neuman.I found that the idea of smoothness prior was invented independently several times in the history." Hodrick–Prescott (1980, p. 4.)

[10] One example is Kalaba–Tesfatsion (1989).

can be shifted, compressed and stretched out easily with this transformation. Similarly to models with time varying parameters, the time varying fractional lag operator is a useful tool to model explicitly phase shift among variables which potentially varies over time.

(a) Using the concept of the time varying fractioanl lag operator, I propose a simple model with two time varying parameter in which one of the parameter measures the time varying correlation between two series and the other measures the time varying phase shift between these two series, respectively. I propose a Bayesian estimation techniques based on the concept of the smoothness priors to estimate the time varying parameters of the model.

(b) As an application of this model, first, I extensively test it on artificial data set and compare the results with some alternative models. Next, based on the experiments of the artificial data set, I investigate the synchronization of 24+1 countries' business cycle. The novelty of this empirical analysis is that it is the first attempt that takes into consideration consistently and models explicitly a possibly time varying phase shifts among countries' business cycles.

(c) I investigate to what extent countries' (mainly EU member countries and Japan, Norway, Switzerland, USA) business cycles are synchronized with the European Monetary Union aggregate business cycle. I find that the synchronizations of these countries with the EMU aggregate are heterogenous. Only Hungary and Slovenia exhibit synchronization amongst the new EU member countries, while the business cycles of the rest of this country group do not show any synchronization with the EMU aggregate business cycle. The cycles of the current EMU members (apart from Finland and Portugal) are highly synchronized with that of the EMU considering both the relative amplitude of and the phase shift among the cycles. The degree of synchronization of the Danish, UK, Sweden busi-

ness cycle with EMU is also high similar to the Swiss case, nevertheless they experience higher synchronization than Norway does. Interestingly, the business cycle of the USA is highly synchronized with the EMU's cycle, but there is a definite lead, i.e. the EMU's aggregate cycle lags behind the USA's cycle by two quarters approximately. I do not find significant synchronization between the Japanese and EMU cycles.

(d) These results suggest some cautious policy conclusions as well. It is often considered that one of the criteria for a set of countries being an optimal currency area is that member countries' economies have to exhibit strong comovement. Most of the current EMU member countries fulfill this criteria, however, Finland and Portugal has some handicap from this respect. As for the new EU member states, most of them lack strong comovement with the EMU business cycle, therefore, accessing to EMU in the future, as they engaged themselves in their accession treaties, and adopting the common monetary policy might be risky for them. Two exceptions might be Hungary and Slovenia, as they exhibit similar strong comovement as theEMU members do currently. The business cycles of the old EU member but not EMU member countries are highly synchronized with the EMU aggregate cycle, that might encourage them to join to the EMU club.

3. In the third chapter of the thesis, I present an inflation forecasting model for Hungary, in which the consumer prices are determined by their costs. The model is disaggregated explaining the prices of 43 consumer goods aggregated from CSO's (Central Statistic Office of Hungary) consumer price statistic table which contains the price indices of 160 consumer goods.

   (a) The dynamics of prices changes is captured by a relatively long distributed lag structure which has been estimated by Bayesian approach using smoothness prior enhanced with sign constraint and parameter restrictions. The proposed estimation procedure is a more developed version

of that of Shiller's (1973): (1) it uses smoothness prior in a multivariate framework, (2) it recons with parameter restrictions when it defines the smoothness priors, (3) it derives posterior distribution in the presence of sign restrictions.

(b) The estimated distributed lag coefficients outline some common tendency. It is a general finding that the wage cost passes through slowly with a half-one year lag into consumer prices. An other common finding is that changes in foreign prices show up definitely sooner in consumer prices than a change in the exchange rate does. Comparing the estimates derived from different subsamples, I find that the estimated (mean of the) coefficients are stable across different subsamples. Only the parameters of the exchange rate and of the foreign prices has changed remarkably, due to the change in monetary regime, presumably.

(c) The forecasting ability of the disaggregated cost pass-through based inflation forecasting model is outstanding. Compared with Reuters' consensus forecast, though the comparison is burdened with different set available for model forecast and for the analyst, it turns out that the model gives a relatively more precise forecast both in short and long run.

(d) Experiencing the model forecasts gives some impetus for further developments:

   i. Some of the CSO's consumer price data is burdened with breaks and irregularity, thus filtering out them may improve both the estimates and forecasts.

   ii. It would be reasonable to clean the data from (changes in) lump sum taxes, as I do in case of fuel, because the neglected changes of lump sum taxes may distort the results.

   iii. There is some evidence that changes in VAT rate might induces strategic pricing (see for instance Gábriel–Reiff, 2006), therefore, handling this effect might also improve the model.

iv. I find that cost factors have poor predictive power in certain case, e.g. price of vegetable oil. In these cases new cost factors might help, e.g. including commodity market price of sunflower seed into equation describing the price of vegetable oil.

v. In some cases the residuals of long term cost equations are cyclical. Thus, it seems promising to include a demand variable in the model which might capture these cycles.

vi. Finally, the most important impetus might come from the real ex-ante forecasts which might shed some light on further potential weaknesses and help to assess the role and the importance of exogenous cost factor in forecast inflation.

After having summarized the results I shortly review the applied methodologies and models assessing how they relate to previous literature and to what extent they contribute to it.

Shiller in his paper (Shiller, 1973) worked out a (bivariate) linear distributed lag model with smoothness prior. He mentioned a special case as well when zero end-point constraint is assigned to the coefficients of the distributed lags, i.e. when the virtual coefficients of lags beyond the last lag presented in the model equal zero. Shiller (1975) extended this framework by imposing sign constraints on the lag coefficients. However, without the modern Bayesian methods, he could not derive the posterior distribution, instead, he gave a point estimate only.

Hodrick–Prescott (1980, 1997) used basically the same smoothness prior to describe the evolvement of time varying coefficient, but they did not use Bayesian approach, hence they could derive point estimates only.[11]

Lütkepohl–Herwartz (1996) also used smoothness prior to describe the evolvement of time varying parameters with special distinction to time varying seasonality

[11] Interetingly, Araujo–Areosa–Neto (2003) noted that the Hodrick–Prescott filter can be generalized to any higher order differences (Hodrick-Prescott filter uses the second order difference), but they remained in the frameworks of classical econometrics, moreover, they did not cited Shiller' original works neither.

in an autoregressive model. However, their paper remained in the classical econometrics framework, and did not cite Shiller's work.[12]

From methodological point of view I make several contribution to smoothness prior literature in the thesis.

1. I apply the smoothness prior to estimate a model with time varying fractioanl lag introduced in the second chapter of the thesis.

2. In the third chapter I generalize the Shiller's distributed lags to multivariate cases extended by sign restrictions, zero starting- and end-point constraints and parameter restrictions. I derive the posterior distribution in the presence of sign restrictions also which is a contribution to Shiller's (1975) paper.

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[12]But they cite a paper by Kalaba–Tesfatsion (1989) using an approach named "flexible least square" completely similar to smoothness priors. Thus, it seems that Kalaba and Tesfatsion reinvented the smoothness prior again in 1989.

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5 List of publications

5.1 Publications related to thesis

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