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# A Review of Panel Data on Spatial Econometrics Models

A M Astuti<sup>1,2</sup>, Setiawan<sup>3</sup>, I Zain<sup>4</sup> and J D T Purnomo<sup>5</sup>

<sup>1</sup>Ph.D student at Statistics Department, Institut Teknologi Sepuluh Nopember, Surabaya, East Java

<sup>2</sup>Mathematics Education Department, Universitas Islam Negeri Mataram, Mataram, West Nusa Tenggara

<sup>3,4,5</sup> Statistics Department of Institut Teknologi Sepuluh Nopember, Surabaya, East Java

e-mail: <sup>1</sup>[alfiramulyastuti@uinmataram.ac.id](mailto:alfiramulyastuti@uinmataram.ac.id) <sup>3</sup>[setiawan@statistika.its.ac.id](mailto:setiawan@statistika.its.ac.id)  
<sup>4</sup>[ismaini\\_z@statistika.its.ac.id](mailto:ismaini_z@statistika.its.ac.id) <sup>5</sup>[jerry@statistika.its.ac.id](mailto:jerry@statistika.its.ac.id)

**Abstract:** Literature that discusses spatial econometrics is undergoing a very rapid development in modelling and determining parameter estimates. The modelling of relationship between variables is made in single equations and simultaneous equations. This paper presents some recent development of literatures in spatial econometrics models with panel data, both for single and simultaneous equations and the dynamic characteristics. The simultaneous equation models can accommodate the relationships among variables not only in one way, but also in two-way relationship. The dynamic effects can be used to analyze the long and short term effects of a policy. This study focuses on the specifications and parameter estimation methods of the model. This paper aims at facilitating researchers to determine the future research topics.

## 1. Introduction

Observation of treatment on economics or another field is not adequate if it is observed only at the same time, but it needs to treat for several periods of time. Therefore, data combining cross section data and time series data is needed. The combination of cross section data and time series is called panel data.

Baltagi (2005) argues several benefits by using panel data. Panel data are generally more informative data, more variability, more efficiency, better able to study the dynamics of adjustment, and better able to identify and measure effects that are simply not detectable in pure cross-section or pure time-series data. Hsiao (2014) and Klevermarken (1989) list advantages from panel data. These include the following: controlling for individual heterogeneity, giving more degree of freedom, allowing to construct and test more complicated behavioral models than purely cross-section or time-series data. Setiawan and Kusriani (2010) also suggest the advantages of panel data. Biases resulting from aggregation over firms or individuals on panel data may be reduced or eliminated. Hence, panel data is widely used in econometrics. There were 121 articles which examined panel data from 1969 - 1989 in the Journal of Economic Literature (Baltagi and Raj, 1992).

The econometrics literature has continuously developed over time. One of its developments is considering spatial effects on model. If spatial interaction effect is involved in the analysis process, the resulting model is called the spatial econometrics model. The spatial interaction effect is indicated by



the presence of a spatial weighted matrix on the model. It is symbolized by  $W$ . Gallo and Pirotte (2017) revealed the addition of spatial effect in panel data was developed since 2000. It was also reviewed by Elhorst (2003), Anselin, et al (2008), Lesage and Pace (2009), Lee and Yu (2010), Pesaran and Tosetti (2011), along Shi and Lee (2017).

The relationship of economic variables on econometrics is not only in a single equation form, but also in simultaneous equations form. Cornwell, et al (1992), Park (2005), Gebremariam, et al (2011), Bazaldua and Khrisnakumar (2013) applied simultaneous equations with panel data on their studies. The simultaneous equation models can accommodate the relationships among variables not only in one way, but also in two-way relationship. According to Gujarati (2003), the relationship among variables in simultaneous equations can present more comprehensive information about interrelated problems. The form of linkage is shown by the presence of a variable which in certain equations as the dependent variable, but in other equations as independent variables and conversely. In simultaneous equation, the dependent variable term is called an endogenous, and independent variable is called the predetermined variable. It is divided into exogenous and lagged endogenous variables (Setiawan and Kusriani, 2010). Besides the simultaneous characteristics, the economic variables are also dynamic in nature. It means the values of a variable are influenced by the values of other variables and also the values of the variable in the previous periods. The dynamic model could be used to analyze the long and short terms effects of economic policy.

