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Spatial Econometric Models for Simultaneous Systems: Comparisons of Some Models for Selected Regions in France

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**Spatial Econometric Models for Simultaneous Systems:
Comparison of Some Models for Selected Regions in France**

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Abstract: In this paper we compare several spatial econometric approaches to estimation of multi-equation models of small region development. We construct spatial extensions of the Carlino and Mills (1987) and Boarnet (1994) models to analyze the urban spread of population and employment in the French rural hinterland. We used a sample of 3500 rural communes in six French regions. We present a comparison of results from the Henry *et al.* extension of the Boarnet model, the Carlino-Mills and Boarnet models of local change and with three spatial autoregressive models suggested in Rey and Boarnet (1998). We find that the tests for spread and backwash effects in the spatial autoregressive, and the Carlino-Mills and Boarnet models with spatial autoregressive terms added, reveal a general tendency of spread to rural areas across labor and residential areas. The Henry *et al.* modification to Boarnet adds insight into how urban growth affects proximate rural areas by decomposing the spatial cross-regressive term in “own”, urban core and fringe effects.

JEL: R11 - R12

Key Words: Spatial Econometric Models - Rural Urban Linkages - Urban Growth Effects

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Spatial Econometric Models for Simultaneous Systems: Comparison of Some Models for Selected Regions in France

I. INTRODUCTION

Rural places have a fundamental stake in the processes that are forming urban spatial structure (Goffette-Nagot, 1999). The emergence of edge cities in Western Europe and the United States is one outcome of the forces promoting suburbanization in urban spatial structure (Anas *et al.*, 1998, p.1430). While suburbs and city centers may exhibit some complementary relationships -- for example, higher rates of income growth in city centers associated with corresponding increases in the suburbs (Voith, 1993) -- most analysts find that jobs follow people to the suburbs (Dietz, 1998). The renewed emphasis on agglomeration economies in location decisions of firms suggests that rural places may be increasingly disadvantaged as urban complexes grow -- especially in regions with emerging edge cities (Kilkenny, 1998a, 1998b has developed models to examine some of these issues in the context of the new economic geography). Moreover, even a casual inspection of the data reveals that most rural residents depend on service and manufacturing jobs -- just like in urban complexes. Accordingly, in many regions, rural and urban businesses compete for the same customers and draw from labor pools that overlap.

The urban spread/backwash question has been a longstanding concern for regional scientists since spatial patterns of urban change raise general welfare questions (Anas *et al.*, 1998). Debate among urban planners and economists about what constitutes 'smart growth' of urban areas reveals the need for better information on spatial economic processes (Chronicle of Higher Education, 1999). Along with the renewed interest in urban sprawl, advances in spatial econometric models of the urban development process (Rey and Boarnet, 1998) provide new avenues for investigating how urban complexes and the hinterland are connected. The spatial economic issue that we address in this paper is whether urban growth spreads jobs and people to nearby rural places or draws people and jobs

away from rural communities (see Barkley *et al.* (1996) and Hansen (1972) for some descriptions of possible spread and backwash effects).

To examine spatial and nonspatial endogeneity issues, we estimate several related spatial econometric models for simultaneous equation systems from the taxonomy developed in Rey and Boarnet (1998). Since Stiennes and Fisher (1974), models of the urban development process have considered population and employment to be endogenous (Rey and Boarnet, 1998, p. 2). Accordingly, we begin by estimating the two-equation Carlino-Mills (CM) model (1987) that jointly determines population and employment in a rural commune (French municipality), but without spatial lags. Following Boarnet (1994), we extend CM by estimating a spatial cross-regressive model. In the Boarnet model, the right-hand-side of each equation includes a spatial lag of the endogenous variable of the other equation. Rey and Boarnet (1998) suggest that these spatial lags capture a simultaneity effect that differs from the traditional CM variety.

Since our focus is on possible spread and backwash effects of urban growth on proximate rural areas, we use the model in Henry *et al.* (1997) to estimate the effects of urban growth on rural population and employment. This extension of Boarnet's spatial cross regressive model represents an addition to the family of spatial models in Rey and Boarnet (1998). It facilitates testing for the impacts of alternative urban growth patterns on proximate rural areas.

Given the evidence in Rey and Boarnet (1998) that both endogenous spatial lags and nonspatial (CM type) endogenous variables are important in these models, it seems prudent to include both types in our tests of alternative models. Accordingly, we estimate three models as alternative tests of spread/backwash for comparison with the Henry *et al.* approach. First, a traditional, single equation test of the spread/backwash problem is made using only a spatial autoregressive (SAR) term in each of the two equations. – without including the other endogenous variable on the right-hand-side of each equation. Then, we add 'own' spatial lags to both the CM and Boarnet models to examine the urban spread hypothesis.

In the next section, we describe the models estimated. In section III, the data and empirical results for selected French regions are examined. Comparative results of Carlino and Mills (1987), Boarnet (1994), the Henry *et al.* (1997) and spatial autoregressive models are analyzed. A concluding statement is provided in section IV.

