Dynamic Effects of Oil Price Fluctuations on Business Cycle and Unemployment Rate in Japan

Koki Kyo and Hideo Noda

***Abstract*—This paper studies the dynamic effects of oil price fluctuations on business cycles and the unemployment rate in Japan. Much of the conventional research on relations between several economic variables has applied models based on the assumption of parameter invariability. However, when we consider a time series model over a period of several decades, assuming no structural changes is clearly unrealistic. In the present paper, we apply a time-varying coefficient vector autoregressive modeling approach based on a Bayesian method using smoothness priors. The results suggests that oil price fluctuations strongly influence business conditions. Oil price fluctuations also affect cyclical unemployment rate during the recession. Notably, the influence of oil price fluctuations on business conditions and unemployment has become large in recent years.**

***Index Terms*—Bayesian modeling, time-varying coefficient VAR model, oil price, unemployment rate, composite index.**

I. Introduction

Rapid changes in oil price exert an economic influence that cannot be ignored in Japan. In recent years Japan has also suffered simultaneously from a rise in unemployment rate and a long-term economic depression. However, no studies have synthetically analyzed oil price fluctuations, unemployment and business conditions within a dynamic framework. Therefore in this paper we analyze the dynamic effects of oil price fluctuations on business cycles and unemployment rate in Japan using time series data.

Major studies on the macroeconomic effects of oil price fluctuations include those of Hamilton [1], [2] and Zhang [3]. However, the conventional methods represented by the preceding studies are not entirely satisfactory. The foremost reason for this is the treatment of coefficients in the modeling as constant parameters despite the use of long-term time series data. Although this reflects the assumption of invariability in the model structure, the assumption that no structural changes occur when the model covers several decades is clearly unrealistic. Such insufficiency of strict treatment for structural changes can also be seen in the preceding studies on the macroeconomic effects of unemployment (see [4]). Recently it was verified that the Bayesian method based on the smoothness prior approach proposed by [5] is useful for modeling and statistically analyzing the dynamic structure of an economy (see [6]–[9]). The smoothness prior approach allows the expression of diverse structural change patterns in parameters and continuous observation of these changes, thus allowing the construction of a much more flexible model than would normally be possible.

Additionally, vector autoregressive (VAR) modeling is useful for analyzing a vector time series (see [10]). However, a VAR model can only be applied to stationary time series. Jiang and Kitagawa proposed an extension to vector time series with nonstationary covariance by developing a time-varying coefficient vector autoregressive (TVCVAR) modeling method in [11]. The TVCVAR model can explain the dynamic relationship between all variates of a vector time series (see [12]). Kyo and Noda successfully used the TVCVAR modeling method to analyze the dynamics of the relationship between oil price fluctuations and Japanese industrial production in [13].

In this paper, we extend the TVCVAR model constructed in [13] to a vector time series of the following three variates: 1) the variation in a component of the unemployment rate in Japan, 2) the variation in the composite index in Japan, 3) the rate of change in the oil price. The parameters in our TVCVAR model are estimated by a Bayesian method using a smoothness priors approach. To examine the relationships among the three variates, the time-varying cross-spectrum, power contribution, and covariance function for the time series are then computed based on the estimates of parameters in the model.

The rest of this paper is organized as follows. In Section II, we introduce our model and explain how to use it to analyze the dynamic characteristics of time series with nonstationary covariance. In Section III we present and analyze our main results from an economic perspective. Finally, in Section IV we give conclusions.

II. Model and Applications

Consider a set of monthly data containing the seasonally adjusted time series x_{n1}, x_{n2}, and x_{n3} with n being the time point for a month. x_{n1} expresses the cyclical unemployment rate that arises in Japan from a decrease in labor demand during a recession. x_{n2} expresses the composite index (CI) in Japan, and x_{n3} is the real oil price in Japanese Yen. A vector time series of three variates can then be generated as follows:

$$y_{n1} = x_{n1} - x_{(n-1)1},\ y_{n2} = x_{n2} - x_{(n-2)2},$$
$$y_{n3} = \log x_{n3} - \log x_{(n-2)3}.$$

That is, y_{n1} and y_{n2} denote the variations in the unemployment rate and CI in Japan relative to their two-month-ahead values, respectively, while y_{n3} denotes the rate of change in the oil price relative to its two-month-ahead value.

Manuscript received October 5, 2015; revised December 7, 2015.

Koki Kyo is with the Obihiro University of Agriculture and Veterinary Medicine, Obihiro, Hokkaido 080-8555, Japan (e-mail: kyo@obihiro.ac.jp).

