

Productivity growth and space: a multilevel Verdoorn model

GUSTAVO BRITTO

***Abstract:** The paper proposes and tests an alternative way to incorporate a spatial dimension to the Verdoorn Law using multilevel models, tailored to deal with nested data. This methodology allows extending the Verdoorn equation, incorporating elements from Urban Economics. The estimations used firm-level data from the Brazilian manufacturing industry from 1996 to 2002. The results showed that, after controlling for firms' characteristics, the spatial dimension is crucial to explain rates of labour productivity and output growth. Moreover, the estimations showed substantial knowledge spillovers and that urbanisation externalities are beneficial to firms' growth, whereas localisation externalities tend to be harmful.*

Key Words: productivity, Verdoorn, increasing returns, regional externalities, Brazil.

JEL Classification: O14, O18, R11, R30.

Acknowledgments: To ensure data confidentiality, the empirical work was carried at the Brazilian Bureau of Geography and Statistics (IBGE), in Rio de Janeiro. I am indebted to the technical and material support provided by IPEA/Diset and CAPES. I am also grateful for comments received during the 2008 Regional Science International World Conference. The usual disclaimers apply.

CAMBRIDGE CENTRE FOR ECONOMIC AND PUBLIC POLICY

CCEPP WP03-08

LAND ECONOMY DEPARTMENT

UNIVERSITY OF CAMBRIDGE

(JUNE, 2008)

1. Introduction

In the past decade, a renewed interest on the interaction of spatial factors and economic activities has been observed in the mainstream economic literature. In particular, new branches of research within neoclassical economics have spawned from the inclusion of a spatial perspective on partial and general equilibrium models. The most notable examples are the New Economic Geography and Urban Economics. Concepts such as urban externalities, centrifugal and centripetal forces are key for authors of urban economics as for instance Glaeser et al. (1992), Glaeser (1999), Glaeser and Maré (2001), Henderson et al. (1995) and Henderson (1999). Likewise, urban externalities, particularly Marshallian, are central in the development of New Economic Geography Models (NEG), as summarised by Fujita et al. (1999).

The models produced by NEG authors, in particular, have been able to emulate a number of different patterns of urban agglomerations using the combination of increasing returns to scale as centripetal forces and transport costs and centrifugal forces. The ability to endogenise increasing returns to scale in a regional perspective has been praised outside mainstream economics as a major breakthrough. However, the excessive level of abstraction of the models and the lack of practical applications also generated criticism and an increasing polarisation of the debate (Martin, 1999; Martin & Sunley, 1996).

Using a different approach, models inspired by the cumulative causation literature and by Verdoorn's Law have been improved to account for the influence of regional factors through the use of spatial econometrics. This approach was adopted using regional data, for instance, by Fingleton and McCombie (1998), Fingleton (2001a, 2001b, 2003a, 2005) and Angeriz et al. (2006), amongst others. For Fingleton, the use of spatial econometrics opens a line of research between the high levels of abstraction of new economic geography models, and economic geography.

In this paper, we propose and test an alternative way to incorporate a spatial dimension to the Verdoorn Law and to the study of productivity growth through the use of hierarchical (multilevel) models (Goldstein, 1995; Hox, 1995; Raudenbush & Bryk, 2002). Multilevel models were tailored to deal with the interaction between variables proper to individuals and those characterising groups. The ability to treat simultaneously data that

pertain to distinct analytical levels allows us to link various strands of the economic literature such as cumulative causation, economic geography and urban economics. The underlying assumption of a hierarchical Verdoorn model is that firms from the same group are more similar than firms pertaining to different groups due to factors related exclusively to the regions. The inclusion of regions as the higher level in a Verdoorn equation represents the introduction of space as a separate analytical dimension.

The paper is divided in four sections apart from this introduction. Section two briefly describes the criticism of economic geography regarding the treatment of space within and without mainstream economics. In addition, the most recent efforts to incorporate a regional perspective to the cumulative causation models are presented. Section three introduces hierarchical linear models as an alternative to extend Verdoorn's Law equation to incorporate a spatial dimension and establish links with other schools of thought, such Urban Economics. Section four describes the data and presents the model specifications and estimation results. Brief concluding remarks follow.

2. Space and economics

Concern with the importance of location to economic activities can be traced as far back as von Thünen's seminal work in 1826, Alfred Weber (1929) and August Lösch (1954). The concepts developed by the classical theories of localisation, such as agglomerative and disagglomerative forces, have undoubtedly influenced subsequent work. Another important source of inspiration for contemporary theories can be found in Marshall's (1890) *Principles of Economics*. The author described factors that drive spatial concentration of similar economic activities, later known as Marshallian externalities. More recently, Jacobs' (1969) paradigm changing *The Economy of Cities* introduced another type of externalities, this time linked with higher economic diversity and to the availability of specialised services. Concepts central to modern theories that study the forces driving agglomeration and regional growth. This is the case of Urban Economics and, more notably, New Economic Geography (NEG).