II. Models

We first consider the model in Henry *et al.* (1997) since it is not in the set defined by Rey and Boarnet (1998). To include urban growth influences, the Boarnet (1994) model is extended as follows:

$$P_{i,t}^* = \Psi (C_i, EMP_{i,t}^*, g_1, g_2) \quad (1)$$

$$E_{i,t}^* = \Phi (D_i, POP_{i,t}^*, h_1, h_2) \quad (2)$$

where, $P_{i,t}^*$ and $E_{i,t}^*$ are equilibrium population and employment in the i th rural commune at time period t ; $EMP_{i,t}^*$ and $POP_{i,t}^*$ are equilibrium employment and population in *local labor market* and *residential zones* centered on the i th rural commune - not single communes; g_1 (g_2) is the urban center (urban fringe) employment growth rate for the functional economic region, FER, to which the i th rural commune belongs; h_1 (h_2) is the urban center (urban fringe) population growth rate for the FER to which the i th rural commune belongs. C_i and D_i are vectors of residential and firm related "amenities" that the i th rural commune has to offer¹ Using linear forms of (1) and (2) with urban growth rate interaction terms and with substitution to eliminate unknown equilibrium values, we solve for the change in population and employment in each rural commune as shown in equations (3) and (4) (see Henry *et al.*, 1997, for demonstration).

¹ Urban growth rates reflect the pattern of change in spatial structure in a given urban complex (core and fringe). For example, if the fringe is growing rapidly while the core is stagnant or declining, there is a pattern of decentralization. Rapid growth of the core with fringe decline yields a more center oriented urban complex. In both cases, the local labor market area, EMP_i , or residential zone, POP_i for a rural place might be affected. Accordingly, urban spatial growth patterns may influence the desirability of a rural place as a location choice for a new firm because the local labor force pool, POP_i , may increase with rapid urban fringe growth or decrease with rapid urban core growth. In terms of equation (2), the relative values of h_1 and h_2 affect POP_i . For example, a low h_1 and a high h_2 mean that urban population is spreading to the suburbs. This suggests that nearby rural places will have a larger labor pool available to potential new firms and favorably affect E_i , employment in a rural place. Alternatively, the desirability of a rural place as a location choice for a new household, equation (1), may increase or decrease as urban spatial employment growth patterns (g_1 and g_2) affect the size of the local job opportunity pool, EMP_i .

$$dP_i = \mathbf{g}_0 + C_i \mathbf{g}_1 - \mathbf{I}_p P_{i,t-1} + [\mathbf{a}_2 + \mathbf{a}_3 \mathbf{g}_1 + \mathbf{a}_4 \mathbf{g}_2] \text{EMP}_{i,t-1} + \left[\frac{\mathbf{g}_2}{\mathbf{I}_e} + \frac{\mathbf{g}_3}{\mathbf{I}_e} \mathbf{g}_1 + \frac{\mathbf{g}_4}{\mathbf{I}_e} \mathbf{g}_2 \right] (\text{EMP}_{i,t} - \text{EMP}_{i,t-1}) + \mathbf{e}_1 \quad (3)$$

$$dE_i = \mathbf{d}_0 + D_i \mathbf{d}_1 - \mathbf{I}_e E_{i,t-1} + [\mathbf{b}_2 + \mathbf{b}_3 h_1 + \mathbf{b}_4 h_2] \text{POP}_{i,t-1} + \left[\frac{\mathbf{d}_2}{\mathbf{I}_p} + \frac{\mathbf{d}_3}{\mathbf{I}_p} h_1 + \frac{\mathbf{d}_4}{\mathbf{I}_p} h_2 \right] (\text{POP}_{i,t} - \text{POP}_{i,t-1}) + \mathbf{e}_2 \quad (4)$$

In equations (3) and (4), λ_e and λ_p are the rates of adjustment to equilibrium employment and population, respectively, dP_i and dE_i are the population and employment changes and ε_1 and ε_2 are random disturbance terms. Following Boarnet (1994), we introduce a spatial linkage matrix, W , which has non-zero elements, w_{ij} , for communes that are within the same zone (local labor market or residential zone). Accordingly, *local labor market* and *residential zone* variables are redefined as: $\text{EMP}_{i,t} = (\mathbf{I} + \mathbf{W}) E_{i,t}$, $\text{POP}_{i,t} = (\mathbf{I} + \mathbf{W}) P_{i,t}$, $(\text{EMP}_{i,t} - \text{EMP}_{i,t-1}) = (\mathbf{I} + \mathbf{W}) dE_i$, and $(\text{POP}_{i,t} - \text{POP}_{i,t-1}) = (\mathbf{I} + \mathbf{W}) dP_i$. Substitution of the commuting zone variables into equations (3) and (4), dropping the community i subscripts, and simplifying the parameter notation yields the reduced form model in Henry *et al.* (called H) used to estimate potential spatial linkages between the urban centers, urban fringe and rural hinterland in equations (5) and (6):

$$\mathbf{H}: \quad \begin{aligned} dP &= \mathbf{a}_0 - \mathbf{I}_p P_{t-1} + [\mathbf{a}_2 + \mathbf{a}_3 \mathbf{g}_1 + \mathbf{a}_4 \mathbf{g}_2](\mathbf{I} + \mathbf{W}) E_{t-1} + [\mathbf{a}_5 + \mathbf{a}_6 \mathbf{g}_1 + \mathbf{a}_7 \mathbf{g}_2](\mathbf{I} + \mathbf{W}) dE + C \mathbf{g}_1 + \mathbf{e}_1 \quad (5) \\ dE &= \mathbf{b}_0 - \mathbf{I}_e E_{t-1} + [\mathbf{b}_2 + \mathbf{b}_3 h_1 + \mathbf{b}_4 h_2](\mathbf{I} + \mathbf{W}) P_{t-1} + [\mathbf{b}_5 + \mathbf{b}_6 h_1 + \mathbf{b}_7 h_2](\mathbf{I} + \mathbf{W}) dP + D \mathbf{d}_1 + \mathbf{e}_2 \quad (6) \end{aligned}$$

