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# EXTERNALITIES, ECONOMIC GEOGRAPHY, AND SPATIAL ECONOMETRICS: CONCEPTUAL AND MODELING DEVELOPMENTS

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*On the assumption that it is sometimes necessary to take a step sideways to make progress, this article describes the author's preferred spatial econometric modeling approach based around recent theory developed in the field of urban economics. This has many features in common with geographical economics but is seen as more amenable to the analysis of externalities and to the development of new, more realistic, economic geography theory.*

***Keywords:*** *spatial econometrics; technological externalities; knowledge spillovers; geographical economics; new economic geography; urban economics*

## THE EVOLUTION OF THINKING ABOUT EXTERNALITIES

As Fujita, Krugman, and Venables (1999) reminded us, thinking about externalities in urban and regional development continues to be heavily influenced by the work of Alfred Marshall (1920). Marshall identified three external economies of importance to the localized concentration of production: the famous trio of labor market pooling, intermediate inputs, and knowledge spillovers. Labor market pooling offered an obvious locational advantage to firms needing a convenient supply of skilled workers, and the concentration of firms is advantageous to workers seeking employment. The local concentration of workers and jobs is self-evidently symbiotic. Second, the concentration of similar producers in a specific locale provided a sufficiently large market to support specialized local suppliers, while the presence of specialist suppliers is attractive to producers. Third, the fact that industry and labor tended to agglomerate concentrated know-how, thus reinforcing the agglomeration tendency and further deepening the pool of local knowledge.

These ideas are a fundamental backdrop to modern approaches to our understanding of what causes production to evolve to become spatially concentrated. For instance, cumulative dynamic processes are very much the hallmark of contempo-

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rary theory as set out by Fujita, Krugman, and Venables (1999); Krugman (1991); and Fujita and Thisse (1996). As Gordon and McCann (2000) pointed out,

> In terms of modern thinking, Marshall's observation of the advantage of a specialized local labor pool can be described in terms of a labor market system which maximizes the job-matching opportunities between the individual worker and the individual firm (Simpson 1992) and thus reduces the search costs for both parties. (P. 516)

Likewise, extensive local provision of nontraded inputs is nowadays described as "service economies of scale or scope in the employment of either public or private capital," and the maximum flow of information and ideas is "the efficient transfer of technology" (p. 516).

Marshall (1920) considered his trio to be external effects acting on firms under perfect competition and subject to constant returns to scale. Thus, economies of scale are external, not internal. This assumption of perfect competition might be viewed as a limitation, but nonetheless Marshall's theory does give useful insights, and external economies remain an important part of the contemporary spatial concentration of production story. The development of ideas about externalities under imperfect markets can be traced to Scitovsky (1954), who differentiated between "pecuniary external economies," representing externalities due to market imperfections in supply and demand, and technological externalities. As Fujita and Thisse (1996, 345) observed, pecuniary externalities are the benefits of economic interactions "which take place through usual market mechanisms via the mediation of prices." Marshall's trio can be thought of as a mix of the two. López-Bazo, Vayá and Artís (2001), for instance, treated input-output and thick-market effects as equivalent to pecuniary externalities and knowledge spillovers as technological externalities.

Technological external economies do not depend on market interactions but are production or consumption externalities and exist directly as arguments in the firm's production function or the individual's utility function, so that output or utility is partly a side effect of the actions of other agents over which the firm or individual has no control. In other words, one agent's objective function contains one or more argument that depends on choices made by another agent or agents. In the modern economy, technological externalities appear as benefits or costs due to transfers of information or knowledge. Knowledge generated by one agent for its own benefit is not exhausted by use but persists and spreads, affecting other agents. Following Marshall (1920), the importance of information access, flow, and accumulation as the basis for agglomeration was recognized by Jacobs (1969) and by many others, notably Saxenian (1994), who highlighted "face-to-face" communication in the creative process as a mechanism causing firms to cluster together.

However, it is pecuniary-like externalities, not technological externalities, that have been found to be amenable to formal analysis, producing the modern approach leading to increasing returns to scale. The breakthrough giving a theoretically compelling treatment came from the theory of monopolistic competition initially developed in the 1930s by Joan Robinson and E. H. Chamberlin, via Spence (1976) and Dixit and Stiglitz's (1977) work on industrial organization. Monopolistic competition is characterized by many small firms with product differentiation. Hence, external economies due to the availability of specialized local producer services are replaced by the market for specialized services. This allows internal increasing returns and a basis for agglomeration economies, as illustrated by Abdel-Rahman and Fujita (1990) and Rivera-Batiz (1988). The usual assumption is that there are two sectors, a final traded goods sector and a nontraded service sector. This reflects the reality that service industries are often characterized by numerous small producers offering differentiated local services to final producers who benefit from a larger variety. Assuming a constant elasticity of substitution production function for the immobile nontraded services, one can see the level of composite services increase nonlinearly in the number of service firms and, hence, city or region size when there are internal increasing returns at equilibrium. Since composite services combine with labor as inputs to the production technology for competitive traded goods production, it also experiences increasing returns with city or region size.

