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A Simple Bayesian VAR Analysis of Tourism Demand for Japan’s Two Major Prefectures in the Kansai Region

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Abstract

This paper investigates the influence of economic variables on tourism demand for Japan's two major cities in western region is conducted by utilizing BVAR methodology. In this research, we assume that prior distribution function and the posterior one are in the same distribution family and utilize one of the conjugate priors － Litterman or Minnesota prior. The cumulative impulse response of Kyoto are consistent with the conventional belief. However, the estimated responses of tourism demand in Osaka to the several economic shocks seem to be inconsistent with the conventional assumption.

***Keywords* :** Bayesian VAR, Litterman or Minnesota prior, tourism demand

***JEL classification* :** C11, O20, Z30

1. Introduction

As is well known, VAR (vector autoregression) methodology has been broadly utilized to analyse social change since the pioneering work of Sims (1980). Especially, SVAR (structural vector autoregression) or identified VAR model is widely applied to macro-economic research. For example, Sims (1992) puts stress on the role of short-term market interest rate as the factor for monetary policy with recursive identification frameworks of SVAR. Blanchard and Watson (1986), Gali (1992), Gordon and Leeper (1994), and Lastrapes and Selgin (1995) apply a non-recursive approach to impose contemporaneous restrictions for identification. In addition, Bernanke and Mihov (1998) adopt the block-recursive approach to identify the shocks to monetary policy.

On the other hand, the BVAR (Bayesian vector autoregression) model has been used as the Bayesian-flavored VAR specification for empirical analysis, which connects priors with information incorporated in sample. BVAR decreases the risk of over-parameterization by the imposition of special restrictions on the parameters in VAR process (the so-called "shrinking parameters") through their prior probability distribution functions. The prior probability distribution function contains the prior which include the mean and variance of the distribution. The prior probability distribution function describes the range of uncertainty of the prior mean, and it revised by sample information if underlying distribution significantly differs from the prior. Furthermore, the posterior distribution function for parameter in BVAR model can be given from the combination of the prior distribution function and the distribution of the sample data. One difficult problem is whether the prior distribution function and the posterior are in the same distribution family. In this research, we assume that they are in the same distribution family and utilize one of the conjugate priors － Litterman or Minnesota prior. Taking the above features into account, the empirical analysis utilizing BVAR methodology to investigate the influence of economic variables on tourism demand for Japan's two major cities in western region is conducted in this study.

The reminder of this paper is organized as follows. Section 2 highlights the characteristics of the Bayesian econometric analysis with the Litterman or Minnesota Prior. Section 3 is for data set. Section 4 describes the empirical study utilizing the BVAR, and Section 5 presents the concluding remarks.

2. Bayesian Econometric Analysis with the Litterman or Minnesota Prior

Vector autoregression (autoregressive) (VAR) models have been widely used as a tool for empirical multivariate economic analysis since the 1980s. However, it is said that VAR models include the so-called "overparameterization problem" when it applied in large models with many parameters. We have at least two kinds of coping methods for this problem – "structural vector autoregression model" (SVAR: way of application of theoretical constraints) and "Bayesian vector autoregression model" (BVAR: way of application of Bayesian theory).

Generally, a VAR models for our estimation are inclined to have many parameters, and some of them might be significant only by coincidence. In this kind of situation, they do not have substantive information if estimated. In this context, the BVAR approach deals with this kind of topic by defining the prior for parameters.

Bayesian statistical flamework connect the distribution properties of the prior distribution, likelihood, posterior distribution based on the assumption that the parameters can be regarded as random variable. The “prior” expresses the external distributional information derived from the “belief” on the parameters. The “likelihood” means the information of the sample probability distribution function. By the “Bayes’ Theorem”, the “prior distribution” is related to the data likelihood results in the “posterior distribution”.

If we denote the data by y , the parameters of interest by $\theta = (\beta, \Sigma)$, the prior distribution by $\pi(\theta)$, the likelihood by $l(y|\theta)$, we can express $\pi(\theta|y)$, “posterior distribution”, as

$$\pi(\theta|y) = \frac{\pi(\theta)l(y|\theta)}{\int \pi(\theta)l(y|\theta)d\theta} \qquad (1)$$

where the denominator describes a normalizing constant without randomness. Therefore, the posterior is proportional to the product of $l(y|\theta)$ and the $\pi(\theta)$:

$$\pi(\theta|y) \propto \pi(\theta)l(y|\theta). \qquad (2)$$

The theoretical connection between this specification and BVAR approach requires the following the basic VAR(p) model

$$y_t = a_0 + \sum_{j=1}^{p} a_j\, y_{t-j} + \epsilon_t \qquad (3)$$

where y_t (for $t = 1,\cdots,T$) is an $m \times 1$ vector with observations on m different series. ϵ_t is an $m \times 1$ vector of errors where $\epsilon_t \sim N(0, \Sigma_\epsilon), i.i.d.$.

For simplicity, this equation can be written as:

$$Y = XA + E \qquad (4)$$

or

$$y_t = \left(I_m \otimes X\right)\theta + e \qquad (5)$$

where Y and E are $T \times m$ matrices, $X = (x_1,\cdots,x_t)'$ is a $T \times (mp + 1)$ matrix for $x_t = \left(1, y'_{t-1},\cdots, y'_{t-q}\right), I_m$ is the m-dimension identity matrix, $\theta = vex(x)$, and $e \sim N\left(0, \Sigma_\epsilon \otimes I_T\right)$.

By applying equation (5), the likelihood function is written as the following form.

$$l(\theta, \Sigma_\epsilon) \propto \left|\Sigma_\epsilon \otimes I_T\right|^{-\frac{1}{2}} exp\left\{-\frac{1}{2}\left(y - \left(I_m \otimes X\right)\theta\right)'\left(\Sigma_\epsilon \otimes I_T\right)^{-1}\left(y - \left(I_m \otimes X\right)\theta\right)\right\} \qquad (6)$$

Assuming that Σ_ϵ is known and a multivariate normal prior for θ to explain the derivation of the posterior moments:

$$\prod(\theta) \propto |V_0|^{-\frac{1}{2}} exp\left\{-\frac{1}{2}(\theta-\theta_0)'V_0^{-1}(\theta-\theta_0)\right\} \qquad (7)$$

where θ_0 is the mean of prior and V_0 is the covariance of the prior. The posterior density is expressed by the following form as a multivariate normal probability density function if we combine equation (6) and (7):

$$\pi(\theta|y) = exp\left\{-\frac{1}{2}\left(\left(\left(V_0^{-\frac{1}{2}}(\theta-\theta_0)\right)'\left(V_0^{-\frac{1}{2}}(\theta-\theta_0)\right)\right) + \left\{\left(\Sigma_\epsilon^{-\frac{1}{2}}\otimes I_T\right)y - \left(\Sigma_\epsilon^{-\frac{1}{2}}\otimes X\right)\theta\right\}'\left\{\left(\Sigma_\epsilon^{-\frac{1}{2}}\otimes I_T\right)y - \left(\Sigma_\epsilon^{-\frac{1}{2}}\otimes X\right)\theta\right\}\right)\right\}. \qquad (8)$$