Together with the attention, these schools of thought have drawn criticism from within and without economics (Anas, 2001; Dymski, 1996; Neary, 2001). The most polarising source of criticism came from geography authors, such as Martin and Sunley (1996) and in Martin (1999), who have targeted the excessive level of abstraction of the

models, particularly from the NEG. The authors recognise that NEG theory, particularly Krugman's contribution, has merits for bringing an innovative perspective to mainstream economics. Specifically, in NEG's assessment, the analysis of economic growth and trade patterns is not dissociable from the process of regional development, in which increasing returns to scale have a crucial function. In this sense, the models go beyond the traditional analysis of comparative advantages by incorporating elements from other branches of economics.

However, for Martin (1999), a full reconciliation between the new economic geography and economic geography proper may be impossible, due to their distinct methodological approaches. A fundamental theoretical impasse originates from the departing point of each school of thought. NEG models assume uniformity of spatial distribution of economic activities to isolate the forces driving agglomerations. The necessity to depart from an abstract economic landscape in order to enable the all-important formalisation of models imposes, according to Martin, a straitjacket on the NEG, forcing social, cultural and institutional factors out of the models together with all the dynamic characteristics. Therefore, even the path dependence or cumulative processes that NEG models are able to reproduce, claimed as a definitive advance over their predecessors, depend largely on initial conditions set prior to the simulations.

Another consequence of the mathematical approach, and another important source of contention that makes conciliation unlikely, is the absence of what Martin calls 'real places' from NEG models. In the simulations, 'space' is unidimensional and cities and regions are distributed along a line, concentric circles or points. Real cities, regions and economic activities, so dear to Marshall and Kaldor for instance, are completely absent. Martin's critical assessment of the importance, or the lack thereof, given to geography in goes beyond his quarrel with NEG's methodological approach. To him, heterodox economists have, more than their orthodox counterparts, largely ignored space and location in important areas such as evolutionary, institutional, post-Keynesian and Kaldorian economics.

This across the board recrimination of economics seems to originate from the perception that economic analysis is polarised between micro and macro levels. The consequence is that the traditional economic analysis fails to go beyond the recognising that economic development is uneven across regions to acknowledge that economic process very much depend on varying spatial conditions.

At the time of the publication of Martin’s critical reflections on the ‘new geographical turn in economics’, however, the explicit concern with spatial factors had already made its way into post-Keynesian and Kaldorian research. The most important breakthrough was the use of advances in spatial econometrics, following the work of Anselin (1988), in the estimation of Verdoorn’s Law. This approach was initially used by Fingleton and McCombie (1998) and Pons-Novell and Viladecans-Marsal (1999) to estimate the Verdoorn coefficient for E.U. regions. Fingleton and McCombie introduced spatially lagged productivity growth terms into their equation.

Fingleton (2000) saw in the application of spatial econometrics to the estimation of Verdoorn’s Law an opportunity for bridging the gap between the two lines, which for Martin are irreconcilable. For Fingleton, the literature related to increasing returns to scale and cumulative causation models was a major and still unexplored point of contact between NEG and economic geography proper. For the author, the Verdoorn Law is still an important alternative to neoclassical growth models for it represents increasing returns as the heart of cumulative causation models. The law expresses the relationship between productivity and output growth, is, in its simple form, given by:

$$p_i = p_a + \lambda q_i \quad (1)$$

or

$$e_i = \tau_a + \beta q_i \quad (2)$$

where $\tau_a = -p_a$ and $\beta = (1-\lambda)$. p_i , q_i and e_i are the rate of growth of productivity, the rate of growth of total output and the rate of growth of employment in the country i respectively. The estimation of equations (1) and (2) has been extensively pursued and produces a coefficient of around one-half (McCombie et al., 2002). For Kaldor, an estimated coefficient (β) that is significantly less than one is a sufficient condition for the presence of both static and dynamic returns to scale, given that constant returns to scale imply equiproportional growth of output and productivity (Kaldor, 1975).

Fingleton’s proposed “third way” consists in building a spatial model that has Verdoorn’s Law at its heart, but unlike the previous estimations that used the same technique, the author’s alternative builds a more detailed structural model of spatial externalities, making explicit the mechanism of spatial productivity spillovers (Fingleton, 2001b, 2003b).