More or less the same body of theory underpins new economic geography, although it is imperfectly tradable final goods producers rather than immobile service providers that are characterized by product differentiation and increasing returns, transport costs enter, and it is consumers that have the preference for variety. The other sector, in this case agriculture with the immobile input land, comprises homogeneous goods produced under perfect competition with constant returns to scale. Labor is required by both sectors but migrates to agglomerations where close proximity to the local concentration of variety means that a given utility level can be obtained at a lower cost than if transport costs are incurred. In turn, this increases market size in agglomerations, and the extra demand locally attracts firms and therefore further increases variety. Nominal wages will be negatively impacted by the extra competition but positively affected by the higher income in the local market and by the increase in the share of all varieties that is locally produced, since the average real cost per unit will be lower as a result of fewer shipped from elsewhere. Low production costs locally due to competition also lower the cost of living in real terms, and the increase in real wages (so that the same utility can be attained at lower cost) attracts more migrants in a process of circular causation. The low prices in the agglomeration will allow the market area to expand, but only to a finite extent because of the exponential rise in transport costs with distance, so that rather than a single central city emerging, smaller peripheral cities will emerge if shipping costs mean that peripheral demand is best served from a peripheral location.

## MODELING KNOWLEDGE EXTERNALITIES

My own recent work (Fingleton 2001a, 2001b, forthcoming-b) has a basis in the theory outlined above. The object of this work is the understanding of manufacturing productivity growth ($p$) in the regions of the European Union, which is shown to depend (in a nontrivial way) on manufacturing output growth ($q$) by region so that there are increasing returns to scale. To see this, assume that the market structure comprises perfectly competitive manufacturing and immobile services under monopolistic competition, so that each service provider produces a differentiated variety, and assume a constant elasticity of substitution subproduction function, so that the level of (composite) immobile services is a function of the equilibrium labor requirement per variety and the number of varieties, the latter raised to the power $\mu > 1$. In other words, as the elasticity of substitution between differentiated varieties decreases with increasing $\mu$, variety is increasingly relevant to the level of services provided. With low elasticity of substitution, as the number of varieties increases as we move from rural regions to agglomerations, there will be a more than proportionate increase in the level of services. The composite services level enters the Cobb-Douglas production function for the level of tradable competitive final manufactured goods, with coefficient $(1 - \beta)$, combining with manufacturing labor input (with coefficient $0 < \beta < 1$). Assume production is per unit area (see Ciccone and Hall 1996) and, thus, there are also congestion effects with diminishing returns $(0 < \alpha < 1)$ to labor and service inputs. The net outcome is the reduced form with the growth of manufacturing labor productivity a linear function of manufacturing output growth, with the coefficient $(\gamma - 1)/\gamma$ in which $\gamma = \alpha [1 + (1 - \beta)(\mu - 1)]$ reflects the net effect of increasing returns from services ($\mu$), the relevance of services to final production ($\beta$), and the strength of diminishing returns congestion effects ($\alpha$). Empirical analysis shows $\gamma > 1$, indicating that overall there are increasing returns.

While this may represent progress in our understanding of some of the causes of increasing returns (including the congestion externality), the agglomeration effects of information flows are unrepresented. There is now a growing literature (see, for instance, Audretsch forthcoming) that recognizes that instead of abandoning attempts to measure knowledge spillovers because "they are invisible" (Krugman 1991), effort should be put into modeling knowledge flows and representing the way they are localized and have a tendency to decay with geographical distance. However, it is my experience in the EU context that the decay of knowledge spillovers is not so rapid as to be confined within regions; therefore, I emphasize spillovers across region boundaries as well as spillovers within regions. One way forward allowing technological externalities within and between regions, suggested in Fingleton (2001a, 2001b, forthcoming-b), is via the technical progress rate ($r$), which enters the linear function linking manufacturing productivity growth to manufacturing output growth as a spatial variable.