We next construct a series of models that are proposed in Rey and Boarnet(1998) to examine the role that spatial and nonspatial endogenous variables play in explaining rural population and employment change. The CM model can be obtained by dropping all the spatial variables (those with an $(\mathbf{I} + \mathbf{W})$ connection) and urban growth variables (those in interaction with endogenous variables) as shown in equations (7) and (8).

$$\mathbf{CM}: \quad \begin{aligned} dP &= \mathbf{a}_0 - \mathbf{I}_p P_{t-1} + \mathbf{a} dE + C \mathbf{g}_1 + \mathbf{e}_1 \quad (7) \\ dE &= \mathbf{b}_0 - \mathbf{I}_e E_{t-1} + \mathbf{b} dP + D \mathbf{d}_1 + \mathbf{e}_2 \quad (8) \end{aligned}$$

The Boarnet (B) model adds to the CM model the cross-regressive terms shown in equations (9) and (10):

$$\mathbf{B:} \quad \begin{aligned} dP &= \mathbf{a}_0 - \mathbf{I}_p P_{t-1} + \mathbf{a}_2(I+W) E_{t-1} + \mathbf{a}_5(I+W) dE + C \mathbf{g}_1 + \mathbf{e}_1 \quad (9) \\ dE &= \mathbf{b}_0 - \mathbf{I}_e E_{t-1} + \mathbf{b}_2(I+W) P_{t-1} + \mathbf{b}_5(I+W) dP + D \mathbf{d}_1 + \mathbf{e}_2 \quad (10) \end{aligned}$$

Three alternatives to Henry *et al.* (1997) for tests of spread effects are considered. First, the spatial autoregressive model (SAR without nonspatial endogenous variables) can be represented as shown in equations (11) and (12).

$$\mathbf{SAR:} \quad \begin{aligned} dP &= \mathbf{a}_0 - \mathbf{I}_p P_{t-1} + \mathbf{a}_5(WdP) + C \mathbf{g}_1 + \mathbf{e}_1 \quad (11) \\ dE &= \mathbf{b}_0 - \mathbf{I}_e E_{t-1} + \mathbf{b}_5(WdE) + D \mathbf{d}_1 + \mathbf{e}_2 \quad (12) \end{aligned}$$

Note that the WdP and WdE spatial variables are spatially endogenous since change in the LHS variables (dP and dE) can ‘spillover’ into the spatial RHS variables (WdP and WdE), even though $w_{ii}=0$). Finally, we augment the CM and Boarnet models as suggested in Rey and Boarnet (1998) by the SAR terms to provide two alternative direct tests of spread effects. The augmented CM model, CM-SAR, is displayed in equations (13) and (14) while the augmented Boarnet model, B-SAR, is represented in equations (15) and (16).

$$\mathbf{CM-SAR:} \quad \begin{aligned} dP &= \mathbf{a}_0 - \mathbf{I}_p P_{t-1} + \mathbf{a} dE + \mathbf{a}_3 WdP + C \mathbf{g}_1 + \mathbf{e}_1 \quad (13) \\ dE &= \mathbf{b}_0 - \mathbf{I}_e E_{t-1} + \mathbf{b} dP + \mathbf{b} WdE + D \mathbf{d}_1 + \mathbf{e}_2 \quad (14) \end{aligned}$$

$$\mathbf{B-SAR:} \quad \begin{aligned} dP &= \mathbf{a}_0 - \mathbf{I}_p P_{t-1} + \mathbf{a}_2(I+W) E_{t-1} + \mathbf{a}_5(I+W) dE + \mathbf{a}_6 WdP + C \mathbf{g}_1 + \mathbf{e}_1 \quad (15) \\ dE &= \mathbf{b}_0 - \mathbf{I}_e E_{t-1} + \mathbf{b}_2(I+W) P_{t-1} + \mathbf{b}_5(I+W) dP + \mathbf{b}_6 WdE + D \mathbf{d}_1 + \mathbf{e}_2 \quad (16) \end{aligned}$$

The spatial weight matrices, W , are the same across all of the estimations. They are designed to connect all communes within a 15 kilometer radius of any given rural commune. The elements along the main diagonal, $w_{ii}=0$. Note that the key idea in the Boarnet and Henry *et al.* models is that households select communes, in part, according to the number of jobs available within a reasonable commuting distance – not simply the number of jobs in a given commune. Firms are assumed to consider communes that are proximate to an adequate supply of labor (households), i.e., within a commuting zone from the establishment site and not just the supply of labor in a given rural commune. In the Boarnet model these spatial variables are not explicitly linked to urban complexes.

In the Henry *et al.* extension of Boarnet, urban growth patterns affect how households and firms view the desirability of rural communes.

III. DATA USED AND EMPIRICAL RESULTS

Data. The model is estimated using French data at the commune (French municipality) level. The communes of six selected regions are organized in different functional economic regions (FERs) using commuting flows between communes (see Figure). In each FER, we identify an employment center (the core), a periurban area (the fringe) and proximate rural communes (the hinterland). The data are assembled from several French statistical sources including: Census Files for Population and Job Data, 1975, 1982 and 1990; Communal Inventory, 1980, 1988; and Taxable Income File, General Director of Taxes, 1984. Variables used to estimate each equation are defined in Table 1.