Defining ω and W as

$$\omega \equiv \begin{bmatrix} V_0^{-\frac{1}{2}}\theta_0 \\ \left(\Sigma_\epsilon^{-\frac{1}{2}}\otimes \mathrm{X}\right) \end{bmatrix} \text{ and } W \equiv \begin{bmatrix} V_0^{-\frac{1}{2}} \\ \left(\Sigma_\epsilon^{-\frac{1}{2}}\otimes \mathrm{X}\right) \end{bmatrix}, \qquad (9)$$

we get the exponential part in equation (8) is described as

$$\prod(\theta|y) \propto exp\left\{-\frac{1}{2}(W - W\theta)'(W - W\theta)\right\} \propto exp\left\{-\frac{1}{2}(\theta-\bar{\theta})'W'W(\theta-\bar{\theta}) + (\omega - W\bar{\theta})'(\omega - W\bar{\theta})\right\} \qquad (10)$$

where the mean value of the posterior, $\bar{\theta}$, has the specification:

$$\bar{\theta} = (W'W)^{-1}W'\omega = \left[V_0^{-1} + \left(\Sigma_\epsilon^{-1}\otimes \mathrm{X}'\mathrm{X}\right)\right]^{-1}\left[V_0^{-1}\theta_0 + \left(\Sigma_\epsilon^{-1}\otimes \mathrm{X}\right)'y\right] \qquad (11)$$

If the Σ_ϵ is known, the $\bar{\theta}$ in equation (10) does not include randomness. In this context, the posterior distribution may be simply described by the form:

$$\prod(\theta|y) \propto exp\left\{-\frac{1}{2}(\theta-\bar{\theta})'W'W(\theta-\bar{\theta})\right\} = exp\left\{-\frac{1}{2}(\theta-\bar{\theta})'\bar{V}^{-1}(\theta-\bar{\theta})\right\} \qquad (12)$$

where the covariance of posterior, $\bar{V}$, is

$$\bar{V} = \left[V_0^{-1} + \left(\Sigma_\epsilon^{-1}\otimes X'X\right)\right]^{-1} \qquad (13)$$

In the Bayesian econometric flamework, the prior distribution function of the parameter for estimation is constituted based on the “belief” of the researcher to reflect the prior information. One of the important problems is whether the prior distribution function and the posterior are in the same distribution family. If they are in the same distribution family, then we can conduct the simple analytical estimation process of the Bayesian VAR by using some conjugate priors. If not, we should implement some kinds of simulation-based inference like the Markov Chain Monte Charlo (MCMC) method, the Gibbs Sampling, and so on.[1] In the case of this study dealing with tourism behavior, our research might be in the former

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[1] See Chan, Koop, Poirier, and Tobias (2019) for details of the Markov Chain Monte Charlo (MCMC) method, the Gibbs Sampling.

one, and we could select some applicable prior, for example, the so-called “Litterman or Minnesota prior”, “The Normal-Wishart Prior”, “The Sims-Zha normal-Wishart prior”, and “The Sims-Zha normal-flat prior”. Concretely, we apply the “Litterman or Minnesota prior” for our estimation, which assumes a normal prior on θ, the prior, with fixed Σ_ϵ in VAR process. This prior was initially developed by, for instance, Litterman (1986) and Doan, Litterman, and Sims (1984). This prior treats Σ_ϵ is fixed or known. Therefore, Σ_ϵ should be replaced by the estimated $\widehat{\Sigma_\epsilon}$. In general, there are three options for estimating $\widehat{\Sigma_\epsilon}$ — (1) Univariate AR estimate, (2) Diagonal VAR estimate, (3) Full VAR estimate. In this sense, we should specify a prior for θ because we estimate $\widehat{\Sigma_\epsilon}$. Usually, the Litterman or Minnesota prior assumes that $\theta \sim N(\theta_0, V_0)$. The hyper-parameter $\mu_1 = 0$ derives $\theta_0 = 0$ (a zero-mean model). But the prior covariance should not be zero, $V_0 \neq 0$. The $\theta_0 = 0$ case could lessen the risk of over-fitting.

The explanatory variables in any equation of the VAR model is divided into own lags of dependent variable, lags of the other dependent variables, and any exogenous variables, including constant term. The factors of V_0 corresponding to exogenous variables are set to infinity. It means that no information of the exogenous variables is included in the prior. The remainder of V_0 is a diagonal matrix that includes diagonal elements v_{ij}^{i} for $l = 1, \cdots, p$

$$v_{ij}^{i} = \begin{cases} \left(\frac{\lambda_1}{l^{\lambda_3}}\right)^2 & \text{for } (i \neq j) \\ \\ \left(\frac{\lambda_1 \lambda_{2\sigma_i}}{l^{\lambda_3}\sigma_j}\right)^2 & \text{for } (i \neq j) \end{cases} \qquad (14)$$

where ${\sigma_i}^2$ is the *i*-th diagonal element of Σ_ϵ. This setting simplifies the selection of the specification of all the elements of V_0 into the choice of the scalars, the hyper-parameters, λ_1, λ_2, and λ_3. The λ_1 and λ_2 are overall tightness and relative cross-variable weight, respectively. The λ_3 is the lag decay and the coefficients are increasingly shrunk toward zero as lag length increases. These hyper-parameter scalar values may lead to smaller or larger variances of coefficients — tightening or loosing the prior. The setting of the values of these scalars depends on the empirical estimation.[2]

After the selection of prior, the posterior for θ takes the following specification:

$$\theta \sim N(\bar{\theta}, \bar{V}) \qquad (15)$$

where

$$\bar{V} = \left[V_0^{-1} + \left(\widehat{\Sigma_\epsilon}^{-1} \otimes \mathrm{X}'\mathrm{X}\right)\right]^{-1} \qquad (16)$$

and

$$\bar{\theta} = \bar{V}\left[V_0^{-1}\theta_0 + \left(\widehat{\Sigma_\epsilon}^{-1} \otimes \mathrm{X}\right)' y\right] \qquad (17)$$

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[2] Litterman (1986) proposes the other type of explanation with respect to this problem.

3. The Data

This section describes the data set used in the empirical analysis utilizing BVAR methodology to investigate the influence of economic variables on tourism demand for Japan's two major prefectures in western region — Kyoto and Osaka— is conducted in this study. Our estimations are conducted utilizing monthly data spanning the period 2013: January to 2021: August, and our data set is constructed by the following variables.[3]

V: approximate total number of overnight guests; prefectural data (Kyoto, Osaka), monthly, data listed in Table 9 in result of the survey "Overnight Travel Statistics," second preliminary estimate, issued by the Japan Tourism Agency, Ministry of Land, Infrastructure, Transport, and Tourism.

C: heavy fuel oil for industry, type A (for heavy loaded lorry), regional basis (Kinki region), monthly, unit: Yen / Litter, excluding consumption tax, in result of the survey of oil marketing products, issued by the Agency for Natural Resources and Energy - Ministry of Economy, Trade and Industry.

I: indices of industrial production, prefectural data (Kyoto, Osaka), monthly, original index, manufacturing (Item Number: 20000000 for Kyoto and 21000011 for Osaka), base year = 2015, issued by each prefectural government office and the Ministry of Economy, Trade, and Industry.

P: consumer price index, data for major cities (City of Kyoto and City of Osaka), monthly, original index, all items, base year = 2020, issued by the Ministry of Internal Affairs and Communications.