To achieve this, a submodel is developed in which technical progress depends on factors within the region and on the technical progress rate (typically) in neighboring regions. The important factors are assumed to be the intensity of human capital ($H$) and the technology gap ($G$). The assumption is that investment in human capital produces returns via the creation and adoption of innovations and in local knowledge accumulation and spread among the region's workforce. Knowledge is embodied in workers and will be carried across the region and across region boundaries as workers switch jobs within local labor market areas, broadly defined by the extent of daily commuting.[1]

Regarding technology, what is considered important here is its level in relation to the leading (i.e., world-class) technology region at the outset, since this will govern the speed with which technical progress occurs subsequently. Lower initial technology (a bigger gap $G$) is associated with faster technical progress because of the superior benefits of innovation adoption for a low-technology region compared with the benefits accruing to regions higher up the technology ladder. World-class innovation diffusion will see an almost simultaneous trickle-down from initial adopter to other firms in the local economy, located both within the region and across region boundaries. This supposed mechanism is a flow of (disembodied) knowledge according to two mechanisms. First, it will occur when firms collaborating with upstream and downstream producers in a local economy benefit from access to know-how elsewhere in the production chain. Second, competitive pressure among firms in a local economy will cause them to be alert to, search out, and consider adopting the technical standards of rival firms. Early innovators will not able to fully internalize the benefits of searching out or internally developing or adapting new technology (despite protection from patent laws and restrictive employment contracts), which will be obtained at lower cost by other firms' "free-riding" on the initial investment.

The importance of proximity for innovation sharing is emphasized by Henderson (1992) and Glaeser et al. (1992), but nevertheless, the complexity of interaction in the modern economy means that all regions interact to some extent, a feature that can be accommodated by a suitable hypothesis about the spatial extent of spillover as represented by the $W$ matrix.[2] It is the latter that gives an explicit spatial econometric orientation to the empirical analysis (see also Anselin, Varga, and Acs 2000). While the above is perhaps a somewhat speculative story line, some of its essence can be captured in the form of a model that has the prospects of providing empirical estimates of the strength and significance of the principal variables. First, I collect them together as a linear equation:

$$p = b_0 + b_1Wr + b_2H + b_3G + b_4q + e,$$

in which $e$ is the disturbance term, the subscripted $b$s are estimable coefficients, and the rate of technical progress is given by

$$r = b_0 + b_1Wr + b_2H + b_3G + e.$$

While the technical progress rate and the spillover from "neighboring" regions ($Wr$) may be thought of as "invisible," I make them a bit more visible as a "residual"; hence,

$$r = p - b_4 q$$

and, therefore,

$$p = b_0 + b_1 Wp + b_2 H + b_3 G + b_4 q - b_5 Wq + e.$$

This last equation has productivity growth as an endogenous variable, with productivity growth in a region partly determined by, and partly determining, productivity growth in "neighboring" regions. Assimilating the technical progress submodel into the productivity-output growth model produces a reduced form with an endogenous space lag that is familiar to spatial econometricians. There is also an exogenous lag with coefficient $b_5 = b_1 b_4$, but in practice in my experience (mainly based on the analysis of EU regional data), exogenous lags have tended not to be significant, and diagnostic indicators have not suggested them as missing variables, so setting $b_5 = 0$ has been the norm in empirical modeling. This amounts to an assumption that the rate of technical progress is not simply a function of the technical progress rate in "neighboring" regions (*Wr*), but it is a function of the neighboring productivity growth rates (*Wp*), which include technical progress but other factors as well.

Because of the presence of (at least) one endogenous right-hand-side variable, consistent estimation requires maximum likelihood, bootstrap estimation or two-stage least squares, the latter two being appropriate when endogenous variables other than *Wp* appear on the right-hand side. For example, circular causation means that output growth may be viewed as both a cause and a consequence of productivity (i.e., employment) growth, and thus consistent estimation may require instrumental variables. These models can be fitted using SpaceStat[3] (in my case, combined with the programming functionality of GENSTAT and the data-visualizing capabilities of ARCVIEW) with diagnostics to check error distribution assumptions and more complex estimation options available as may be required to model error heterogeneity.

One difficulty with these alternatives to maximum likelihood (ML) estimation is there is no automatic guarantee that the estimated $b_1$ will not take a value that is "dangerously" close to the singular points or outside the stable envelope ($1/e_{\min} < b_1 < 1/e_{\max}$, where $e_{\max}$ and $e_{\min}$ are the maximum and minimum eigenvalues of the $W$ matrix), which defines the parameter space for ML estimation (see Fingleton 1999c, 2000b). This possibility becomes apparent if one rewrites the model in matrix form as $p = (I - b_1 W)^{-1}(Xb + e)$, in which $X$ is the $n$ by $k$ matrix of $k - 1$ regressors. The matrix inversion becomes indeterminate at the singular points of $(I - b_1 W)$ such as $b_1 = 1/e_{\max}$, which is equal to 1 when $W$ is row standardized. Outside the stable envelope, one enters the territory of spatial unit root processes and beyond, and while I have pointed out some similarities with time series unit roots, I also show (Fingleton 1999c) that the situation is evidently much more complex, and one cannot simply translate the time series methods to the spatial domain.