This paper presents the development of spatial econometrics models with panel data for both single and simultaneous equations and also the dynamic characteristics. The study focused on model specifications and parameter estimation methods of the model. The organization of this paper is as follows. First, the reason of why panel data and its connection in the development of spatial econometrics model. Next, Section 2 presents spatial panel model. Section 3 continues with simultaneous spatial panel model. Section 4 deals with the spatial dynamic panel model. Section 5 continues with simultaneous dynamic spatial panel model. Section 6 reviews spatial durbin panel models. Section 7 discusses the spatial durbin dynamic panel model. Section 8 considers the futher topics for next study. Finally, Section 9 concludes. The literature review phase is shown in Figure 1.

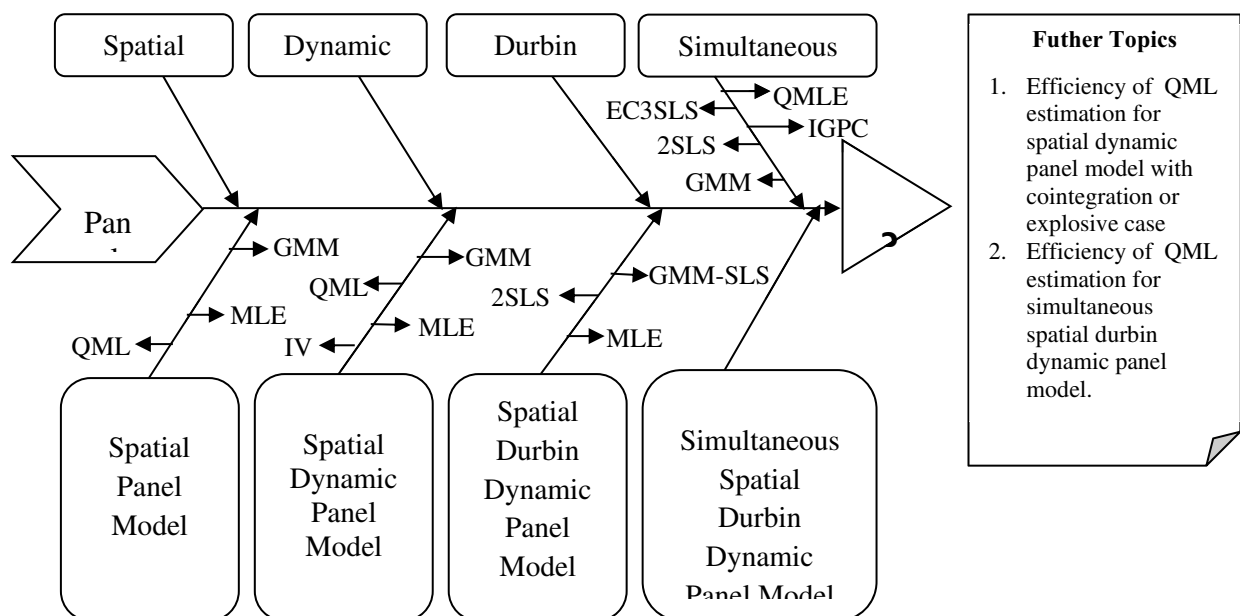


Figure 1. Fish Bone Diagram of Literature Review

## 2. Spatial Panel Model

### 2.1 Specifications

Spatial modeling with panel data provides more choice of models if it was compared by using pure cross section data. Baltagi (2001), Elhorst (2003), and Gallo and Pirotte (2017) have written special topic of spatial panels. Moscone and Tosetti (2010) investigated the spatial autoregressive disturbance panel model with fixed effects. Pesaran and Tosetti (2011) considered models with multifactor error structures and spatial error correlations. Lee and Yu (2012) examined the spatial panel model with a weighted matrix with time variant and an exogenous variable. Elhorst (2014) discussed models with additional spatial and time effects. This model is called General Nesting Spatial (GNS). Shi and Lee (2017) applied model where individual are located by space through time.