Our empirical analysis casts a spotlight on the Japan's two major areas in western region, or on the Kyoto and Osaka. concretely. the variables, "*V*" and "*I*" reflect the prefectural-level data that were observed by several local governmental offices, while "*P"* in our estimation is city-level (municipality) data as the proxy variable for the prefectural one since the data on Kyoto and Osaka prefectures are not available. Similarly, because prefectural data on the heavy fuel oil for industry also are not available, regional basis data for Kinki area (that includes Kyoto and Osaka) on the heavy fuel oil "C" is

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[3] The data on "approximate total number of overnight guests" can be retrieved from the website of the Japan Tourism Agency, Ministry of Land, Infrastructure, Transport, and Tourism (https://www.mlit.go.jp/kankocho/siryou/toukei/shukuhakutoukei.html). The "heavy fuel oil for industry, type A (for heavy loaded lorry), regional basis (Kinki area)" is obtained from the Agency for Natural Resources and Energy's website (https://www.enecho.meti.go.jp/statistics/petroleum_and_lpgas/pl007/results.html). The "consumer price index" is available from the "e-stat" website (https://www.e-stat.go.jp/stat-search/files?page=1&toukei=00200573). The data on "Indices of Industrial Production (prefectural data)" can be retrieved from the website of the Ministry of Economy, Trade, and Industry (https://www.meti.go.jp/statistics/tyo/iip/chiiki/index.html).

adopted. “*V*” and “C” work as the proxy variables for tourism demand and transportation cost of the tourism in our consideration, respectively. “*I*” and “*P*” are the proxy variables for vitality of regional economy and regional price level.

In this study, Logarithmic transformation (natural logarithm) is performed on all the variables listed above, and a first differences of them are taken for the (monthly) rate of change. Namely, $DV = lnV_t - lnV_{t-1}$, $DC = ln\mathrm{C} - lnC_{t-1}$, $DP = lnP_t - lnP_{t-1}$, and $DI = lnI_t - lnI_{t-1}$. ("ln" means the natural logarithm)

4. Empirical Result

This section is constructed to investigate the tourism demand for Japan’s two major prefectures in the Kansai region, namely, Kyoto and Osaka. The empirical estimations by utilizing BVAR (Bayesian vector autoregression) model based on the Litterman or Minnesota Prior with the variables explained in the former section for Kyoto and Osaka are conducted. The following specifications are applied in our estimation.

$$\begin{aligned} DV_t = {} & \alpha_{1,1}DV_{t-1} + \alpha_{1,2}DV_{t-2} + \cdots + \alpha_{1,12}DV_{t-12} \\ & + \alpha_{2,1}DC_{t-1} + \alpha_{2,2}DC_{t-2} + \cdots + \alpha_{2,12}DC_{t-12} \\ & + \alpha_{3,1}DP_{t-1} + \alpha_{3,2}DP_{t-2} + \cdots + \alpha_{3,12}DP_{t-12} \\ & + \alpha_{4,1}DI_{t-1} + \alpha_{4,2}DI_{t-2} + \cdots + \alpha_{4,12}DI_{t-12} \\ & + c_1 + \varepsilon_{1t} \qquad (18) \end{aligned}$$

$$\begin{aligned} DC_t = {} & \alpha_{1,1}DV_{t-1} + \alpha_{1,2}DV_{t-2} + \cdots + \alpha_{1,12}DV_{t-12} \\ & + \alpha_{2,1}DC_{t-1} + \alpha_{2,2}DC_{t-2} + \cdots + \alpha_{2,12}DC_{t-12} \\ & + \alpha_{3,1}DP_{t-1} + \alpha_{3,2}DP_{t-2} + \cdots + \alpha_{3,12}DP_{t-12} \\ & + \alpha_{4,1}DI_{t-1} + \alpha_{4,2}DI_{t-2} + \cdots + \alpha_{4,12}DI_{t-12} \\ & + c_2 + \varepsilon_{2t} \qquad (19) \end{aligned}$$

$$\begin{aligned} DI_t = {} & \alpha_{1,1}DV_{t-1} + \alpha_{1,2}DV_{t-2} + \cdots + \alpha_{1,12}DV_{t-12} \\ & + \alpha_{2,1}DC_{t-1} + \alpha_{2,2}DC_{t-2} + \cdots + \alpha_{2,12}DC_{t-12} \\ & + \alpha_{3,1}DP_{t-1} + \alpha_{3,2}DP_{t-2} + \cdots + \alpha_{3,12}DP_{t-12} \\ & + \alpha_{4,1}DI_{t-1} + \alpha_{4,2}DI_{t-2} + \cdots + \alpha_{4,12}DI_{t-12} \\ & + c_4 + \varepsilon_{4t} \qquad (20) \end{aligned}$$

$$\begin{aligned} DP_t = {} & \alpha_{1,1}DV_{t-1} + \alpha_{1,2}DV_{t-2} + \cdots + \alpha_{1,12}DV_{t-12} \\ & + \alpha_{2,1}DC_{t-1} + \alpha_{2,2}DC_{t-2} + \cdots + \alpha_{2,12}DC_{t-12} \\ & + \alpha_{3,1}DP_{t-1} + \alpha_{3,2}DP_{t-2} + \cdots + \alpha_{3,12}DP_{t-12} \\ & + \alpha_{4,1}DI_{t-1} + \alpha_{4,2}DI_{t-2} + \cdots + \alpha_{4,12}DI_{t-12} \end{aligned}$$

$$+c_3 + \varepsilon_{3t} \qquad (21)$$

Considering the fact that we use the monthly data set, the lag length for each estimation is set as 12. With respect to the BVAR process with Litterman or Minnesota Prior, some conditions explained in section 2 should be settled before estimation. First, initial residual covariance matrix is obtained by the full-VAR estimation in this study. Second, the hyper-parameters, $\mu_1, \lambda_1, \lambda_2$, and λ_3 have to be determined as scalar values. The μ_1, the AR(1) coefficient is set as 0 in our estimation that describes the zero-mean model. The λ_1 is the overall tightness on the variance of the first lag, and this parameter decides the relative importance of sample and prior information. In our estimation, it is set as $\lambda_1 = 0.1.$ The λ_2 represents relative tightness of the variance of other variables, and we set it as $\lambda_2 = 0.99.$ The $\lambda_3 (> 0)$ shows is the relative tightness of the variance of lags, and it is set as $\lambda_3 = 1.$

As is widely known, VAR-type model provides impulse response analysis as a tool for grasping the marginal effects of the assumed shock with respect to one of the variables on the current and future levels of other endogenous variables.[4] In this context, the analysis by utilizing impulse response is applied in this study. Our impulse response is based on a one standard deviation shock and Cholesky decomposition with degrees of freedom correction.