## SOME WAYS FORWARD?

On the whole, spatial econometric modeling has quite naturally tended to focus on static analysis and overlook the dynamics that may be an implied consequence of a cross-sectional model, and yet understanding the way in which economies evolve is of fundamental importance and should enhance the relevance of this work for policy makers with a keen eye on the future. One way forward is therefore to place more emphasis on the temporal aspects of models, for instance, if there are spillover effects, what does this imply for the long run, will there be a tendency for regional differences to be magnified, and how do countervailing forces come into play to nullify any propensity for ever-increasing regional disparities? Likewise, the existence of increasing returns by itself implies divergent paths, and it would be interesting to gain more evidence of the strength and speed of these effects in the context of the other effects acting simultaneously on the regional economy. There is of course tremendous scope for using simulation techniques to generate other possible worlds[4] on the basis of different model assumptions, and indeed within the model framework outlined in the Modeling Knowledge Externalities section of this article, above, with appropriate assumptions regarding parameter values, different spatial patterns and dynamic paths including divergence are options. Having acknowledged the possibilities and recognized that almost any real-world or imagined configuration can be conjured up, my preferred approach to dynamics is probably close to what Fujita, Krugman, and Venables (1999, 347) called "quantification," meaning the use of theory-consistent models whose parameters are "based on some mix of data and assumptions, so that realistic simulation exercises can be carried out." Thus, my simulations are driven by estimated parameters obtained by fitting spatial econometric models to data and by more or less realistic assumptions about the values of variables under alternative scenarios.

The dynamics emerging from this work (Fingleton, 2000b, 2001a) are surprising. While it might be assumed that the presence of externalities and increasing returns would cause productivity levels to diverge, it is shown that the presence of "catching-up" (an empirical necessity for EU regional growth modeling) causes ultimate convergence to a steady state in which productivity growth is equalized across regions, so that the (unequal) ratios of productivity levels become constant. Moreover, it is evident that while cross-region spillovers affect disequilibrium paths, they have no effect[5] on steady-state productivity level ratios. This steady-state outcome mimics the "conditional convergence" result (each region converging to its own rather than a common steady state) produced under neoclassical growth theory (Fingleton and McCombie 1998, Fingleton 1999a, Barro and Sala-i-Martin 1995), but of course, the implied mechanism is different.

Part of the way forward is to use the results of econometric modeling to revolutionize theoretical concepts. Attempting to confront theory with data presents the analyst with both conceptual and practical challenges that are difficult but that may yield new insights. In my own work, I have long understood the need to capture increasing returns and to model the inherent tendency for regional economies to diverge, recognizing the important strand of Keynesian-oriented literature that has consistently maintained this position. This is related to the Verdoorn coefficient[6] and the cumulative causation models deriving from Kaldor (1957) and is represented in the recent literature by the work of Bernat (1996), Fingleton and McCombie (1998), Harris and Lau (1998), León-Ledesma (2000, 2002), and Fingleton (2000a). Krugman (1991) acknowledged a debt to this nonmainstream tradition as a source of inspiration leading to the ideas embodied in new economic geography, but the connection is much closer. In my paper in the *Journal of Regional Science* (Fingleton 2001a), I showed the "equivalence" of the Verdoorn law and the reduced form described in the Modeling Knowledge Externalities section of this article. In this, I prefer to commence from the simpler urban economics version of the theory, since it is from this starting point that one is able to make some first steps along the way to confronting the new theory with data. Sometimes one has to go sideways a little to make progress. While the initial new economic geography and urban economics theories were in many ways an advance on previous theories because of their embodiment of increasing returns in a formal general equilibrium framework, their limitations, or restricting and simplifying assumptions, become all too obvious under the econometric spotlight. For instance, there is a clear need to incorporate spatial technological externalities, as I have argued. Moreover, when one assumes a time-oriented stance, other deficiencies appear. One recent extension to the model framework outlined in the Modeling Knowledge Externalities section, which was devised to monitor the effects of externalities and increasing returns for different time periods, has been the development of multi-equation models (Fingleton 2001b) in the form of spatial seemingly unrelated regressions (see Anselin 1988). Three-stage least squares estimation via LIMDEP and PcFIML enables the testing of across-time parameter restrictions, and these show that one cannot simply assume that returns to scale are invariant across time and space, and this calls into question the stability of the fundamental parameters determining returns to scale outlined above. The inference is that one or more of the parameters representing the elasticity of substitution ($\mu$), the relative importance of services ($\beta$), and congestion effects ($\alpha$), is endogenous, and this invites another layer of theory.