Hideo Noda is with the School of Management, Tokyo University of Science, Kuki, Saitama 346-8512, Japan (e-mail: noda@rs.tus.ac.jp).

doi: 10.18178/ijimt.2015.6.6.633

We regard $y_n = (y_{n1}, y_{n2}, y_{n3})^{\mathrm{T}}$ as a 3-variate time series, and introduce a TVCVAR model as follows:

$$y_n = \sum_{l=1}^{p} A_l(n) y_{n-l} + u_n, \quad (1)$$

where p is the model order, and $A_l(n)\ (l = 1, 2, \ldots, p)$ are time-varying coefficient matrices for each value of lag l at time n. In Eq. (1), u_n is a 3-variate Gaussian white noise sequence with mean zero and covariance matrix $\Sigma(n)$. It is assumed that u_n and y_{n-l} are independent of each other for $l > 0$.

To more efficiently estimate the parameters of the TVCVAR model in Eq. (1), we construct the TVCVAR model in the following form to include a simultaneous response:

$$y_n = D(n) y_n + \sum_{l=1}^{p} B_l(n) y_{n-l} + v_n, \quad (2)$$

where v_n is a 3-variate Gaussian white noise sequence with mean zero and covariance matrix $V = \mathrm{diag}(\sigma_1^2, \sigma_2^2, \sigma_3^2)$. Similarly, we suppose that v_n and y_{n-l} are independent of each other for $l > 0$. The coefficient matrix $D(n)$ for the simultaneous response and the coefficient matrices $B_l(n)$ $(l = 1, 2, \ldots, p)$ are defined as follows:

$$D(n) = \begin{bmatrix} 0 & 0 & 0 \\ b_{210}(n) & 0 & 0 \\ b_{310}(n) & b_{320}(n) & 0 \end{bmatrix},$$

$$B_l(n) = \begin{bmatrix} b_{11l}(n) & b_{12l}(n) & b_{13l}(n) \\ b_{21l}(n) & b_{22l}(n) & b_{23l}(n) \\ b_{31l}(n) & b_{32l}(n) & b_{33l}(n) \end{bmatrix}.$$

To estimate the time-varying coefficients we apply a Bayesian smoothness priors modeling method proposed by [5]. Specifically, order-1 smoothness priors are constructed for all elements in matrices $D(n)$ and $B_l(n)$ as:

$$b_{ijl}(n) - b_{ijl}(n-1) = \eta_{ijl}(n), \quad (3)$$

where $\eta_{ijl}(n)$ is a Gaussian white noise sequence with zero mean and unknown variance τ_i^2. It is assumed that: (1) $\eta_{i_1 j_1 l_1}(n_1)$ and $\eta_{i_2 j_2 l_2}(n_2)$ are independent of each other when $\{i_1, j_1, l_1, n_1\} \neq \{i_2, j_2, l_2, n_2\}$; and that (2) $\eta_{ijl}(n)$ and v_n are independent of each other for all values of $i, j, l,$ and n. Thus, a Bayesian TVCVAR model is constructed based on the models in Eq. (2) and Eq. (3).

A state space model can then be obtained using the procedure developed in [12]. Hence, we can estimate parameters σ_i^2 and τ_i^2 for $i = 1, 2, 3$ using the maximum likelihood method, and can estimate matrices $D(n)$ and $B_l(n)$ using a Kalman filter together with fixed-interval smoothing. Moreover, estimates for the parameters in the original TVCVAR model (1) can be obtained from the relations

$$A_l(n) = (I - D(n))^{-1} B_l(n),$$
$$\Sigma(n) = (I - D(n))^{-1} V (I - D(n))^{-\mathrm{T}}.$$

Statistics, including the time-varying cross-spectrum, time-varying power contribution, and time-varying covariance function, can be obtained from the estimates of $A_l(n)$ and $\Sigma(n)$ using the method proposed in [11]. These statistics, especially the time-varying power contribution and time-varying covariance function, are useful for explaining the dynamic relationship between every variate in a vector time series.

III. Results and Discussion

The approach presented in Section II is applied to Japanese monthly statistics from January 1980 to October 2010. For x_{n1}, representing the cyclical unemployment rate in Japan, we calculate the data using the method proposed by [4]. For x_{n2}, representing the composite index (CI) in Japan, we calculate the data using the lagging CI from the Indexes of Business Conditions published by the Cabinet Office, Government of Japan. For x_{n3}, representing real oil prices in Japanese Yen, we construct the data using the method proposed in [3] as follows:

$$x_{n3} = \frac{dp_n \times \varepsilon_n}{cp_n},$$

where dp_n denotes the oil price, represented by the Dubai spot price index, while ε_n denotes the nominal exchange rate (market rate at the end of the period), and cp_n denotes the consumer price index (CPI) in Japan. The data for dp_n, ε_n, and cp_n are collected from International Financial Statistics (IFS).