Figure 1 indicates the estimated cumulative impulse responses of Kyoto. (The the estimated coefficients of the specification described by the equations (18), (19), (20), and (21) for Kyoto are shown in the appendix 1.) Our cumulative impulse responses capture the marginal effects for 24 periods (24 months) after the one-time shock considering one of the variables on the present and future values of other endogenous variables. The most important result to investigate the influence of economic variables on tourism demand is shown in the first row. With respect to the shock to "*DC*" (transportation cost of the tourism) described in the second column of the first row, it can be seen that the response of "*DV*" (tourism demand) is consistent with the usual assumption, that is, a rise in transportation cost is followed by a decline in tourism demand in the long term. The response of tourism demand to "*DI*" (vitality of regional economy) indicated in the third column of the first row is persistently positive although it is not on a large level. Concerning the shock to "*DP*" (regional price level) displayed in the fourth column, it is followed by cumulative negative response of tourism demand. These responses of Kyoto are consistent with the conventional belief.

Figure 2 reports the cumulative impulse responses of Osaka (The the estimated coefficients of the specification described by the equations (18), (19), (20), and (21) for Osaka are shown in the appendix 2.) The responses do not always indicate the same patterns of behavior as Kyoto. With respect to the first row, the cumulative impulse response for the shock to transportation cost in the second column does not coincides with the usual assumption. A positive shock to

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[4] See Koop (2013) for details.

Figure 1: Cumulative Impulse Responses of Kyoto by utilizing BVAR model

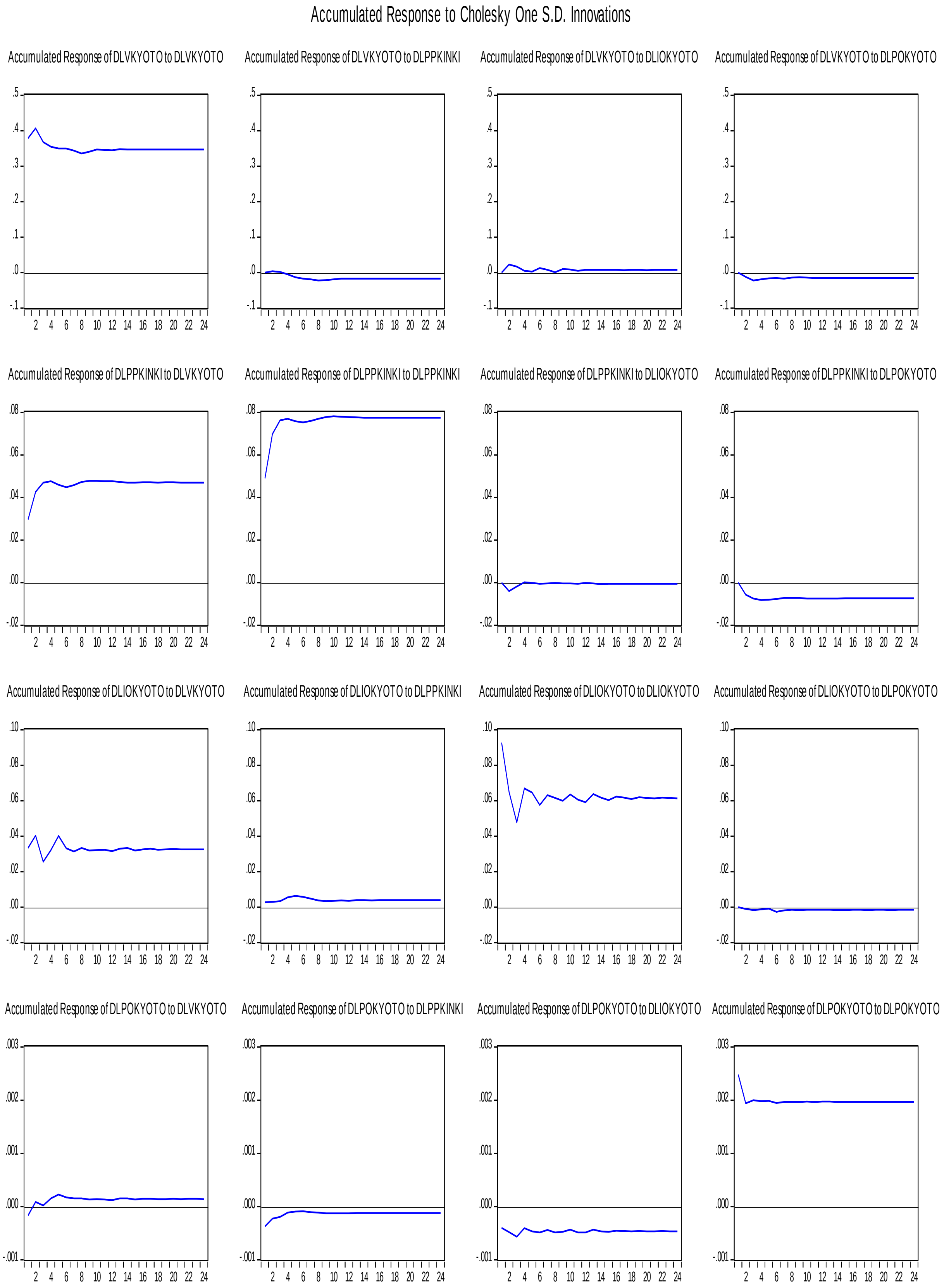
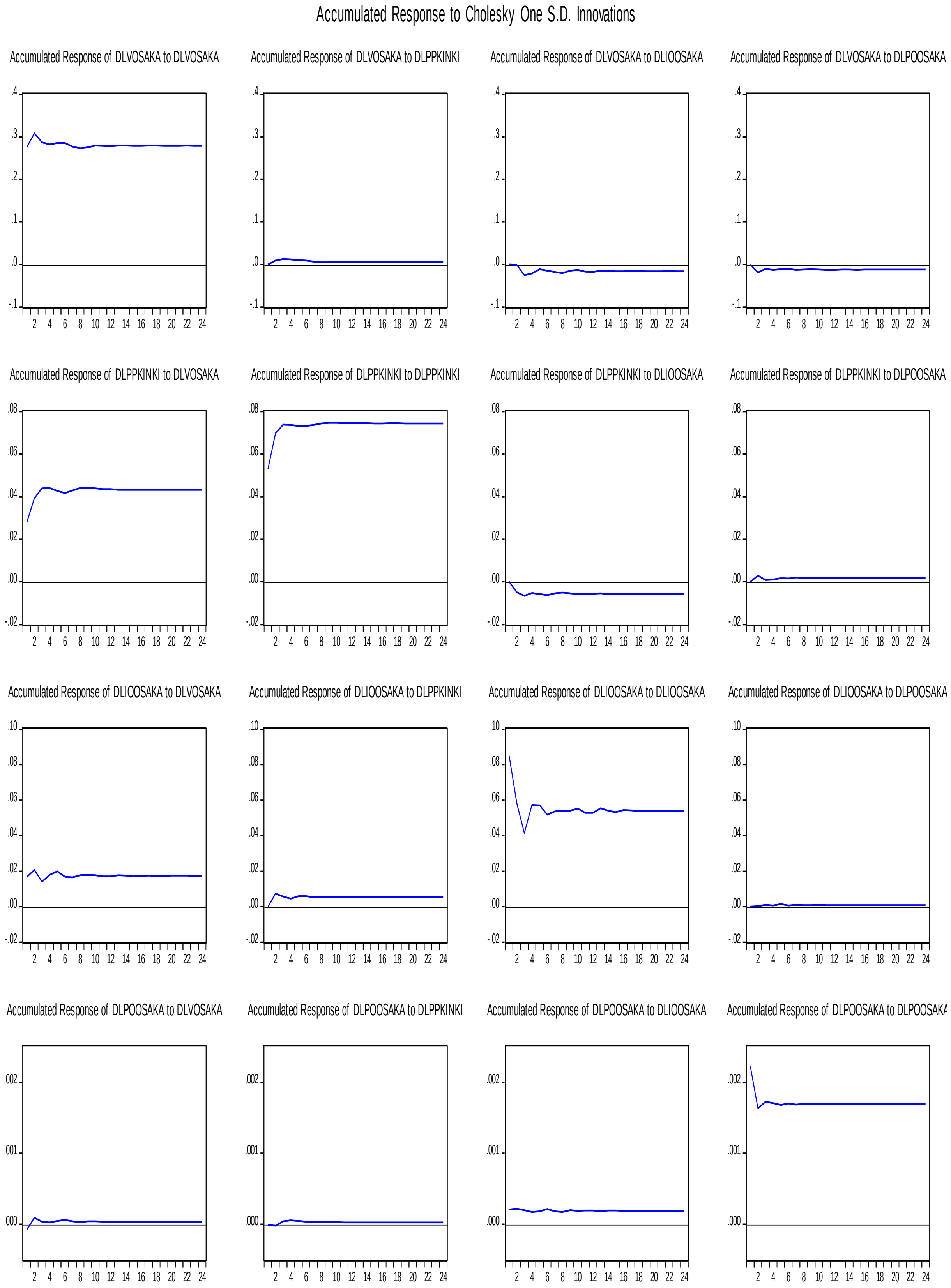