### 2.2 Spatial Dependence Test

The spatial dependence test of panel data model has been developed by Arbia (2016) which is replacing the spatial weighted matrix  $\mathbf{W}$  by  $\mathbf{W}_{NT}$  which has put time effect on it. Other methods of spatial dependence test are the Lagrange Multiplier (LM), Likelihood Ratio (LR), and Wald methods. The LR test adapted the MLE method (Anselin, 1988). LR test is ratio among likelihood function of the spatial model and likelihood function of linear regression (where the spatial weighted is equal to 0). The LM test only based on under  $H_0$  estimation. The errors are calculated based on OLS estimator on model and multiplied by the spatial weighted matrix.

The simple approach to exam the spatial dependence on a two-way of fixed effect model is entering the dummy variable of time and applying the formula of Debarsy, Ertur, and Lesage (2012). But, according to Lee and Yu (2010), the asymptotic properties of parameter estimators for finite T or large, makes the number of dummy variables of time increase if T increases. So, incidental and estimation for dummy variables of time will be inconsistent. As a consequence, this problem will have the impact on the performance of spatial dependence test.

The spatial dependence test for the spatial panel model with fixed effects has been developed by He and Lin (2011). The model which used is SAR model from Lee and Yu (2010). Based on it, He and Lin (2011) defined LM and LR tests with six hypotheses. Specifically for SAR model, the spatial dependence that needs to be examined is only for spatial dependence of the autoregressive model. Therefore, the hypothesis is  $H_0 : \lambda = 0$  or  $H_0 : \rho = 0$ . The marginal of hypothesis test is only on the spatial lag of its dependence.

### 2.3 Methods of Estimation

Elhorst (2003) and Baltagi (2005) examined the single equation of spatial panel data on econometrics model by using Maximum Likelihood Estimation (MLE) approach. According to Baltagi (2005), the weakness of MLE is raise problems in the computational process for large samples (N). MLE has the smallest variant of consistent group estimators but still needs more description on the data generalizing process and the specification of corrected model. Kapoor, Kelejian, and Prucha (2007) suggested to applying the Generalized Method of Moment (GMM) estimation to overcome the computational problems for large samples (N). Lee and Yu (2008) and also Shi and Lee (2017) reviewed the asymptotically estimation result by using the Quasi Maximum Likelihood Estimation (QMLE) method for models with spatial lag. Mult and Pfafemayer (2008) used the Instrumental Variable (IV) method to estimate models with spatial random effects and spatial fixed effects. Moscone and Tosetti (2010) and Wang and Lee (2017) estimated their model by using GMM.

## 3. Simultaneous Spatial Panel Model

Gebremariam, et al. (2011) developed simultaneous spatial panel model. This model was developed by attending Baltagi (2005) with error component model. Gebremariam, et al (2011) have included a model which involving a partial adjustment process. Lu L (2017) applied simultaneous spatial panel

models which involving three effects, i.e., simultaneous effects, spatial effects, and common shock effects.

Simultaneous spatial panel model is reviewed by Lee and Yu (2010). The simultaneous equation system is considered interesting because it can explain the economic problems from the interaction of regions and times. Gebremariam, et al (2011) developed an estimation method with 5 stages called Generalized Spatial Three Stage Least Squares (GS3SLS). This approach has been applied by Kelejian and Prucha (2004). Baltagi and Deng (2012) derived the 3SLS estimator for a simultaneous spatial autoregressive model with random effects. It can overcome the problems of endogenous lags, spatial dependence, heterogeneity and correlations between equations. Deng (2013) examined the spatial autoregressive model with the error component approach. The estimation method which used is combination of instrumental variable approaches with error components from Kelejian and Prucha (1998) and also Lee (2003). It is called the Three Stage Least Square (EC3SLS) Component Error. This estimator was chosen to control endogeneity, spatial lag, and heteroscedasticity. Lu L (2017) used two estimation methods, i.e., QMLE and the iterative generalized principal components (IGPC) method.