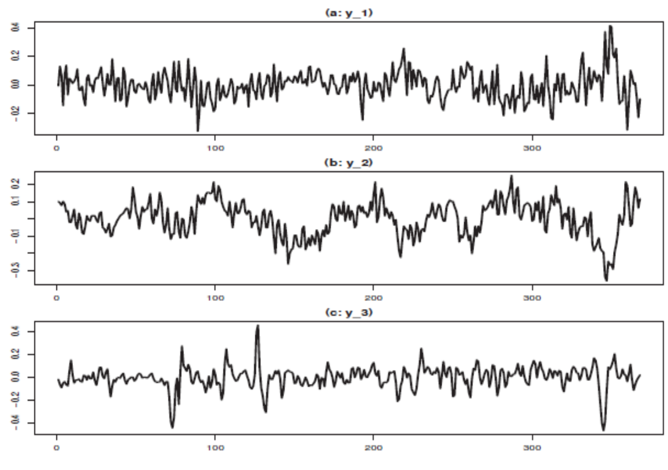

Fig. 1. Time series data: (a) y_{n1}, (b) y_{n2}, (c) y_{n3}.

Fig. 1 shows the line graphs of the time series y_{n1} (changes in cyclical unemployment rate), y_{n2} (changes in CI) and y_{n3} (rate of change in the oil price).

Note that for convenience of estimation we have adjusted the averages of the time series to zero and the standard deviations to 0.1.

First, we show the results for determining the value of p. In theory, the value of p should be determined using the minimum AIC method (see [14]). However, we use a vague distribution of the initial state, which allows us to estimate p using the maximum likelihood method. Table I presents the log-likelihood (LL) values for the Bayesian TVCVAR model in Eqs. (2) and (3) for $p = 1, 2, \ldots, 7$.

TABLE I: LL VALUES OF THE MODEL FOR DIFFERENT VALUES OF p

Value of p	1	2	3	4	5	6	7
LL value	12921	13369	13745	13948	13907	13878	13720

From this table, we can see that $p = 4$ gives the maximum LL value (13948). Thus, we use the model with $p = 4$ in the following analysis.

The estimated time-varying spectra and coherencies for the time series are shown in Fig. 2.

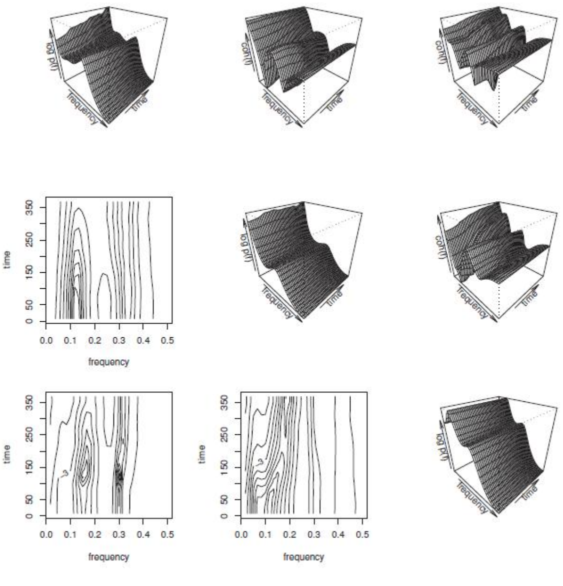

Fig. 2. Estimates of time-varying Spectra and coherencies.

In this figure, the graphs on the diagonal from top left to bottom right show the estimated time-varying spectra for y_{n1}, y_{n2}, and y_{n3}. The graphs for elements of (1,2), (1,3), and (2,3) show the time-varying coherencies. The graphs for elements of (2,1), (3,1), and (3,2) show the corresponding contour maps. For instance, the first row and second column of the graph shows the time-varying coherency between y_{n1} (the changes in cyclical unemployment rate) and y_{n2} (the changes in CI), while the second row and first column shows the corresponding contour map. It can be seen that for y_{n1} the spectrum exhibits large fluctuations over time around the lower-frequency domain, while for y_{n2} and y_{n3} the spectra show large fluctuations over frequency but are stable over time. It can also be seen that the coherencies exhibit large fluctuations over time and frequency. Notably, the coherency can be regarded as a correlation in the frequency domain for two variates in a vector time series.

Fig. 3 shows the estimated time-varying power contribution.