Accumulated Response to Cholesky One S.D. Innovations

Figure 2: Cumulative Impulse Responses of Osaka by utilizing BVAR model



transportation cost is followed by a small positive response of tourism demand. The shock to vitality of regional economy (in the third column) is not consistent with the standard supposition since it gets negative response in the long run. Only the shock to regional price level (displayed in the fourth column) brings the understandable result. Namely, a rise in price level derives the cumulative negative response of tourism demand. Overall, the estimated responses of tourism demand in Osaka to the several economic shocks seem to be inconsistent with the conventional assumption.

5. Concluding Remarks

The BVAR (Bayesian vector autoregression) model has been used as the Bayesian-flavored VAR specification for empirical analysis, which connects priors with information incorporated in sample. BVAR decreases the risk of over-parameterization by the imposition of special restrictions on the parameters in VAR process through their prior probability distribution functions.

In this research, we assume that prior distribution function and the posterior one are in the same distribution family and utilize one of the conjugate priors － Litterman or Minnesota prior. Taking the features of BVAR into account, the empirical analysis to investigate the influence of economic variables on tourism demand for Japan’s two major cities in western region is conducted in this study.

With respect to the estimated cumulative impulse responses of Kyoto, the shock to transportation cost of the tourism is consistent with the usual assumption, that is, a rise in transportation cost is followed by a decline in tourism demand in the long term. The response of tourism demand to vitality of regional economy is persistently positive although it is not on a large level. Concerning the shock to regional price level, it is followed by cumulative negative response of tourism demand. These responses of Kyoto are consistent with the conventional belief.

With respect to the estimated result of Osaka The cumulative impulse response for the shock to transportation cost does not coincides with the usual assumption. A positive shock to transportation cost is followed by a small positive response of tourism demand. The shock to vitality of regional economy is not consistent with the standard supposition since it gets negative response in the long run. Only the shock to regional price level brings the understandable result. Namely, a rise in price level derives the cumulative negative response of tourism demand. Overall, the estimated responses of tourism demand in Osaka to the several economic shocks seem to be inconsistent with the conventional assumption.

Totally, a further research with more sophisticated estimation is required since the empirical analysis in this paper has some unfavorable results.

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Appendix 1: estimated coefficients for Kyoto

Sample (adjusted): 2014M02 2021M08
Included observations: 91 after adjustments
Prior type: Litterman/Minnesota
Initial residual covariance: Full VAR
Standard errors in ( ) & t-statistics in [ ]

	DLVKYOTO	DLPPKINKI	DLIOKYOTO	DLPOKYOTO
DLVKYOTO(-1)	0.049518	0.006402	0.043665	0.000620
	(0.06469)	(0.00993)	(0.01359)	(0.00055)
	[0.76542]	[0.64480]	[3.21334]	[1.13468]
DLVKYOTO(-2)	-0.101026	2.18E-05	-0.012783	1.89E-05
	(0.04227)	(0.00647)	(0.00885)	(0.00035)
	[-2.39014]	[0.00337]	[-1.44423]	[0.05327]
DLVKYOTO(-3)	0.005756	-0.002061	0.006388	0.000134
	(0.03092)	(0.00472)	(0.00646)	(0.00026)
	[0.18616]	[-0.43663]	[0.98884]	[0.52194]
DLVKYOTO(-4)	-0.003201	-0.001583	0.009306	0.000161
	(0.02385)	(0.00364)	(0.00498)	(0.00020)
	[-0.13423]	[-0.43519]	[1.86896]	[0.81243]
DLVKYOTO(-5)	-0.004984	0.000323	-0.003794	-2.24E-05
	(0.01942)	(0.00296)	(0.00405)	(0.00016)
	[-0.25661]	[0.10921]	[-0.93625]	[-0.13882]
DLVKYOTO(-6)	-0.010939	0.001184	-0.002424	-4.82E-05
	(0.01634)	(0.00249)	(0.00341)	(0.00014)
	[-0.66927]	[0.47515]	[-0.71098]	[-0.35581]
DLVKYOTO(-7)	-0.003895	0.000712	0.000492	-4.42E-07
	(0.01409)	(0.00215)	(0.00294)	(0.00012)
	[-0.27645]	[0.33162]	[0.16747]	[-0.00379]
DLVKYOTO(-8)	0.002428	-0.000199	0.000126	-2.66E-06
	(0.01238)	(0.00189)	(0.00258)	(0.00010)
	[0.19612]	[-0.10557]	[0.04878]	[-0.02594]
DLVKYOTO(-9)	0.005369	-0.000401	-0.000937	-2.23E-05
	(0.01102)	(0.00168)	(0.00230)	(9.1E-05)
	[0.48710]	[-0.23847]	[-0.40766]	[-0.24439]
DLVKYOTO(-10)	-4.90E-05	-5.71E-05	-0.000650	-1.27E-05
	(0.00994)	(0.00151)	(0.00207)	(8.2E-05)
	[-0.00493]	[-0.03769]	[-0.31379]	[-0.15483]
DLVKYOTO(-11)	-0.001364	-8.64E-05	0.000529	3.10E-06
	(0.00904)	(0.00138)	(0.00189)	(7.5E-05)
	[-0.15085]	[-0.06273]	[0.28056]	[0.04142]
DLVKYOTO(-12)	0.003278	-0.000221	0.000235	1.13E-05