#### 4. Dynamic Spatial Panel Model

The next development of spatial econometrics models with panel data is the presence of dynamic characteristics in the model, both for single and simultaneous equations. This dynamic relationship is characterized by a lag existence of the dependent variable between the independent variables. Spatial dynamic panel is a further development model when the dependent variable and its error have spatial relevance and a lag time on the dependent variable. Anselin, et al. (2008) divided the dynamic spatial panel model into four categories, namely pure space recursive, time space recursive, time space simultaneous and time space dynamic. There are three cases in dynamic spatial panel model, namely stable, cointegration, and explosive. Lee and Yu (2014) and also Shi and Lee (2017a) discussed the dynamic spatial panel model in a single equation with individual effects and time with many samples ( $n$ ) and time ( $T$ ) are large. Yu, Jong, Lee (2012) examined the spatial dynamic panel model with fixed effects on cointegration cases.

##### 4.1 Taxonomy

The dynamic spatial panel model in Shi and Lee (2017a) can be elaborated in several equations. The first model is a mixture of space and time in the error term specification. Elhorst (2008) developed the ML estimation to estimate this model. Kapoor, et al (2007) developed GMM estimation. The second model is a combination of space and time by specifying the deterministic regression equation as a dynamic panel model and its stochastic error term specification as a spatial error model. Elhorst (2005) considers the ML estimation to estimate the parameters with fixed effects models. Yang, et al (2006) considers the ML estimation method with random effect models (without time effects). The third model is a model that considers the spatial durbin model by incorporating dynamic effects on the response variable. Research with this model has been carried out by Ertur and Koch (2007) and Elhorst et al. (2010). The fourth model is a model that assumes the spillovers spatial effects are zero. it means indirect effects that are assembled with direct effects are considered equal for each explanatory variable. This model is examined by Lee and Yu (2010) and Bouayad and Vedrine (2010).

The fifth model has been considered by Lesage and Pace (2009) and Korniotis (2010). The disadvantage of this model is the model is not suitable for analysis that focuses on spillover effects on short term. The sixth model is a model was developed by Parent, Lesage (2010, 2011). The advantage of this model is the effect of changing of one explanatory variable on the dependent variable can be composed into spatial effects and time effects. The disadvantage is the indirect effect associated with direct effects is considered constant with all the time for each explanatory variable. The last model is the seventh model. This model was worked on by Franzese, and Hays (2007), Kukuena and Monteiro (2008), and Elhorst (2010), Jacobs, Ligthart, Vrijburg (2009) and Brady (2011). Although this model

is not flexible on the ratio between indirect effects and direct effects. This model is the most stringent model, so the evidence for real cases needs to be carried out further empirical research.

#### *4.2 Methods of Estimation*

Elhorst (2005) estimated the dynamic spatial panel model by using the unconditional maximum likelihood estimation method in a single equation. Mult (2006) used the GMM estimation method in three steps. Su and Yang (2007) used the QML method for SEM with fixed and random effects. Lee and Yu (2014) applied the GMM approach to show the parameters obtained were consistent, normal asymptotic, and relatively more efficiency. Shi and Lee (2017a) used the QML method.

### **5. Simultaneous Spatial Dynamic Panel Model**

Yang and Lee (2015) examine the simultaneous equation model and dynamic multivariate spatial autoregressive panel with the QMLE estimation method. Yang and Lee (2018) then examined more deeply the simultaneous dynamic spatial panel model with the same method. The QMLE and MLE methods both have weaknesses when time (T) is smaller than the sample size (N), because the asymptotically distribution and consistency of the estimator are biased and not centered on zero.

### **6. Spatial Durbin Panel Model**

Spatial durbin panel models are an extension of the spatial autoregressive or SAR model (Anselin, 1988). This model incorporates spatial interactions on the dependent variable and explanatory variables. Not many researchers have used this model. Beer and Rield (2011) discussed spatial durbin panel models. The estimation method is the maximum likelihood technique. The study of the estimator characteristics is analyzed by the Monte Carlo method. Debarsy (2012) expanded the Mundlak approach to show the adequacy of random effect specifications on spatial durbin panel models. The Likelihood ratio test and Hausman Test were compared to test the significance of the correlation between regressors and individual effects. The results of the Monte Carlo simulation show that the LR test is better than the Hausman test for small samples.