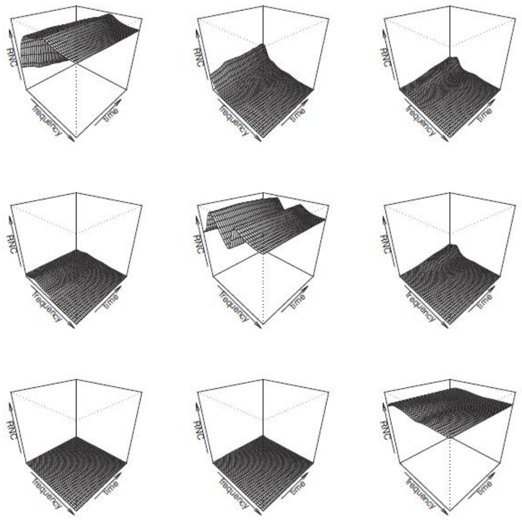

Fig. 3. Estimates of time-varying power contribution.

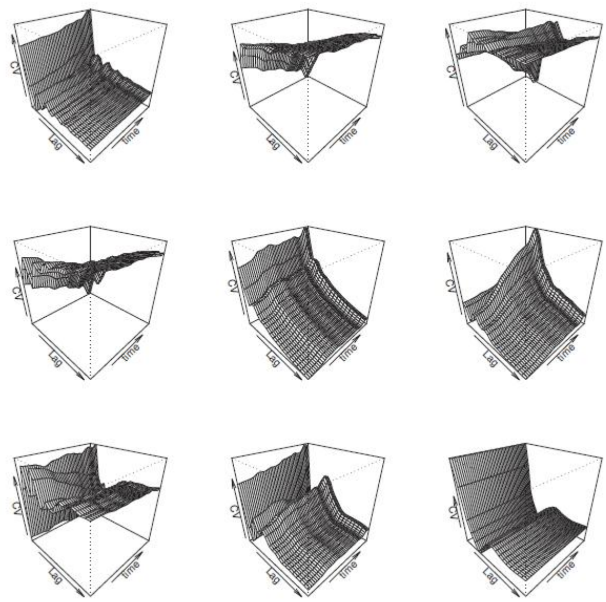

Fig. 4. Estimated time-varying self-covariance and cross-covariance.

From the graph for the element of (1,2) in Fig. 3, it can be observed that y_{n2} strongly contributes to y_{n1} around the low-frequency domain. This suggests that recession has a long-term influence on cyclical unemployment in Japan. The graphs for the elements of (1,3) and (2,3) also represent that y_{n3} (rate of change in the oil price) contributes relatively strongly to y_{n1} and y_{n2} around the low-frequency domain. The results imply that oil price fluctuations have a long-term influence on cyclical unemployment and business conditions in Japan. Moreover the influence of the oil price on cyclical unemployment and business conditions increases over time. The estimated time-varying self-covariance and cross-covariance are shown in Fig. 4.

Following the diagonal from top left to bottom right, the graphs show the estimated time-varying self-covariance for y_{n1} (changes in cyclical unemployment rate), y_{n2} (changes in CI), and y_{n3} (rate of change in the oil price), and the other graphs represent the estimated cross-covariance. Notably, y_n1 and y_{n3} have high self- covariance for lower lag values at all time points, and the self-covariance for y_{n2} has recently increased for lower and middle lag values.

The graphs for the elements of (1,3) and (3,1) in Fig. 4 show that the correlation between cyclical unemployment rate and oil price fluctuation is relatively high for middle and long lags. Also, the graphs for the elements of (2,3) and (3,2) show that the correlation between business concessions and oil price fluctuations is relatively high for short lags. Furthermore, the graphs for the elements of (1,2) and (2,1) show that the correlation between business concessions and cyclical unemployment rate is relatively high for middle and long lags.

IV. Conclusions

In this paper we examined the dynamic effect of oil price fluctuations on business cycle and unemployment rate in Japan via a time-varying coefficient vector autoregressive (TVCVAR) modeling approach based on the Bayesian smoothness priors method. First, a TVCVAR was constructed for a vector time series of the following three variates: (1) the variation in a component of unemployment rate in Japan, (2) the variation in CI in Japan, (3) the rate of change in the oil price. The parameters are estimated by a Bayesian method using a smoothness priors approach. The time-varying cross-spectrum, power contribution, and covariance function for the time series are then computed based on the estimates of parameters.