The rural communes are located in the hinterland zones of the six regions in the Figure.² There are 3,515 rural communes available in these regions. The distance for the W matrix is fixed at 15 km (if the distance between i and j is higher than 15 then $w_{ij}=0$, otherwise $w_{ij}=1$). In total, 11,170 urban and rural communes comprise the data set used in construction of W. The W matrix is used to construct local labor market zones and residential zones centered on each of the 3,515 rural communes.

Estimation issues. The econometric estimates are obtained in a two-stage process using an instrumental variables method since there is simultaneity implied between the changes in population, **dP**, and changes in employment, **dE**, in the rural communes. In stage one, **dP** [**dE**] are predicted values from an auxiliary regression on exogenous variables in the model-- essentially the beginning period characteristics; next, the predicted values are multiplied by $(I+W)$ to form the spatial lags of the predicted values.³ In the

² Each rural commune is in a FER with an urban center of at least 5,000 inhabitants, except that the rural communes less than 50 km from a national boundary are deleted to avoid national boundary influences.

³ Rey and Boarnet, 1998, in Monte Carlo experiments, suggest the use of an alternative first stage estimate of the spatially lagged endogenous variable may be more efficient. We leave this for future analysis.

first stage regressions, the 11,170 communes were bifurcated into rural hinterland (3,515) and other (7,555) categories for use. For the second stage regressions, with \mathbf{dP} [\mathbf{dE}] of the 3,515 rural communes as dependent variables, only the 3,515 rural commune rows of the $(\mathbf{I+W}) \mathbf{E}_{t-1}$, $(\mathbf{I+W}) \mathbf{P}_{t-1}$, etc. vectors are retained as explanatory variables.

Comparison between Carlino-Mills, Boarnet, Extended Boarnet and SAR Models

Rural Population Change. Table 2 presents the results of estimating the population equation for each of the six models described in section II. The main differences between these results concern the spatial and nonspatial endogenous variables. With some exceptions, the parameter estimates on the amenity variables, natural population increase and prior period growth variables are stable across each model. We do not discuss the results on these variables in detail and simply note they tend to have the expected sign and a few are highly significant.

Table 1. List of Variables

Variable	Definition
DP	Change in population density 1982 to 1990 (<i>Census data</i>)
DE	Change in employment density 1982 to 1990 (<i>Census data</i>)
DPOP82	Population density in each commune, 1982 (<i>Census data</i>)
DWPOP82	Local residential zone population density: $(\mathbf{I+W}) \cdot \mathbf{DPOP82}$ (<i>Census data</i>)
DWPOP1	Urban center population growth rate (82-90) in interaction with local residential zone population density: $h_1 \cdot \mathbf{DWPOP82}$ (<i>Census data</i>)
DWPOP2	Fringe population growth rate (82-90) in interaction with local residential zone population density: $h_2 \cdot \mathbf{DWPOP82}$ (<i>Census data</i>)
WVDPOPE	Estimated value of population density change in local residential zone: $\hat{dP} \cdot (\mathbf{I+W})$
WVDPH1E	Urban center population growth rate (82-90) in interaction with local residential zone population change: $h_1 \cdot \mathbf{WVDPOPE}$
WVDPH2E	Fringe population growth rate (82-90) in interaction with local residential zone population change: $h_2 \cdot \mathbf{WVDPOPE}$
DEMP82	Employment density in each commune, 1982 (<i>Census data</i>)
DWEMP82	Local labor market zone employment density: $(\mathbf{I+W}) \cdot \mathbf{DEMP82}$ (<i>Census data</i>)
DWEMPG1	Urban center employment growth rate (82-90) in interaction with local labor market zone employment density: $g_1 \cdot \mathbf{DWEMP82}$ (<i>Census data</i>)
DWEMPG2	Fringe employment growth rate (82-90) in interaction with local labor market zone employment density: $g_2 \cdot \mathbf{DWEMP82}$ (<i>Census data</i>)
WVDEMPE	Estimated value of employment density change in local labor market zone: $\hat{dE} \cdot (\mathbf{I+W})$
WVDEG1E	Urban center employment growth rate (82-90) in interaction with local labor market zone employment change: $h_1 \cdot \mathbf{WVDEMPE}$
WVDEG2E	Fringe population growth rate (82-90) in interaction with local residential zone population change: $h_2 \cdot \mathbf{WVDEMPE}$
NATBAL_P	Natural Population Growth (births-deaths), 1982 to 1990 (<i>INSEE data</i>)
VDP7582	Change in population density during previous period 1975-1982 (<i>Census data</i>)
VDE7582	Change in employment density during previous period 1975-1982 (<i>Census data</i>)