Mustaqim (2018) discusses instrumental variable efficiency in simultaneous spatial durbin panel models. The estimation methods are 2SLS and GMM-S2SLS. The results of the analysis show that the GMM-S2SLS method produces a smaller bias than the 2SLS method.

### **7. Spatial Durbin Dynamic Panel Model**

The dynamic spatial durbin panel model is a combination of dynamic panel models and spatial durbin models. This model involves spatial interactions on endogenous variables and exogenous variables. Debarsy et al. (2012) have examined dynamic spatial durbin models in a single equation. Lee and Yu (2015) also developed this model. Lee and Yu (2015) examined parameter estimates in the dynamic spatial durbin panel model by using the 2SLS and ML methods. The parameters in the model are identified by the moment of relation on 2SLS and the log likelihood function or quasi likelihood function. The model is examined with a Monte Carlo simulation. Debarsy et al (2012) estimated parameters with the Bayesian Markov Chain Monte Carlo procedure.

### **8. Some Future Research Topics**

This section presents several future research topics based on the summary of research developments for spatial data panel econometric model topic. The table of summary can be seen in Table 1.

**Table 1.** Summary of research developments for spatial data panel econometric model topic.

No	Authors (Year)	Core of Study	Estimation Method	Comments
1	Baltagi (2001) and (2005)	Discussed the static and dynamic models of panel data and involved spatial effect	Maximum Likelihood Estimation (MLE) and Generalized Method of Moment (GMM)	The simultaneous equations has not been discussed
2	Elhorst (2003)	Studied about specifications and estimation method of the Spatial Panel Data Model for the Spatial error model (SEM) and spatial autoregressive (SAR) models.	Feasible Generalized Least Square (FGLS)	The dynamic models has not been discussed. The model was single equations
3	Mutl (2006)	Discuss the three-step estimation procedure of spatial dynamic panel data for spatial error correlated with Large N and T finite.	Used the Instrumental Variables (IV) method in the first step then used GMM in the second step and lowering it for large samples in the third step.	The models were still single equation
4	Su and Yang (2015)	The dynamic panel data model used is a model with random effects and fixed effects and reduces the limiting distributions of the QML estimator which is formed under the assumption of a fixed T and a large N	Quasi Maximum Likelihood (QML)	The spatial weighted of the dependencies is only on errors. The models was still a single equation.
5	Kapoor, Kelejian and Prucha (2007)	Panel data model with error components that are spatially correlated.	Feasible Generalized Least Square based on the initial Generalized Moment method	The model was a single equation and dynamic model

Tabel 1. Continuance

No	Authors (Year)	Core of Study	Estimation Method	Comments
6	Anselin, Gallo and Jayet (2008)	Reviewed the various models of Spatial panel data, and discussed specifically for spatial dependencies.	MLE and GMM	The model was a single equation
7	Mult and Pfaffermayer (2008)	Discusses the spatial model with fixed effects and random effects and calculated the value of heterogeneity as well as the spatial correlation between the spatial unit lags.	Used IV to estimate SEM models with fixed and random effects specifications and proposed the Hausman test	Only discussed a single spatial lag model
8	Kukenova and Monteiro (2008)	Discussed the spatial dynamic model of panel data with extended GMM estimation approach and used Monte Carlo investigation.	GMM	The spatial weighted did not interact with $Y_{t-1}$ , only $Y_t$ . Not yet discussed the simultaneous model.
9	Lee and Yu (2009)	Discussed the development of spatial panel data models and explained the differences between static and dynamic spatial research.	MLE	The model discussed is still a single model.
10	LeSage and Pace (2009)	Discussed SAR, SEM, Spatial Durbin models for temporal spatio models. Introduced the concept of spatial spillover to measure the direct and indirect effects of a single equation.	MLE and Bayesian method	The model used has not yet entered the domain of simultaneous and spatial dynamic models
11	Moscone and Tosetti (2011)	Reduced the asymptotic distribution of the GMM estimation by using Monte Carlo. The GMM estimator is investigated on a small sample based on variations in moment conditions.	GMM	The models was not dynamic models. The model used is a single model
12	Yu, Jong, and Lee (2012)	Researched the unstable case of a dynamic spatial data panel model where there were unit roots generated by spatial and temporal correlations.	QML, Two stage least square (2SLS), and GMM	The model used not yet discussed the simultaneous model