The main results using the monthly statistics from January 1980 to October 2010 are summarized as follows: From the estimated time-varying power contribution, recession has a long-term influence on cyclical unemployment; oil price fluctuations have a long-term influence on the rate of cyclical unemployment and business conditions in the Japanese economy; Moreover, such influence increases over time during the studied period. In terms of estimated time-varying self- and cross- covariance, the correlation between the cyclical unemployment rate and oil price fluctuation is relatively high for middle and long lags; the correlation between business concessions and oil price fluctuation is relatively high for short lags; the correlation between business concessions and cyclical unemployment rate is relatively high for middle and long lags.

Hence, we can obtain the following findings. First, business conditions in Japan are susceptible to oil price fluctuations. Second, oil price fluctuations affect cyclical unemployment rate through the recession. Third, the influence of oil price fluctuations on the rate of cyclical unemployment and business conditions in Japan has become large in recent years.

Acknowledgment

This work is supported in part by a Grant-in-Aid for Scientific Research (C) (25380263) from the Japan Society for the Promotion of Science.

References

[1] J. D. Hamilton, "What is an oil shock?" *Journal of Econometrics*, vol. 113, pp. 363-398, 2003.
[2] J. D. Hamilton, "Causes and consequences of the oil shock of 2007-08," *Brookings Paper on Economic Activity*, vol. 40, pp. 215-261, 2009.
[3] D. Zhang, "Oil shock and economic growth in Japan: A nonlinear approach," *Energy Economics*, vol. 30, pp. 2374-2390, 2008.
[4] K. Kyo, H. Noda, and G. Kitagawa, "Bayesian analysis of unemployment dynamics in Japan," *Asian Journal of Management Science and Applications*, vol. 1, pp. 4-25, 2013.
[5] G. Kitagawa and W. Gersch, *Smoothness Priors Analysis of Times Series*, Springer-Verlag, New York, 1996.
[6] K. Kyo and H. Noda, "Bayesian analysis of the dynamic structure in China's economic growth," in *Bayesian Inference and Maximum Entropy Methods in Science and Engineering*, M. S. Lauretto, C. A. B. Pereira, and J. M. Stern Eds. New York: American Institute of Physics, 2008.
[7] H. Noda and K. Kyo, "Bayesian methods for TFP analysis of a multi-region economy with dynamic structure and application to Japan," *Journal of Economic Research*, vol. 14, pp. 151-195, 2009.
[8] H. Noda and K. Kyo, "Bayesian estimation of the CES production function with a time-varying efficiency parameter," *The Empirical Economics Letters*, vol. 8, pp. 949-960, 2009.
[9] H. Noda and K. Kyo, "Smoothness prior approach to capturing rapid changes in time-varying TFP and application to the Chinese economy," *Journal of Economic Research*, vol. 16, pp. 127-146, 2011.
[10] H. Akaike and T. Nakagawa, *Statistical Analysis and Control of Dynamic Systems*, Kluwer Dordrecht, 1989.
[11] X. Q. Jiang (K. Kyo) and G. Kitagawa, "A time varying coefficient vector AR modeling of nonstationary covariance time series," *Signal Processing*, vol. 33, pp. 315-331, 1993.
[12] X. Q. Jiang (K. Kyo), "Time varying coefficient AR and VAR models," in *The Practice of Time Series Analysis*, H. Akaike and G. Kitagawa Eds., ch. 11, New York: Springer, New York, 1999, pp. 175-191.
[13] K. Kyo and H. Noda, "Bayesian analysis of the dynamic relationship between oil price fluctuations and industrial production performance in Japan," *Information*, vol. 16, pp. 4639-4659, 2013.
[14] H. Akaike, "A new look at the statistical model identification," *IEEE Transactions on Automatic Control*, vol. 19, pp. 716-723, 1974.

Koki Kyo was born in Shenyang, China, on September 27, 1957. He received his BE degree and ME degree in management engineering from Northeastern University, China, in 1982 and 1984 respectively, and PhD degree in statistical science from the Graduate University for Advanced Studies, Japan, in 1993. He is a Professor of Statistics at Obihiro University of Agriculture and Veterinary Medicine. His current research interests include Bayesian statistical modeling, estimation and identification of dynamic systems and Bayesian methods of economic analysis. Prof. Kyo is a member of the Japan Statistical Society, a member of the Institute of Systems, Control and Information Engineers, and many others.

Hideo Noda was born in Saga, Japan, on Aug. 26, 1972. He received his Ph.D. degree in economics from Kyushu University, Japan, in 2004. He has been an associate professor at Tokyo University of Science, Japan, since 2013. His work has appeared in *Economic Issues*, *Empirical Economics Letters*, *Journal of Economic Research*, and many others. His current research interests include economic growth, business cycles and global environmental problems. Dr. Noda is a member of the Japanese Economic Association.