3. Multilevel Verdoorn Law

These works show that a significant effort to include a regional perspective in studies of productivity change have been done in recent years. In the remainder of the paper we propose the use of hierarchical linear models as alternative to extend the Kaldorian literature to incorporate a regional perspective. In addition, by modelling two distinct levels of analysis, this methodology allow us modify the tradition Verdoorn equation to encompass elements from other areas such as urban and evolutionary economics. In this way, the application also aims to provide a step forward to bridge the gap between the micro and more aggregated regional analysis.

Hierarchical linear models are statistical tools developed specifically to treat data or experiments that have a clustered or nested structure.¹ The statistical consequences of the lack of treatment of nested data are twofold. First, in many cases aggregation bias may arise, given that some variables can have distinct interpretations in each level of analysis. Secondly, traditional techniques can generate incorrect standard errors due to the assumption of inappropriate error structures. OLS models assume that each observation is independent from another. This is not the case when data are clustered, and failure to account for this characteristic can lead to misestimated results (Raudenbush, 1988; Steenbergen & Jones, 2002).

For Raudenbush (1988), the problems that have motivated the development of hierarchical models and the advantages of these techniques that have inspired various applications can be divided in two groups. First, the statistical advantages of a more suitable method motivate those interested mainly in micro-parameters. In this case, the research problem focuses on a particular individual of level-1 (student, child, patient, organization). The second group regards applications whose attention focuses on macro-parameters. This is the case of studies that aim to explain why some groups have smaller regression slopes than others, or which group variables can explain the growth of individuals, etc.

Both types of problems have motivated a large number of applications o hierarchical models in several fields of research. Amongst them, the most common field is still education,

¹ Hierarchical models are also referred to as multilevel models, linear models, mixed-effect and random-effects models and covariance component models. In econometrics, the most common term is random-coefficient regression models (Hox, 2002).

from which the models were developed. Applications include repeated measures, logit and probit, causality studies, latent variables models, meta-analysis, discrete response models, multiple membership models, factor analysis, amongst others (Moerbeek et al., 2003; Pickett & Pearl, 2001; Raudenbush & Kasim, 1998; Sampson et al., 1997).

In economics specifically, multilevel applications are still rather scarce and are usually concentrated in very few areas or research. There are however, a few exceptions. Cardoso (1999, 2000) are examples of applications using firm-level data. The author uses multilevel models to investigate labour market inequality. Steenbergen and Jones (2002) uses more aggregated data to fit a multilevel model to analyse levels of public support to the European Union.

Apart from the better statistical properties of the estimators, the application of hierarchical modelling to the study of productivity change and the Verdoorn Law has two main advantages. First, the existence of residual variance at the group level allows us to explore the influence of regional characteristics on the estimated coefficients by introducing new variables measured at the group level. Secondly, the estimated models can be extended to include interaction terms between the individual and group levels. These cross-level interactions are the tool that allows us to bridge the cumulative causation literature at the micro level to the economic geography literature, assessing the existence and the relevance of urban factors as a separate dimension.

A two-level hierarchical model with intercepts and sloped as outcomes can be described by the following equations:

$$Y_{ij} = \beta_{0j} + \beta_{1j}(X_{ij}) + r_{ij} . \quad (3)$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01}(Z_j) + u_{0j}, \quad (4)$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}(Z_j) + u_{1j}. \quad (5)$$

The combined hierarchical model is now given by

$$Y_{ij} = \gamma_{00} + \gamma_{10}(X_{ij}) + \gamma_{01}Z_j + \gamma_{11}Z_jX_{ij} + u_{1j}(X_{ij}) + u_{0j} + r_{ij}. \quad (6)$$

where Y_{ij} denotes the outcome variable for each individual i in group j . X_{ij} is a vector of individual-level variables, (Z_j) a vector of group-level variables, r_{ij} is the error of the level-1 and (u_{0j}) the level-2 error term. The random terms of the equation (6) are the key element of

any hierarchical model. Together with an intra-class correlation coefficient different than zero, this model renders OLS and GLS procedures inapplicable.

From Verdoorn Law's perspective, and following the notation used above, the outcome variable Y_{ij} denotes the rate of productivity growth for each firm i in region j . This outcome is a function of a set of m individual characteristics indicated by X_{mij} , which includes the rate of each firm's output growth. At the group level Z_{qj} represents variables measured at the q cities.

If Y_{ij} is the rate of productivity growth of each firm, city level variables can be added to assess two different types of issues. First it is possible to assess how regional factors affect the slope of the model (β_{0j}), which in our case represents the autonomous rate of productivity growth. Secondly, regional variables can be added to analyse how the impact of firm-level variables (X_{qij}), such as the rate of growth of output, for instance, varies across cities. The inclusion of randomly varying slopes and interaction effects to the analysis adds an alternative regional perspective to the study of the Verdoorn Law.