**Tabel 1.** Continuance

No	Authors (Year)	Core of Study	Estimation Method	Comments
13	Gebremariam et all (2011)	Examined the simultaneous model of spatial data panels for growth models.	Two Step of GMM	The model was still a dynamic lag model on X, not Y
14	Su and Yang (2015)	Reviewed about estimation method of spatial dynamic models with spatial errors. when N is large. Applied it to models with random effects or with fixed effects. Reduced the limit distribution of the QML estimator with different assumptions in the first observation	QML	The model was still a single model
15	Baltagi and Deng (2012)	Studied about estimation method for simultaneous equations of spatial autoregressive panel data with random effects.	Three stage least square (3SLS)	The model was still a static model
16	Lee and Yu (2014)	Discussed the efficiency of using GMM estimates in the spatial dynamic data panel model with fixed effects. Compared the GMM method with the 2SLS method, and provide GMM estimation methods in many forms.	2SLS and GMM	Not yet discussed the simultaneous model.
17	Yang and Lee (2015)	Discussed multivariate models and simultaneous spatial equations of spatial autoregressive dynamic panel data with their stability and spatial cointegration.	QML	The estimation method tends to be difficult to converge
18	Dogan O (2015)	Reviewed the advantages of Robust GMM estimator compared to MLE in spatial autoregressive models. Demonstrated the consistency of Robust GMM estimators and their asymptotic distribution.	MLE and GMM	The model was Still a single equation.
19	Cizek, Jacob, Lightart and Vrijburg (2015)	Reviewed GMM estimation on dynamic panel data fixed effect model with spatial lag and spatial error. Proved the	GMM	The model was Still a single equation.

**Tabel 1.** Continuance

No	Authors (Year)	Core of Study	Estimation Method	Comments
		consistency and normal asymptotic for large numbers of spatial units and fixed periods		
20	Kesina M (2016)	examined the estimation for time invariant variable effect on the spatial panel data model. It involved spatial lag as the dependent variable in the regression model	Hausman Taylor Variant spatial in the estimation process	The model was Still a single equation.
21	Hsio and Zhou (2017)	Reviewed the moment method estimation of the simultaneous dynamic panel data model using the Jackknife Instrumental Variable Estimator (JIVE) GMM to obtain a valid infinite statistics.	Jackknife bias reduction method	It has already used simultaneous equations but has not reviewed spatial effects.
22	Miranda, Martinez and Manjon (2017)	Reviewed the relationship of random effects on dynamic durbin spatial panel data models through identification of observational effects and spatial spillovers.	QML estimation without involving the covariance variance matrix	The model was Still a single equation
23	Lu L (2017)	Examined the simultaneous spatial panel data model by involving three effects namely, simultaneous effects, spatial effects, and common shock effects	QMLE and iterative generalized principal components (IGPC) method	It has already used simultaneous equations and spatial effects, but the model was static

Several future research topics based on Table 1, i.e.:

- 8.1 Examining the efficiency of the QML estimation for dynamic spatial panel models with cointegration or explosive cases on single equations or simultaneous equations
- 8.2 Applying spatial durbin dynamic panel models in the simultaneous equations is a study that can provide more detailed information from a case. The simultaneous equation with dynamic and spatial effect has endogeneity problems. It will incur a big error correlation. According to Andren (2007), estimating an equation which has endogeneity will result in a biased, inconsistent estimator and the hypothesis will not be valid. The solution to this problem is QML approach. Thus, research is needed on efficiency of QML approach in the spatial durbin dynamic panel model for simultaneous equations.

Detail information of literature review shown on Figure 2. The models can be applied on social and econometrics field.

