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A spatial autoregressive stochastic frontier model for panel data with asymmetric efficiency spillovers

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ABSTRACT

By blending seminal literature on non-spatial stochastic frontier models with key contributions to spatial econometrics we develop a spatial autoregressive (SAR) stochastic frontier for panel data. The specification of the SAR frontier allows efficiency to vary over time and across the cross-sections. Efficiency is calculated from a composed error structure by assuming a half-normal distribution for inefficiency. The SAR frontier is estimated using maximum likelihood methods taking into account the endogenous SAR variable. The application of the estimator to an aggregate production frontier for European countries highlights, among other things, the asymmetry between efficiency spillovers to and from a country.

1. Introduction

In cross-sectional and panel data modeling, the presence of omitted variable bias due to the omission of a spatial lag of the dependent variable, which captures what is referred to as spatial autoregressive (SAR) dependence in the cross-sections, has long been recognized. Among other reasons, this motivated the development of the SAR model in key contributions by Cliff and Ord (1973, 1981), which involves augmenting the standard non-spatial specification with the weighted average of the dependent variable for neighboring units.[1] This SAR term is endogenous which is accounted for using various methods in the spatial econometrics literature. For stochastic frontier models, biased parameter estimates due to the omission of the SAR variable also has implications for the efficiency scores. We therefore merge techniques used in spatial econometrics with those from the stochastic frontier literature to develop a stochastic frontier for panel data with SAR dependence. The composed error structure of stochastic frontiers consists of inefficiency and an idiosyncratic error, where we follow much of the literature on non-spatial stochastic frontiers and make distributional assumptions to distinguish between the components of the composed error.

The approach which we employ can also be easily adapted to develop a spatial error stochastic frontier model for panel data. Such a model would involve augmenting the standard non-spatial stochastic frontier with the weighted average of the spatially autocorrelated errors for neighboring units. We do not pursue such a specification here because we have a strong preference for the SAR specification. This is because although both models capture global spillovers, in the spatial error specification these spillovers relate to the latent nuisance term, whereas global spillovers in a SAR specification have a structural economic interpretation because, as will become apparent, these spillovers can be related to the independent variables.[2] The marginal effects from

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1 This is based on the assumption that the spatial weights matrix is row-normalized i.e. the row sums of the spatial weights matrix sum to 1.

2 To illustrate the difference between global spillovers and local spillovers, suppose a region's set of neighbors is assumed to be based on contiguity and thus consists of the regions with whom it shares a border. Local spillovers to a region would be those from its contiguous neighbors (i.e. 1st order neighbors). Global spillovers to a region would be those that come from its contiguous neighbors, the contiguous neighbors of its neighbors (i.e. 2nd order neighbors), the contiguous

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the SAR specification are referred to as: direct (i.e. own), indirect (i.e. spillover) and total (direct plus indirect) impacts (LeSage and Pace, 2009).[3]

The literature on spatial stochastic frontier modeling is rather sparse. A small number of studies estimate spatial stochastic frontiers and calculate efficiency using the cross-sectional specific effects. The first of these studies is due to Druska and Horrace (2004). By extending the spatial error model for cross-sectional data as set out by Kelejian and Prucha (1999), they develop a GMM spatial error stochastic frontier model with fixed effects. They then calculate time-invariant efficiency from the cross-sectional specific effects using the Schmidt and Sickles (1984) (SS from hereon) estimator. The SS efficiency estimator assumes a composed error structure which consists of time-invariant inefficiency and the idiosyncratic disturbance. The unit with the largest (smallest) fixed/random effect is placed on the concave (convex) frontier and the efficiency estimates are the exponential of the difference between the best performing unit's fixed/random effect and the corresponding effect for each of the other units in the sample. Glass et al. (2013) adopt a similar approach by following Cornwell et al. (1990) (CSS from hereon) which involves using the cross-sectional specific effects from a SAR stochastic frontier model to estimate time-variant efficiency.

We are not aware of a stochastic frontier model that accounts for global spatial dependence via the endogenous SAR variable or via the endogenous spatial autocorrelated error term; whilst also calculating efficiency from a composed error structure by making an assumption about the inefficiency distribution. Such a model which accounts for SAR dependence is therefore developed in this paper. To the best of our knowledge, Adetutu et al. (2015) is the only study that introduces a spatial relationship into a stochastic frontier model where an assumption is made about the distribution of the inefficiency component of the error structure. Their model, however, unlike the estimator we develop, overlooks global spatial dependence as they omit, for example, the endogenous SAR variable. That said, although their model specification represents a simple way of accounting for spatial interaction they limit their analysis to local spatial dependence by including only spatial lags of the exogenous variables. Such local spatial stochastic frontiers can therefore be estimated using the standard procedures for the non-spatial stochastic frontier.

