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A Moran coefficient-based mixed effects approach to investigate spatially varying relationships

Daisuke Murakami [a,*], Takahiro Yoshida [a,b], Hajime Seya [c], Daniel A. Griffith [d], Yoshiki Yamagata [a]

[a] *Center for Global Environmental Research, National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki, 305-8506, Japan*

[b] *Graduate School of Systems and Information Engineering, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, 305-8573, Japan*

[c] *Department of Civil Engineering, Graduate School of Engineering, Kobe University, 1-1 Rokkodai, Nada, Kobe, 657-8501, Japan*

[d] *School of Economic, Political and Policy Science, The University of Texas, Dallas, 800 W Campbell Rd, Richardson, TX, 75080, USA*

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ABSTRACT

This study develops a spatially varying coefficient model by extending the random effects eigenvector spatial filtering model. The developed model has the following properties: its spatially varying coefficients are defined by a linear combination of the eigenvectors describing the Moran coefficient; each of its coefficients can have a different degree of spatial smoothness; and it yields a variant of a Bayesian spatially varying coefficient model. Moreover, parameter estimation of the model can be executed with a relatively small computational burden. Results of a Monte Carlo simulation reveal that our model outperforms a conventional eigenvector spatial filtering (ESF) model and geographically weighted regression (GWR) models in terms of the accuracy of the coefficient estimates and

* Corresponding author.
E-mail addresses: murakami.daisuke@nies.go.jp (D. Murakami), yoshida.takahiro@sk.tsukuba.ac.jp (T. Yoshida), hseya@people.kobe-u.ac.jp (H. Seya), dagriffith@utdallas.edu (D.A. Griffith), yamagata@nies.go.jp (Y. Yamagata).

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computational time. We empirically apply our model to the hedonic land price analysis of flood hazards in Japan.

1. Introduction

Spatial heterogeneity is one of the important characteristics of spatial data (Anselin, 1988). Geographically weighted regression (GWR) (Fotheringham et al., 2002; Wheeler and Páez, 2009; Fotheringham and Oshan, 2016) is one useful approach for explicitly accounting for spatial heterogeneity of the model structure through spatially varying coefficients (SVCs). GWR has been widely applied in socioeconomic studies (e.g., Bitter et al., 2007; Huang et al., 2010), ecological studies (e.g., Wang et al., 2005; Austin, 2007), health studies (e.g., Nakaya et al., 2005; Hu et al., 2012), and many others.

Despite the wide-ranging set of applications, existing studies have shown that the basic (original) GWR specification has several drawbacks. First, the coefficients of the basic GWR typically suffer from multicollinearity (Páez et al., 2011; Wheeler and Tiefelsdorf, 2005). Second, the basic GWR assumes the same degree of spatial smoothness for each coefficient, which is a rather strong assumption that fails to hold in most empirical applications. Fortunately, several extended GWRs have been proposed to address these problems. With regard to the first problem, Wheeler (2007, 2009) proposes regularized GWR, by combining ridge and/or lasso regression with GWR, and its robustness in terms of the multicollinearity problem has been demonstrated. The limitations of regularized GWR specifications are its bias in coefficient estimates, just like conventional ridge and/or lasso regression. With regard to the second problem concerning uniform smoothers, Yang et al. (2014) and Lu et al. (2015) attempted to overcome this limitation.

The Bayesian spatially varying coefficients (B-SVC) model, based on a geostatistical (Gelfand et al., 2003) or lattice autoregressive approach (Assunçao, 2003), is another form of the spatially varying coefficients model that requires Markov chain Monte Carlo (MCMC). Wheeler and Calder (2007) and Wheeler and Waller (2009) suggest that the coefficient estimates for the B-SVC model of Gelfand et al. (2003) are robust in terms of multicollinearity. In contrast to the GWR model, the B-SVC model allows differential spatial smoothness across coefficients. However, this differential makes computational costs prohibitive if a sample size is moderate to large (Finley, 2011). Although Integrated Nested Laplace Approximation (INLA)[1] based SVC estimations are becoming available now (Congdon, 2014),[2] their estimation accuracy and computational efficiency are largely unexplored.

Hence, a SVC model with the following properties still needs to be developed: (a) robust to multicollinearity; (b) the possibility for each coefficient to have a different degree of spatial smoothness; and, (c) computational efficiency. This study develops a model satisfying these requirements by combining an eigenvector spatial filtering (ESF; Griffith, 2003; Chun and Griffith, 2014) based SVC model (Griffith, 2008) and a random effects ESF (RE-ESF: Murakami and Griffith, 2015) model.

The following sections are organized as follows. Sections 2 and 3 introduce the GWR model and ESF-based SVC model of Griffith (2008), respectively. Section 4 introduces the RE-ESF model, and extends it to a SVC model. Section 5 compares the properties of our model with those of other SVC models. Section 6 summarizes results from a comparative Monte Carlo simulation experiment, and Section 7 uses our model in a hedonic analysis. Section 8 concludes our discussion.

1 See Rue et al. (2009) for details on the INLA approach and Blangiardo and Cameletti (2015) for its R programming.

2 Congdon (2014) publishes an R code of an INLA to estimate a conditional autoregressive model-based SVC model (see Gamerman et al., 2003).