	(0.00830)	(0.00126)	(0.00173)	(6.9E-05)
	[0.39515]	[-0.17476]	[0.13577]	[0.16417]
DLPPKINKI(-1)	0.019373	0.408110	0.015794	0.001472
	(0.39413)	(0.06094)	(0.08307)	(0.00334)
	[0.04915]	[6.69684]	[0.19012]	[0.44117]
DLPPKINKI(-2)	-0.071927	-0.036107	0.015487	0.000568
	(0.27370)	(0.04248)	(0.05770)	(0.00231)
	[-0.26280]	[-0.85004]	[0.26840]	[0.24615]
DLPPKINKI(-3)	-0.086301	-0.023603	0.040253	0.001484
	(0.19471)	(0.03024)	(0.04104)	(0.00164)
	[-0.44322]	[-0.78059]	[0.98084]	[0.90684]
DLPPKINKI(-4)	-0.095544	-0.003953	0.020719	0.000232
	(0.15132)	(0.02351)	(0.03189)	(0.00127)
	[-0.63140]	[-0.16816]	[0.64974]	[0.18296]
DLPPKINKI(-5)	-0.027233	0.006594	-0.007507	2.02E-05
	(0.12335)	(0.01917)	(0.02599)	(0.00103)
	[-0.22077]	[0.34406]	[-0.28885]	[0.01952]
DLPPKINKI(-6)	-0.037416	0.012352	-0.019177	-0.000241
	(0.10400)	(0.01616)	(0.02191)	(0.00087)
	[-0.35976]	[0.76430]	[-0.87522]	[-0.27639]
DLPPKINKI(-7)	-0.030258	0.008072	-0.015224	-0.000150
	(0.08991)	(0.01397)	(0.01894)	(0.00075)
	[-0.33653]	[0.57774]	[-0.80382]	[-0.19887]
DLPPKINKI(-8)	0.026712	9.99E-05	-0.006694	-0.000213
	(0.07912)	(0.01229)	(0.01666)	(0.00066)
	[0.33764]	[0.00812]	[-0.40168]	[-0.32164]
DLPPKINKI(-9)	0.030610	-0.001208	0.001233	-5.72E-05
	(0.07053)	(0.01096)	(0.01486)	(0.00059)
	[0.43398]	[-0.11022]	[0.08299]	[-0.09698]
DLPPKINKI(-10)	0.010944	-0.001611	-0.000796	-4.00E-06
	(0.06364)	(0.00989)	(0.01340)	(0.00053)
	[0.17196]	[-0.16293]	[-0.05938]	[-0.00752]
DLPPKINKI(-11)	-8.96E-05	-0.001385	0.001260	3.31E-07
	(0.05795)	(0.00901)	(0.01220)	(0.00048)
	[-0.00155]	[-0.15374]	[0.10327]	[0.00068]
DLPPKINKI(-12)	0.003858	-0.001880	0.003184	0.000105
	(0.05318)	(0.00827)	(0.01120)	(0.00044)
	[0.07255]	[-0.22746]	[0.28430]	[0.23741]
DLIOKYOTO(-1)	0.217011	-0.054284	-0.302360	-0.001838
	(0.23060)	(0.03550)	(0.04876)	(0.00195)
	[0.94106]	[-1.52906]	[-6.20147]	[-0.94409]

DLIOKYOTO(-2)	-0.032771	0.021043	-0.285583	-0.001865
	(0.17368)	(0.02675)	(0.03684)	(0.00147)
	[-0.18869]	[0.78665]	[-7.75217]	[-1.27065]
DLIOKYOTO(-3)	-0.087833	0.003505	0.071515	0.000664
	(0.13621)	(0.02098)	(0.02895)	(0.00115)
	[-0.64484]	[0.16710]	[2.47061]	[0.57886]
DLIOKYOTO(-4)	-0.089775	0.009585	0.010466	5.78E-05
	(0.10737)	(0.01653)	(0.02283)	(0.00090)
	[-0.83609]	[0.57967]	[0.45847]	[0.06406]
DLIOKYOTO(-5)	0.066837	-0.004408	-0.012566	5.49E-05
	(0.08785)	(0.01353)	(0.01868)	(0.00074)
	[0.76080]	[-0.32587]	[-0.67268]	[0.07442]
DLIOKYOTO(-6)	-0.018618	0.000458	0.008037	7.93E-05
	(0.07444)	(0.01146)	(0.01583)	(0.00062)
	[-0.25011]	[0.03999]	[0.50766]	[0.12703]
DLIOKYOTO(-7)	-0.053440	0.004457	-0.016888	-0.000388
	(0.06445)	(0.00992)	(0.01371)	(0.00054)
	[-0.82915]	[0.44923]	[-1.23206]	[-0.71920]
DLIOKYOTO(-8)	0.058756	-0.002740	0.002594	9.08E-05
	(0.05710)	(0.00879)	(0.01214)	(0.00048)
	[1.02895]	[-0.31179]	[0.21359]	[0.19000]
DLIOKYOTO(-9)	-0.008379	-0.001184	0.015850	0.000214
	(0.05105)	(0.00786)	(0.01086)	(0.00043)
	[-0.16413]	[-0.15064]	[1.45969]	[0.50222]
DLIOKYOTO(-10)	-0.015805	0.000414	-0.013466	-0.000199
	(0.04618)	(0.00711)	(0.00982)	(0.00039)
	[-0.34225]	[0.05829]	[-1.37101]	[-0.51472]
DLIOKYOTO(-11)	0.019362	0.000400	-0.009702	-9.89E-05
	(0.04218)	(0.00649)	(0.00897)	(0.00035)
	[0.45906]	[0.06170]	[-1.08148]	[-0.28048]
DLIOKYOTO(-12)	-0.001287	-0.001875	0.017111	0.000256
	(0.03874)	(0.00596)	(0.00824)	(0.00032)
	[-0.03322]	[-0.31443]	[2.07634]	[0.79092]
DLPOKYOTO(-1)	-5.038650	-2.294251	-0.474045	-0.216693
	(8.18172)	(1.26068)	(1.72618)	(0.06982)
	[-0.61584]	[-1.81986]	[-0.27462]	[-3.10378]
DLPOKYOTO(-2)	-4.569193	-0.307321	-0.202250	-0.018459
	(5.26687)	(0.81136)	(1.11070)	(0.04475)
	[-0.86754]	[-0.37877]	[-0.18209]	[-0.41247]
DLPOKYOTO(-3)	-0.299711	-0.036790	0.099422	-0.002113
	(3.72063)	(0.57291)	(0.78420)	(0.03152)
	[-0.08055]	[-0.06422]	[0.12678]	[-0.06704]