Breaking free from the neoclassicism embodied in the standard Barro-regression approach to regional growth, with its implication of diminishing returns, and widening the closed-off worldview of basic new economic geography theory to admit greater realism seem to be ways forward for economic geography and regional science. One other strand of research I have pursued (Fingleton 1997, 1999a, 1999b) relates to the application of Markov chains and the concept of an "untidy" convergence to a stochastic equilibrium in place of the smooth progression to a deterministic equilibrium that is embodied in the basic neoclassical approach (Quah 1993). However, more recently (Fingleton forthcoming-a), this has evolved to retain the notion of the stochastic steady state without imposing the rather uninformative state space structure that characterizes the Markov approach. The motive is the same, avoidance of the determinism and lack of reality of conventional theory, but unlike primarily data-driven Markov chain or stochastic kernel approaches, there is now an explicit basis in the more realistic economic geography theory which, as I have outlined, is emerging in the wake of the initial wave of new economic geography theorizing.

There are numerous questions and problems that arise in the context of modeling spatial externalities. I conclude by raising a few issues that appear to be important at the present moment, without claiming that this represents a comprehensive or easily resolvable research agenda. One issue that is important is of course the way in which spillover between regions is modeled. The most obvious approach for spatial econometricians is to invoke the *W* matrix and the endogenous spatial lag, but in some ways this is unsatisfactory because the structure of *W* is more often than not assumed not estimated, and the assumptions are not tested or underwritten by a strong theory. In other words, what is the theoretical and empirical basis of assumptions about the spatial reach of externalities, and how can this be enhanced? Can progress be made explicitly modeling knowledge spillovers between interacting firms or by modeling knowledge flows due to job switching in labor market areas? A second item on the research agenda is how one might model overarching "exogenous" impacts due to developments in communications technology, institutions, and economic integration, which may change the scale and scope of externality effects and returns to scale. These and many other questions can be considered to be an integral part of a "third way" (Fingleton 2000b), combining spatial econometrics with economic geography, in which the theory to data ratio is neither too high nor too low but just right (in Goldilocks fashion). This, I argue, has an important role to play in fostering a revitalized, more scientific, economic geography. Rigorously confronting theory with evidence, rather than simply appealing to "stylized facts," is seen as "a way forward" toward an economic geography in which theory is not simply imagined but is the product of the creative interplay of imagination and evidence.

## Notes

1. Much of the empirical work in this area uses the comprehensive NUTS 2 region system of the EU, which on the whole comprises formal or administrative regions. The alternative Functional Urban Regions (see, for instance, Cheshire and Magrini 2000) will tend to limit but not completely eliminate spillover, since travel-to-work areas are constantly evolving. It is partly for this reason that it is preferable to allow for spatial interaction at the modeling rather than data collection stage.

2. Usually, *W* is row standardized. This simplifies estimation, aids interpretation, and has the effect that matrix product *Wp* is a vector of weighted averages of elements of vector *p* with weight determined by the rules used to form the elements of *W*. Standardization means that *W* is asymmetric, so that the externality effect of location *i* on *j* does not equal the *j* to *i* effect.

3. L. Anselin, SpaceStat, a software package for the analysis of spatial data, version 1.90 (Ann Arbor, MI: BioMedware, 1999).

4. An obvious advantage of the mathematical modeling approach over the qualitative approaches that have been much in vogue among many economic geographers "proper," a point made by Plummer and Sheppard (2001).

5. This holds as long as one assumes $b_5 = 0$. If, however, one imposes the constraint $b_5 = b_1 b_4$, then the productivity levels ratios to which the regions converge is a function of the spillover intensity because $b_5$ is then a function of $b_1$. I am grateful to Enrique López-Bazo for help in clarifying this point.

6. The productivity-output growth relationship, known among regional economists familiar with the work of Kaldor as the dynamic Verdoorn law, has long been seen as evidence of the presence of internal and external economies of scale, such as due to the division of labor and agglomeration economies. It turns out that the same relationship can also be obtained as a reduced form of the foregoing monopolistic competition theory underpinning increasing returns in urban economics and new economic geography. This connection provides an alternative perspective on what is meant by increasing returns with an explicit micro-theoretical foundation.

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