DPBAS90C	Distance (centroid to centroid) to the urban center (<i>Lambert's coordinates, IGN data</i>)
D2PBAS90	Distance to the urban center squared (<i>Lambert's coordinates, IGN data</i>)
DIAUTOR	Distance to the nearest freeway entrance point in 1988 (<i>Communal inventory & IGN data</i>)
DIAGGLO	Distance to the nearest urban agglomeration $\geq 200,000$ inhabitants (<i>Census & IGN data</i>)
SCHOLDIST	Distance to the nearest secondary school in 1980 (<i>Communal inventory & IGN data</i>)
HOSPDIST	Distance to the nearest hospital in 1980 (<i>Communal inventory & IGN data</i>)
NOT80	Frequency of twenty-eight types of residentiary services in 1980 (<i>Communal inventory</i>)
HOUS82_P	Percentage in 1982 of commune houses built before 1975 (<i>Census data</i>)
RNMOY84	Household taxable income in 1984 (<i>DGI data</i>)
WTAXIN84	Local residential zone household income in 1984: TAXINC84*(I+W) (<i>DGI data</i>)
CAPPACC80	Number of tourist beds (<i>Communal inventory data</i>)
WNOBLU82	Active population in executive and intermediate occupations [multiplied by (I+W)] by active population of manual and clerical workers [multiplied by (I+W)] in 1982 (<i>Census</i>)
WSKIWO82	Active population of skilled manual workers [multiplied by (I+W)] by unskilled manual workers [multiplied by (I+W)] in 1982 (<i>Census data</i>)
WSELF82	Percentage of non-salaried jobs in non agricultural sectors in 1982: Non-salaried jobs [multiplied by (I+W)] % Total jobs [multiplied by (I+W)] (<i>Census data</i>)
WCHOM82	Unemployment rate in 1982: Unemployed [multiplied by (I+W)] % Active population [multiplied by (I+W)] (<i>Census data</i>)

FIGURE 1 ABOUT HERE

The coefficients on the variables that describe the linkage between population and employment in the Carlino-Mills, Boarnet, Henry *et al.*, and SAR extensions, however, vary across models and suggest the following comments. In the population change equation, the sign of the regression coefficient on beginning period population density changes across models. It is positive in the Carlino-Mills specifications (CM and CM-SAR), but negative in the SAR, Boarnet models (B and B-SAR) and Henry *et al.* model. In the structural models, this parameter is $-\lambda_p$. (so the CM model yields a negative λ_p parameter and the others a positive λ_p parameter). A negative value of this rate of adjustment to equilibrium population may indicate dynamic instability in the population - employment equation system (Mulligan, *et al.*, 1997, p. 12). It likely indicates that, at this level of analysis (commune levels), a Carlino-Mills model is not the correct specification. In the Boarnet model (as in Henry *et al.* model), when the spatial cross regressive terms are added to the CM model, the λ_p parameter not only reverses to the correct sign but also decreases in absolute value compared to the CM result.

With the introduction of the urban growth effects in the Henry *et al.* model, the parameter values for the spatial employment density and spatial employment change variables decline, compared to Boarnet, because their impact is now partly reflected in the interaction variables. As shown in the appendix, these urban growth rate parameters can be used to simulate the impact on rural population change from alternative rates of employment growth in the urban core and fringe. Over the range of urban growth rates considered, faster urban employment growth tends to ‘spillover’ into greater increases in population in proximate rural communes – but the spillover rates vary by urban growth rates of the fringe and core.

The SAR, CM-SAR, and B-SAR models support the conclusion that there are spread effects but they are spillovers of proximate area population growth (not only urban areas) to the rural commune population. It is only in the H model that urban growth rates are explicitly considered. Without that, it is difficult to know the exact role of the urban center growth on the rural hinterland development.

In parallel, when we introduce a spatial autoregressive effect, the impact of rural employment change on rural population change disappears. Thus there should be a spread effect of population but not a “people follow jobs” effect.

Rural Employment Change. In the employment equations, CM now has the correct sign on the DEMP82 – as do all the other models. In CM, there is a strong positive effect from rural commune population change on rural commune employment change (the parameter on VDP8290 is .198). In Boarnet, the change in the size of the residential zone around the rural commune has a similar effect on rural commune employment change (the parameter on WVDPOP is .194). However, the results in Henry *et al.* shows a residential zone effect on rural employment change that varies with the pattern of growth of the urban complex.. Increasing the beginning period size of the residential zone (DWPOP) and faster urban core population growth rates (H_2) mean more rural commune employment. And increasing the number of people in the residential zone (WVDP) with faster urban fringe population growth (H_2) also means more employment in the rural commune. But the impact on rural employment from urban population growth depends on the magnitudes of urban core and fringe growth rates. Some simulations are presented in the appendix and in Henry *et al.* (1998). Over most rates of urban population growth, there are urban spread effects, but some combinations of size and change in the residential zone and urban growth rates may produce no effect or backwash effects on proximate rural communes.

In contrast to the population results that showed spread effects (though not necessarily an urban spread effect) for the SAR, CM-SAR and B-SAR models, only the simple SAR model suggests spread of urban jobs to proximate rural communes. The parameter estimates on WVDEMP, the spatial lag of a rural communes employment change, are not significant in either the CM-SAR or B-SAR models. Again, the drawback to these SAR models is that they are not a test of urban to rural spread but rural labor zone to rural commune employment. It is worth noting that when we introduce

both spatial autoregressive and crossregressive variables, the spread effect disappears but not the population change effect on employment change. Thus the rural employment change could be interpreted as the result of a “jobs follow people” effect without employment spread effect.

Two alternative model specifications were estimated for which results are not presented here but are available on request. In the first, we extend the Carlino-Mills model to include urban growth interactions with the beginning period rural population (employment) density and rural population (employment) change. We again find an indication of dynamic instability in the Carlino-Mills specification, i.e., the sign of the λ_p parameter is positive. Deleting the Boarnet spatial variables (I+W)E82 and (I+W)dE appears to be associated with this problem in the Carlino-Mills specification.