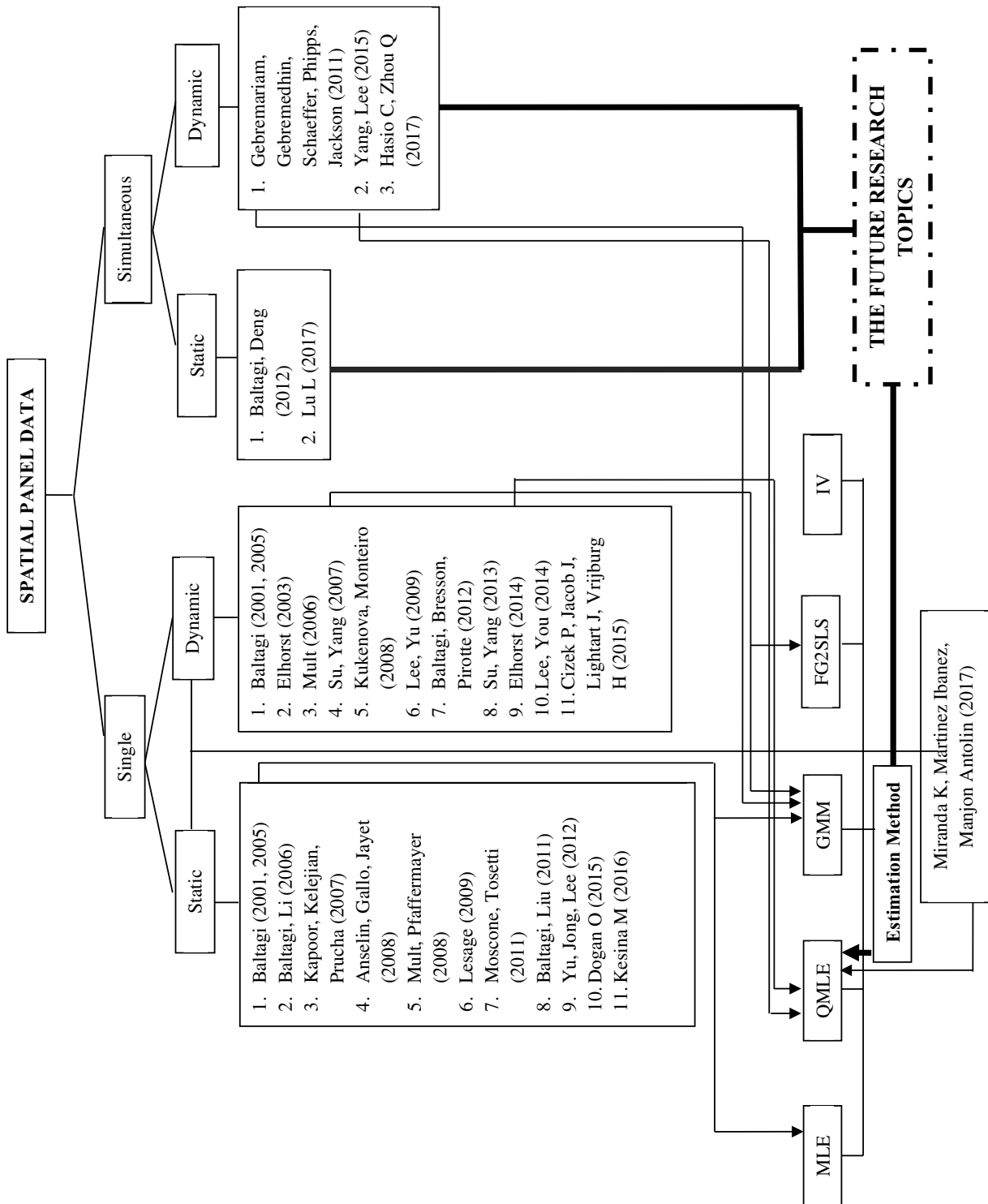


Figure 2. Research Chart

## 9. Conclusion

This paper presents the development of spatial econometrics models with panel data for both single and simultaneous equations and also the dynamic characteristics. The study focused on model specifications and parameter estimation methods of the model. The results of this study are expected to facilitate the next researcher determining the topic.

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