The spatial stochastic frontier estimator which we present represents an alternative to using the cross-sectional specific effects from a spatial stochastic frontier to estimate efficiency. In addition, there is plenty of scope to extend the spatial stochastic frontier estimator which we develop. For example, rather than assume that the inefficiency distribution is half-normal, as we do here, we could use the time-varying decay efficiency estimator (Battese and Coelli, 1992) or assume that inefficiency follows a truncated normal distribution (e.g. Stevenson, 1980) or, alternatively, is Gamma distributed (e.g. Greene, 1990). Furthermore, the SAR stochastic frontier which we propose captures supply chain management issues across space such as outsourcing to a firm in another location or, at the aggregate level, importing from another country. This is because, for example, a SAR stochastic production frontier is such that via the spillover input elasticities, a unit's output depends on the inputs of the other units in the sample. The issue then is how efficiently does a unit use the inputs of other units in different locations (i.e. efficiency across space). A central feature of the SAR stochastic frontier which we develop is spatial efficiency, or in other words, efficiency spillovers, which complements the literature on estimating productivity spillovers (Chandra and Staiger, 2007; Girma, 2005; Takii, 2005; Girma and Wakelin, 2007; Girma et al., 2008).

We apply our spatial estimator to an aggregate production frontier using balanced panel data for 41 European countries over the period 1990–2011 and estimate the model using maximum likelihood (ML) methods. Using spatial econometric techniques to analyze country productivity has been a fertile area for research in recent years. López-Bazo et al. (2004), Egger and Pfaffermayr (2006), Ertur and Koch (2007), Koch (2008) and Pfaffermayr (2009) all extend the standard Solow (1956, 1957) neoclassical growth set-up by endogenizing technical change. They then estimate the reduced form equation for output per worker using a non-frontier SAR model or a non-frontier spatial error specification. Rather than estimate the reduced form equation for output per worker we estimate the assumed underlying spatial Cobb–Douglas technology using a stochastic frontier specification.

It is important to note that the efficiency estimates from our SAR stochastic frontier are directly comparable to the efficiency estimates from the corresponding non-spatial stochastic frontier. For such spatial and non-spatial stochastic frontiers where an assumption is made about the inefficiency distribution, the efficiencies are calculated relative to an absolute best practice frontier. In contrast, when the cross-sectional specific effects are used to calculate time-invariant efficiency, efficiency is estimated relative to the best performing unit in the sample. In addition to estimating the SAR stochastic frontier by making an assumption about the inefficiency distribution, a novel feature of our approach is how we adapt the SS method and apply it to the efficiencies to calculate time-varying relative direct, relative indirect and relative total efficiencies in order to analyze spatial efficiency. The SS method assumes efficiency is time-invariant but we adapt this approach to obtain time-varying estimates of relative direct, relative indirect and relative total efficiencies by placing the best performing unit in the sample in each time period on the frontier, where the best performing unit and thus the benchmark may change from one period to the next.

The relative direct, relative indirect and relative total efficiencies are calculated and interpreted along the same lines as the direct, indirect and total marginal effects. There are two valid ways of estimating relative indirect efficiency which yield estimates of different magnitude giving rise to asymmetric directional efficiency spillovers. In turn this leads to two estimates of total efficiency which differ in magnitude.[4] Intuitively, relative indirect efficiency benchmarks how successful a unit is at exporting/importing productive performance *vis-à-vis* its peers in the sample. For example, firms in different countries may export and import efficiency via knowledge spillovers.[5]

neighbors of its neighbors' neighbors (i.e. 3rd order neighbors) and so on and so forth.

3 A direct elasticity is interpreted in the same way as an elasticity from a non-spatial model, although a direct elasticity takes into account feedback effects (i.e. effects which pass through 1st order and higher order neighbors and back to the unit which initiated the change). An indirect elasticity can be calculated in two ways yielding the same numerical value. This leads to two interpretations of an indirect elasticity: (i) the average change in the dependent variable of all the other units following a change in an independent variable for one particular unit; or (ii) the average change in the dependent variable for a particular unit following a change in an independent variable for all the other units.

4 Glass et al. (2014) show how efficiencies which are estimated using the cross-sectional specific effects from a SAR stochastic frontier can be used to compute relative direct, relative indirect and relative total efficiencies. In this paper we show that this approach to calculate relative direct, relative indirect and relative total efficiencies can also be applied to a SAR stochastic frontier when an assumption is made about the inefficiency distribution. Unlike Glass et al. (2014), however, we do not confine our analysis to just one way of estimating the relative indirect and relative total efficiencies.

5 The literature on knowledge spillovers is vast but key references include Coe and Helpman (1995), Keller (2002) and Keller and Yeaple (2013). For other studies on knowledge spillovers see Branstetter (2001), Bottazzi and Peri (2003), Blazek and Sickles (2010) and Bahar et al. (2014).

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