We also estimated a Boarnet model in which we included g_1 , g_2 (urban core and fringe employment growth rates) and h_1 , h_2 (urban core and fringe population growth rates) as simple right hand side variables, i.e., without interactions with the spatial variables (I+W)E82, (I+W)dE, (I+W)P82 and (I+W)dP. Results show that only g_2 , the urban fringe employment growth rate, acts directly on rural population change. The parameters for the urban core employment growth rate (g_1) and urban core and fringe population growth rate (h_1 , h_2) are not statistically significant. This suggests that the role that urban growth plays in rural change is in combination with the local labor market zones and residential zones as specified in equations (5) and (6).

Table 2 - Parameter Estimates of the Population Change Equation

Variables	MODEL			Spatial	Carlino-Mills	Boarnet-SAR
	Carlino-Mills (CM)	Boarnet (B)	Henry <i>et al.</i> (H)	AutoRegressive (SAR)	SAR (CM-SAR)	(B-SAR)
Constant	3.096*** <i>3.44</i>	2.583*** <i>2.63</i>	2.608*** <i>2.64</i>	.802 <i>.831</i>	-.351 <i>-.38</i>	-.229 <i>-.222</i>
DPOP82	.0672*** <i>8.84</i>	-.043*** <i>-25.08</i>	-.043*** <i>-25.17</i>	-.043*** <i>-26.1</i>	.063*** <i>8.67</i>	-.044*** <i>-26.5</i>
DEMP82	-.202*** <i>-10.56</i>				-.204*** <i>-11.11</i>	
VDE8290	.1264* <i>1.96</i>				.088 <i>1.41</i>	
DWEMP82		.0235*** <i>3.12</i>	.0168** <i>3.16</i>			.033*** <i>4.40</i>
WVDEMPE		.659*** <i>7.30</i>	.3926*** <i>3.55</i>			.008 <i>.066</i>
WVDDPOP				.428*** <i>12.36</i>	.383*** <i>11.85</i>	.377*** <i>7.40</i>
DWEMPG1			.002*** <i>3.25</i>			
DWEMPG2			.00082** <i>2.45</i>			
WVDEG1E			.019**			
WVDEG2E			-.0066 <i>-1.22</i>			
NATBAL_P	.1358*** <i>9.18</i>	.1007*** <i>6.38</i>	.0997*** <i>6.30</i>	.092*** <i>5.96</i>	.113*** <i>7.88</i>	.085*** <i>5.50</i>
DPBAS90C	.0122 <i>.697</i>	.0158 <i>.840</i>	.00039 <i>.02</i>	-.015 <i>-.82</i>	-.004 <i>-.26</i>	.0013 <i>.07</i>
D2PBAS90	-.00009 <i>-.367</i>	-.00012 <i>-.42</i>	-.00004 <i>-.142</i>	.0002 <i>.757</i>	.00013 <i>.519</i>	.0004 <i>.15</i>
NOT80	.0369** <i>2.298</i>	.079*** <i>4.96</i>	.077*** <i>4.82</i>	.083*** <i>5.32</i>	.046*** <i>2.94</i>	.086*** <i>5.47</i>
HOUS82_P	-.019** <i>2.241</i>	-.004 <i>-.4526</i>	-.0028 <i>-.31</i>	.00384 <i>.428</i>	.00057 <i>.069</i>	.00531 <i>.59</i>
DIAUTOR	-.018*** <i>6.01</i>	-.014*** <i>-4.16</i>	-.013*** <i>-4.049</i>	.00075 <i>.206</i>	.00225 <i>.664</i>	.00019 <i>.0495</i>
SCHOLDIST	-.016 <i>-.678</i>	-.056** <i>-2.25</i>	-.0526** <i>-2.09</i>	-.043* <i>-1.78</i>	.00167 <i>.073</i>	-.028 <i>-1.14</i>
HOSPDIST	-.030* <i>-1.89</i>	-.038** <i>-2.19</i>	-.035** <i>-2.035</i>	-.025 <i>-1.50</i>	.00128 <i>.082</i>	-.013 <i>-.75</i>
RNMOY84	.012** <i>.025</i>	.018*** <i>3.08</i>	.017*** <i>2.94</i>	.017*** <i>3.12</i>	.00995* <i>1.90</i>	.016*** <i>2.83</i>
VDP7582	.448*** <i>30.21</i>	.539*** <i>36.98</i>	.535*** <i>36.46</i>	.530*** <i>37.1</i>	.418*** <i>28.9</i>	.523*** <i>36.5</i>
RMSE	4.57	4.86	4.87	4.73	4.40	4.72
ADJ RSQ	.5818	.5293	.5319	.5332	.5881	.5361
I-Moran	.135	.126	.129	.0938	.073	.092