DLPOKYOTO(-4)	0.401954	0.054049	0.219989	0.005410
	(2.85795)	(0.43997)	(0.60220)	(0.02417)
	[0.14064]	[0.12285]	[0.36531]	[0.22379]
DLPOKYOTO(-5)	0.382919	0.108976	-0.460406	-0.010245
	(2.31536)	(0.35639)	(0.48778)	(0.01957)
	[0.16538]	[0.30578]	[-0.94389]	[-0.52362]
DLPOKYOTO(-6)	-0.846982	0.091857	0.018241	-0.000497
	(1.94432)	(0.29924)	(0.40955)	(0.01642)
	[-0.43562]	[0.30697]	[0.04454]	[-0.03030]
DLPOKYOTO(-7)	0.640848	-0.003131	0.050525	-0.000564
	(1.67369)	(0.25757)	(0.35252)	(0.01413)
	[0.38290]	[-0.01216]	[0.14333]	[-0.03995]
DLPOKYOTO(-8)	0.174204	0.044278	-0.029626	-0.000889
	(1.46908)	(0.22607)	(0.30940)	(0.01240)
	[0.11858]	[0.19586]	[-0.09575]	[-0.07174]
DLPOKYOTO(-9)	-0.059693	-0.058834	0.031148	0.002024
	(1.30800)	(0.20128)	(0.27547)	(0.01104)
	[-0.04564]	[-0.29230]	[0.11307]	[0.18339]
DLPOKYOTO(-10)	-0.023293	-0.005431	-0.023528	-0.001633
	(1.17899)	(0.18142)	(0.24829)	(0.00995)
	[-0.01976]	[-0.02993]	[-0.09476]	[-0.16413]
DLPOKYOTO(-11)	-0.118222	-0.024065	0.059780	0.002264
	(1.07281)	(0.16508)	(0.22593)	(0.00905)
	[-0.11020]	[-0.14578]	[0.26460]	[0.25011]
DLPOKYOTO(-12)	0.057376	0.029581	-0.017443	-0.000330
	(0.98427)	(0.15145)	(0.20728)	(0.00830)
	[0.05829]	[0.19531]	[-0.08415]	[-0.03969]
C	-0.004946	-0.001069	-0.003082	3.21E-05
	(0.02233)	(0.00344)	(0.00470)	(0.00019)
	[-0.22149]	[-0.31114]	[-0.65547]	[0.17213]
R-squared	0.170624	0.381696	0.508568	0.157707
Adj. R-squared	-0.777235	-0.324938	-0.053069	-0.804914
Sum sq. resids	6.021211	0.137453	0.406940	0.000271
S.E. equation	0.378632	0.057207	0.098433	0.002540
F-statistic	0.180010	0.540161	0.905510	0.163831
Mean dependent	-0.003723	-0.001621	-0.002875	2.20E-05
S.D. dependent	0.284017	0.049700	0.095921	0.001890

Appendix 2: estimated coefficients for Osaka

Sample (adjusted): 2014M02 2021M08
Included observations: 91 after adjustments
Prior type: Litterman/Minnesota
Initial residual covariance: Full VAR
Standard errors in ( ) & t-statistics in [ ]

	DLVOSAKA	DLPPKINKI	DLIOOSAKA	DLPOOSAKA
DLVOSAKA(-1)	0.098139	0.013327	0.019361	0.000511
	(0.06201)	(0.01775)	(0.01536)	(0.00058)
	[1.58271]	[0.75097]	[1.26043]	[0.88356]
DLVOSAKA(-2)	-0.073294	0.004746	-0.006455	-0.000211
	(0.04146)	(0.01183)	(0.01020)	(0.00038)
	[-1.76801]	[0.40112]	[-0.63253]	[-0.54849]
DLVOSAKA(-3)	-0.005463	-0.001798	0.008157	-7.02E-05
	(0.03054)	(0.00871)	(0.00744)	(0.00028)
	[-0.17891]	[-0.20639]	[1.09573]	[-0.24974]
DLVOSAKA(-4)	0.004019	-0.002708	0.002651	5.53E-05
	(0.02373)	(0.00677)	(0.00576)	(0.00022)
	[0.16940]	[-0.39989]	[0.46051]	[0.25415]
DLVOSAKA(-5)	0.003605	-0.001924	-0.003871	6.31E-05
	(0.01932)	(0.00551)	(0.00467)	(0.00018)
	[0.18662]	[-0.34909]	[-0.82833]	[0.35725]
DLVOSAKA(-6)	-0.021710	0.003285	-0.001257	-3.13E-05
	(0.01630)	(0.00465)	(0.00393)	(0.00015)
	[-1.33223]	[0.70628]	[-0.31941]	[-0.21021]
DLVOSAKA(-7)	-0.004186	0.001452	0.001091	-6.34E-07
	(0.01408)	(0.00402)	(0.00339)	(0.00013)
	[-0.29739]	[0.36132]	[0.32159]	[-0.00494]
DLVOSAKA(-8)	0.003883	-0.000332	0.001171	-3.36E-06
	(0.01235)	(0.00353)	(0.00298)	(0.00011)
	[0.31433]	[-0.09411]	[0.39354]	[-0.02984]
DLVOSAKA(-9)	0.005541	-0.001112	-8.32E-05	-7.80E-06
	(0.01101)	(0.00314)	(0.00265)	(0.00010)
	[0.50343]	[-0.35390]	[-0.03138]	[-0.07784]
DLVOSAKA(-10)	-0.000179	-0.000540	-0.001264	5.35E-06
	(0.00993)	(0.00283)	(0.00239)	(9.0E-05)
	[-0.01799]	[-0.19072]	[-0.52924]	[0.05924]
DLVOSAKA(-11)	-0.001498	7.20E-05	0.000319	-1.61E-05
	(0.00904)	(0.00258)	(0.00217)	(8.2E-05)
	[-0.16578]	[0.02791]	[0.14673]	[-0.19553]
DLVOSAKA(-12)	0.003631	-0.000667	-0.000178	1.12E-05

	(0.00829)	(0.00237)	(0.00199)	(7.5E-05)
	[0.43790]	[-0.28170]	[-0.08899]	[0.14848]
DLPPKINKI(-1)	0.173497	0.317986	0.136463	-0.000267
	(0.23842)	(0.06878)	(0.05924)	(0.00223)
	[0.72769]	[4.62304]	[2.30371]	[-0.11956]
DLPPKINKI(-2)	-0.018977	-0.019872	-0.031618	0.001038
	(0.15349)	(0.04452)	(0.03774)	(0.00142)
	[-0.12364]	[-0.44632]	[-0.83787]	[0.72892]
DLPPKINKI(-3)	0.032307	-0.023028	0.007619	0.000331
	(0.10739)	(0.03120)	(0.02630)	(0.00099)
	[0.30083]	[-0.73812]	[0.28966]	[0.33354]
DLPPKINKI(-4)	-0.031994	-0.000719	0.005435	-0.000254
	(0.08246)	(0.02397)	(0.02014)	(0.00076)
	[-0.38800]	[-0.03001]	[0.26977]	[-0.33349]
DLPPKINKI(-5)	-0.029826	0.007380	-0.001178	-0.000219
	(0.06683)	(0.01944)	(0.01630)	(0.00062)
	[-0.44628]	[0.37957]	[-0.07226]	[-0.35614]
DLPPKINKI(-6)	-0.031942	0.009161	-0.003388	-6.42E-05
	(0.05614)	(0.01634)	(0.01367)	(0.00052)
	[-0.56902]	[0.56077]	[-0.24778]	[-0.12421]
DLPPKINKI(-7)	-0.011195	0.003587	-0.003294	8.95E-05
	(0.04837)	(0.01408)	(0.01177)	(0.00045)
	[-0.23145]	[0.25476]	[-0.27980]	[0.20119]
DLPPKINKI(-8)	0.008953	-0.000370	0.000233	-4.79E-06
	(0.04246)	(0.01236)	(0.01033)	(0.00039)
	[0.21085]	[-0.02991]	[0.02253]	[-0.01226]
DLPPKINKI(-9)	0.014035	-0.000360	0.002390	-9.71E-05
	(0.03782)	(0.01101)	(0.00920)	(0.00035)
	[0.37111]	[-0.03268]	[0.25993]	[-0.27931]
DLPPKINKI(-10)	0.002013	-0.000747	-0.000793	-2.65E-05
	(0.03410)	(0.00993)	(0.00829)	(0.00031)
	[0.05902]	[-0.07519]	[-0.09568]	[-0.08446]
DLPPKINKI(-11)	-0.005040	2.63E-05	-0.001003	-3.30E-05
	(0.03103)	(0.00904)	(0.00754)	(0.00029)
	[-0.16243]	[0.00291]	[-0.13302]	[-0.11559]
DLPPKINKI(-12)	0.002194	-0.001311	0.000152	4.80E-05
	(0.02847)	(0.00829)	(0.00692)	(0.00026)
	[0.07708]	[-0.15808]	[0.02194]	[0.18329]
DLIOOSAKA(-1)	0.005059	-0.061256	-0.313010	0.000759
	(0.19193)	(0.05519)	(0.04752)	(0.00179)
	[0.02636]	[-1.10999]	[-6.58686]	[0.42448]