T in italics. *** significance at 0.01 two-tail test; ** at 0.05; and * at 0.10

Table 3 - Parameter Estimates of the Employment Change Equation

Variables	MODEL		Henry <i>et al.</i> (H)	Spatial	Carlino-Mills	Boarnet-SAR
	Carlino-Mills (CM)	Boarnet (B)		AutoRegressive (SAR)	SAR (CM-SAR)	(B-SAR)
Constant	-2.03 -1.46	-1.526 -1.01	-.649 -.423	-.2.09 -1.40	-1.73 -1.2	-1.306 -.857
DEMP2	-.074*** -4.73	-.034*** -8.84	-.034*** -8.87	-.033*** -8.68	-.074*** -4.77	-.033*** -8.72
DPOP82	.028*** 4.39				.0285*** 4.39	
VDP8290	.198*** 7.74				.195*** 7.44	
DWPOP82		.00007 .026	-.0033 -.63			-.0017 -.522
WVDPOP		.194*** 4.39	-.027 -.035			.154*** 2.81
WVDEMP				.295*** 3.81	.057 .743	.140 1.25
DWPOPH1			.00096** 2.08			
DWPOPH2			.0001 .04			
WVDPH1			-.0003 -.04			
WVDPH2			.01048*** 2.58			
DPBAS90C	.0123 .747	.00228 .132	-.016 -.91	.006 .35	.013 .76	.002 .14
D2PBAS90	-.00001 -.057	.00014 .56	.00025 .983	.0001 .41	-.0001 -.06	.00014 .574
DAGGLO	-.00053 -.1641	.00158 .4478	.00083 .234	-.001 -.308	-.00013 -.04	.00128 .3645
DIAUTOR	.005 1.33	.00428 1.056	.0009 .218	-.001 -.348	.005 1.38	.00352 .8618
WNOBLU82	.007 .483	-.0008 -.476	.006 .34	.007 .457	.004 .26	-.0079 -.475
WSKIWO82	.00317 .7829	.00403 .9514	.004 .917	.003 .729	.003 .79	.004 .9473
WSELFJ82	.00006 .0056	-.008 -.71	-.014 -1.17	-.006 -.52	-.0006 -.05	-.0102 -.857
WCHOM82	.03487 .6633	.043 .77	.063 1.13	.012 .227	.032 .625	.039 .6971
WTAXIN84	-.00573 -.26	-.00199 -.08	-.013 -.56	.020 .899	-.00897 -.41	.00024 .0099
VDE7582	-.243*** -16.2	-.305 -22.1	-.306*** -22.1	-.308*** -22.5	-.244*** -16.3	-.306*** -22.2
CAPPACC80	.0002 .149	.00025* 1.77	.00026* 1.84	.0003** 2.18	.00001 .1032	.00026* 1.82
RMSE	4.28	4.46	4.45	4.45	4.28	4.45
ADJ RSQ	.4008	.3748	.378	.3737	.4007	.3749
MORAN I	-.005	-.005	-.005	-.007	-.007	-.008

Diagnostics

In general, the results of estimating each set of equation by the two step instrumental variable regression are reasonable. The R^2 ranges from about 0.53 to 0.59 for the population equation and 0.37 to .40 for the employment equation. These values are comparable to related studies (Boarnet, 1994 ; Henry *et al.*, 1997). The Moran I statistics for the regression residuals are not large for the employment equations and the z values indicate that there is not a strong pattern of spatial correlation in the error term. For the population equation, the Moran I test, using the method suggested by Anselin and Kelejian (1997), indicated spatial autocorrelation between the errors in the population change equation. Using a WGLS correction for first range contiguity, we also estimated the population regression in equation (5) as $dP_i - \rho * dP_{i-1} = \mathbf{a} * (1 - \rho) + \mathbf{b} * [X_i - \rho X_{i-1}] + \mathbf{e}_i$, where dP_{i-1} is the dP value of the contiguous communes, X_{i-1} the independent variables (including dE) values of the contiguous communes and ρ is a constant between 0 and 1.⁴ After the correction, the Moran-I values are smaller than before and none significant at the 5 % level. However, there is little change in parameter values or standard errors.

IV. CONCLUSIONS

Our main findings are: **1.** Adding the spatial cross-regressive terms to the CM model (as in Boarnet) provides an important correction (by including spatial dependence) that results in empirical results consistent with the theory in CM and Boarnet; **2.** Tests for spread and backwash effects in the SAR, and the CM and Boarnet models with SAR terms added, reveal a general tendency for spread to rural areas across residential or labor market areas. However the introduction of SAR term in Boarnet model deletes the crossregressive effect on population change but not on employment change. We can conclude that a population spread effect exists but not a ‘people follow jobs’ effect on rural population change. Further, there is no employment spread effect but a ‘jobs follow people’ effect on rural employment change; and **3.** The Henry *et al.* modification to Boarnet adds insight

⁴ D. S. Fingleton, 1999, *Spatial Econometrics*.

into how urban growth affects proximate rural areas by “decomposing” the spatial cross-regressive term into “own”, urban core and urban fringe effects. The results suggest that the general tendency of spread masks both backwash and spread effects – depending on the pattern of urban growth between the core and fringe. In turn, this means that in some areas, urban growth may not ‘sprawl’ into the countryside but rather intensify development in suburban rings — forming edge cities.

The fit of the alternative models, as measured by root mean square error, varies little across each specification. In choosing a model structure, we conclude that one should consider the consistency of the parameter estimates with respect to theoretical expectations and the information content of the alternative models for understanding urban impacts on proximate rural areas. If *urban* to *rural* spread/backwash issues are of interest, the model must reflect the pattern of urban growth. Given the evidence is Rey and Boarnet (1998) and here, CM type feedback simultaneity, and cross-regressive simultaneity should be reflected in models that test for urban spread effects.