DLIOOSAKA(-2)	-0.276097	-0.018442	-0.290129	9.55E-05
	(0.14776)	(0.04245)	(0.03685)	(0.00138)
	[-1.86855]	[-0.43440]	[-7.87284]	[0.06919]
DLIOOSAKA(-3)	-0.007259	0.007183	0.039847	5.83E-05
	(0.11722)	(0.03372)	(0.02912)	(0.00109)
	[-0.06192]	[0.21303]	[1.36856]	[0.05352]
DLIOOSAKA(-4)	0.028752	-0.003012	0.003989	-4.70E-05
	(0.09242)	(0.02660)	(0.02291)	(0.00086)
	[0.31109]	[-0.11325]	[0.17415]	[-0.05488]
DLIOOSAKA(-5)	0.014930	-0.001054	0.003519	0.000247
	(0.07586)	(0.02184)	(0.01877)	(0.00070)
	[0.19682]	[-0.04825]	[0.18750]	[0.35172]
DLIOOSAKA(-6)	-0.013617	0.004172	-0.001358	-0.000135
	(0.06434)	(0.01853)	(0.01589)	(0.00059)
	[-0.21164]	[0.22517]	[-0.08542]	[-0.22703]
DLIOOSAKA(-7)	-0.059255	0.004354	-0.009974	-0.000160
	(0.05580)	(0.01607)	(0.01377)	(0.00052)
	[-1.06188]	[0.27086]	[-0.72436]	[-0.31026]
DLIOOSAKA(-8)	0.037384	-0.000447	0.004702	0.000123
	(0.04936)	(0.01422)	(0.01216)	(0.00046)
	[0.75734]	[-0.03140]	[0.38659]	[0.26944]
DLIOOSAKA(-9)	0.023184	-0.002484	0.015510	-6.86E-05
	(0.04416)	(0.01273)	(0.01087)	(0.00041)
	[0.52493]	[-0.19517]	[1.42647]	[-0.16843]
DLIOOSAKA(-10)	-0.019358	-0.001960	-0.015917	6.26E-05
	(0.04000)	(0.01153)	(0.00984)	(0.00037)
	[-0.48401]	[-0.17005]	[-1.61801]	[0.16991]
DLIOOSAKA(-11)	0.000247	-0.000204	-0.007719	7.05E-05
	(0.03657)	(0.01054)	(0.00899)	(0.00034)
	[0.00675]	[-0.01938]	[-0.85887]	[0.20942]
DLIOOSAKA(-12)	0.006302	0.001136	0.013256	-0.000103
	(0.03358)	(0.00968)	(0.00825)	(0.00031)
	[0.18770]	[0.11738]	[1.60717]	[-0.33251]
DLPOOSAKA(-1)	-8.508390	1.344986	0.099986	-0.266644
	(6.85303)	(1.96783)	(1.70519)	(0.06451)
	[-1.24155]	[0.68349]	[0.05864]	[-4.13324]
DLPOOSAKA(-2)	2.102019	-0.888017	0.362231	-0.024913
	(4.61462)	(1.32627)	(1.14194)	(0.04338)
	[0.45551]	[-0.66956]	[0.31721]	[-0.57422]
DLPOOSAKA(-3)	-1.111590	0.139274	0.079360	-0.009023
	(3.30902)	(0.95218)	(0.81336)	(0.03097)
	[-0.33593]	[0.14627]	[0.09757]	[-0.29137]

DLPOOSAKA(-4)	0.715225	0.304186	0.531880	-0.015106
	(2.56223)	(0.73778)	(0.62748)	(0.02392)
	[0.27914]	[0.41230]	[0.84765]	[-0.63157]
DLPOOSAKA(-5)	0.366975	-0.070594	-0.277698	0.004130
	(2.08600)	(0.60093)	(0.50948)	(0.01943)
	[0.17592]	[-0.11747]	[-0.54506]	[0.21252]
DLPOOSAKA(-6)	-0.842069	0.185999	0.110321	-0.002760
	(1.75293)	(0.50511)	(0.42756)	(0.01632)
	[-0.48038]	[0.36824]	[0.25803]	[-0.16915]
DLPOOSAKA(-7)	0.122714	-0.032895	-0.140910	0.001842
	(1.51216)	(0.43581)	(0.36840)	(0.01406)
	[0.08115]	[-0.07548]	[-0.38249]	[0.13095]
DLPOOSAKA(-8)	0.164823	-0.056861	0.042804	0.001528
	(1.32909)	(0.38311)	(0.32353)	(0.01235)
	[0.12401]	[-0.14842]	[0.13230]	[0.12374]
DLPOOSAKA(-9)	-0.238755	0.039815	0.040551	-0.002563
	(1.18427)	(0.34139)	(0.28815)	(0.01100)
	[-0.20161]	[0.11663]	[0.14073]	[-0.23296]
DLPOOSAKA(-10)	-0.196507	0.003541	-0.030875	0.001375
	(1.06764)	(0.30779)	(0.25969)	(0.00992)
	[-0.18406]	[0.01150]	[-0.11889]	[0.13862]
DLPOOSAKA(-11)	-0.145225	-0.009187	-0.029438	0.000532
	(0.97230)	(0.28032)	(0.23642)	(0.00903)
	[-0.14936]	[-0.03277]	[-0.12451]	[0.05888]
DLPOOSAKA(-12)	0.180836	-0.009838	0.004424	-0.000454
	(0.89219)	(0.25723)	(0.21690)	(0.00828)
	[0.20269]	[-0.03824]	[0.02040]	[-0.05479]
C	-0.004548	-0.001114	-0.000705	-1.28E-05
	(0.01534)	(0.00442)	(0.00372)	(0.00014)
	[-0.29656]	[-0.25186]	[-0.18930]	[-0.09110]
R-squared	0.173495	0.322212	0.432861	0.197096
Adj. R-squared	-0.771083	-0.452403	-0.215298	-0.720509
Sum sq. resids	3.189437	0.150676	0.314223	0.000210
S.E. equation	0.275570	0.059896	0.086496	0.002236
F-statistic	0.183674	0.415964	0.667831	0.214794
Mean dependent	-0.004376	-0.001621	-0.001110	-5.44E-06
S.D. dependent	0.207068	0.049700	0.078461	0.001705