Appendix

This appendix elaborates on the tests for the significance of the urban growth effects on rural change. Inspection of the t-values for the parameters in equations (5) and (6) may be misleading since there are interaction variables. These t-values are from the second stage regressions and are derived from the asymptotic variance/covariance matrix. At this juncture, what is interesting is to look at several values for g_1 , g_2 , h_1 or h_2 - the urban growth rates - and test their effect on rural growth. For example, consider the mean g_1 , a low g_1 (the mean minus one standard deviation) and a high g_1 (the mean plus one standard deviation) for urban center employment growth rates. To test for the effect that a mean g_1 and g_2 has on rural change, the following steps are needed:

a. Recall equation (5):

$$dP = \mathbf{a}_0 - \mathbf{a}_1 P82 + [\mathbf{a}_2 + \mathbf{a}_3 g_1 + \mathbf{a}_4 g_2](I + W)E82 + [\mathbf{a}_5 + \mathbf{a}_6 g_1 + \mathbf{a}_7 g_2](I + W)dE + C g_1 + \mathbf{e}_1$$

where its seen that g_1 and g_2 may affect rural dP in two ways :

$$1. \text{ Via: } \mathbf{a}_2(I + W)E82 + \mathbf{a}_3 g_1(I + W)E82 + \mathbf{a}_4 g_2(I + W)E82$$

$$\text{which rewrites as: } (\mathbf{a}_2 + \mathbf{a}_3 g_1 + \mathbf{a}_4 g_2) [(I + W)E82]$$

$$2. \text{ Or via: } \mathbf{a}_5(I + W)dE + \mathbf{a}_6 g_1(I + W)dE + \mathbf{a}_7 g_2(I + W)dE$$

$$\text{which rewrites as: } (\mathbf{a}_5 + \mathbf{a}_6 g_1 + \mathbf{a}_7 g_2) [(I + W)dE]$$

2. b. The terms in parentheses require a joint t-test and thus a standard error that reflects covariance between both terms in the parentheses. In turn, this requires that the variance/covariance matrix is obtained from the regressions.

For example:

2. The joint variance for $(\mathbf{a}_2 + \mathbf{a}_3 g_1 + \mathbf{a}_4 g_2)$ is computed as:

$$3. \text{ } \underline{\text{var}(\mathbf{a}_2 + \mathbf{a}_3 g_1 + \mathbf{a}_4 g_2) = s_{22} + 2 g_1 s_{23} + g_1^2 s_{33} + 2 g_2 s_{24} + g_2^2 s_{44} + 2 g_1 g_2 s_{34}}$$

where s_{ij} are elements in the variance/covariance matrix. See Aiken and West (1991, p. 24-26).

c. To test for joint slope significance($\mathbf{a}_2 + \mathbf{a}_3 g_1 + \mathbf{a}_4 g_2$) form the usual t-test using the standard error in step c above. These t-tests can be made for each of the interaction variables and at alternative levels of the urban growth rates: g_1, g_2, h_1, h_2 . Results of this process are presented in Appendix Tables A1 and A2 using a range of growth rates for urban core and fringe population(employment) running from one standard deviation below the sample mean(low to the mean to one standard deviation above the mean(high)).

Table A1 - Effects of Urban Employment Growth on the Rural Population Change

		URBAN FRINGE GROWTH (g ₂)					
Urban Core	Urban Fringe	LOW Coeff.	T-value	MEAN Coeff.	T-value	HIGH Coeff.	T-value
a. $(\alpha_2 + \alpha_3 g_1 + \alpha_4 g_2)(I+W)E_{82}$							
URBAN CORE (g ₁)	LOW	-0.0122	(-1.487)	-0.0031	(-0.429)	0.0060	(0.747)
	MEAN	0.0005	(0.068)	0.0096	(1.478)	0.0187 ***	(2.789)
	HIGH	0.0133	(1.328)	0.0224 ***	(2.666)	0.0314 ***	(3.896)
b. $(\alpha_5 + \alpha_6 g_1 + \alpha_7 g_2)(I+W)dE$							
URBAN CORE (g ₁)	LOW	0.367 ***	(2.984)	0.309 ***	(2.778)	0.250 **	(1.960)
	MEAN	0.482 ***	(4.328)	0.424 ***	(4.869)	0.365 ***	(3.741)
	HIGH	0.597 ***	(4.474)	0.539 ***	(5.151)	0.480 ***	(4.608)

Note: *** indicates significance at 0.01; ** at 0.05; and * at 0.10

Table A2 - Effects of Urban Population Growth on the Rural Employment Change

		URBAN FRINGE GROWTH (h ₂)					
Urban Core	Urban Fringe	LOW Coeff.	T-value	MEAN Coeff.	T-value	HIGH Coeff.	T-value
a. $(\beta_2 + \beta_3 h_1 + \beta_4 h_2)(I+W)P_{82}$							
URBAN CORE (h ₁)	LOW	-0.0078 *	(-1.792)	-0.0077 **	(-2.073)	-0.0076 *	(-1.806)
	MEAN	-0.0030	(-0.672)	-0.0029	(-0.914)	-0.0028	(-0.921)
	HIGH	0.0018	(0.317)	0.0019	(0.453)	0.0020	(0.575)
b. $(\beta_5 + \beta_6 h_1 + \beta_7 h_2)(I+W)dP$							
URBAN CORE (h ₁)	LOW	0.011	(0.170)	0.092	(1.517)	0.173 **	(2.418)
	MEAN	0.010	(0.143)	0.090 *	(1.810)	0.171 ***	(3.398)
	HIGH	0.008	(0.091)	0.090	(1.351)	0.170 ***	(3.108)

Note: *** indicates significance at 0.01; ** at 0.05; and * at 0.10

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Figure 2. Rural Hinterland of LMAS in Six French Regions