4. Data and Results

Data

The dataset used in the estimations was built using firm-level data was drawn from the Industrial Annual Survey (PIA) from 1996 and 2002. The data on sectoral employment was extracted from Annual Registry of Social Information (RAIS) and the population by city from the year 2000 Census from the Brazilian Institute of Geography and Statistics (IBGE). The final sample includes all firms present in the survey in 1996 and in 2002. In total, 12.381 firms from 1.538 cities are present in the sample. At the firm (individual level) the dependent variables used are the rate of growth of labour productivity, output and of employment, measured in total number of employees.

Variables

Level 1: firm level

Output growth (dy): exponential growth rate from 1996 to 2002. This variable was also calculated as the deviation between each firm's rate of output growth and the sample mean to allow meaningful interactions between levels.

Schooling (lschool): average number of schooling years of each firm's employees. This variable is used as a proxy of the level of qualification. It is assumed that the higher the

level of education of a firm's workforce, the higher the workers' efficiency and capacity to absorb new work techniques and new technologies in general. Thus, this variable is expected to have a positive impact on the rate of productivity growth.

Productivity gap (lgap): ratio, in the base year 1996, between the output per worker from each firm and the output per worker of the leading firm of each sector (three digits). This variable incorporates a catch-up element into the equation. The assumption is that the higher the gap between a particular firm and the sector's leader, the greater the potential for the lagging firm to absorb and improve the technologies adopted by the leading company. In this sense, the higher the gap, the higher the potential for productivity growth.

Level 2: cities

Total Population (lpop): natural logarithmic of the total population of each city in the year 2000. This variable is a proxy for the urban scale and is expected to capture the impact of the urban scale and economies of agglomeration on the rate of growth of productivity.

Regions: dummy variables for each one of the country's administrative regions. São Paulo is the base and dummies were created for the remainder of the Southeast (*se*) region, South(*s*), centre-West (*cw*), North (*n*) and Northeast (*ne*).

Municipal schooling (lschoolc): average number of years of schooling of a particular city. This variable was calculated using all the firms present in each city.

Industrial scale (lind): the ratio between each city's share of industrial employment in total employment and the national share of industrial employment in total employment. This variable measures the relative concentration of industrial activities in each city in comparison with the national ratio. It is a *proxy* for externalities stemming from industrial agglomeration (Marshallian).

Services density (lserv): each city's share of employment of modern services sector in total employment. This variable measures the relative importance of the modern services, which is intimately related to the diversity of local economies.² Hence, this variable is expected to capture the impact of agglomeration economies typically Jacobian.

² Chen (2002) applies the same rationale to capture urban externalities linked to urban diversity. However, the paper calculates a Hirschman-Herfindahl index, which also takes the number of activities in each city. Our argument here, for taking the Central Place Theory into consideration, assumes that a higher number of available services in general are forcefully related to a higher share of modern services.

Regressions' results

To make the most of the benefits of hierarchical models, three models were estimated. The first model's primary aim is to test the relevance of the technique to estimate the Verdoorn Law and to evaluate the significance of the regional level. To this effect, human capital and gap variables were introduced at the first level and variables to capture different regions and different urban scales were added at the second level. The second model tests the ability of hierarchical models to capture different meanings of the same variable in distinct levels of aggregation. In this case, the variable schooling was used at the second level as an indication of knowledge spillovers. Both models have randomly varying intercepts. The third model allows slopes to vary. Variables to test for the impact of externalities were introduced at the second level.

Model 1: Catch-up, Human Capital and Space

The first model to be estimated includes two extensions in comparison with the standard Verdoorn equation. At the lowest level, the model is extended to include two new variables that can affect the rate of productivity growth of the firm. The first variable is schooling, measured as the average number of schooling years of each firm's employees. The inclusion of this variable is in line with human capital theory that indicates individuals' earning levels are correlated with the number of years spent acquiring education or training (Becker, 1962; Mincer, 1974). Higher levels of education reflect higher labour productivity and at the firm level can be associated with faster rates of productivity growth.

The second variable was added to test the relevance of the catching-up hypothesis, proposed at the country level by Abramovitz (1986). The basic hypothesis is that innovation is introduced by the leading firms of each sector and is subsequently diffused through the economy by means of technological imitation by the follower firms (Schumpeter, 1939).³ Thus, in the Verdoorn equation, the introduction of a gap variable will test if faster rates of

³ This hypothesis has been widely tested from an aggregate point of view. See Dosi (1988), Dosi et al. (1990) and Verspagen (1994).

productivity growth are associated with the productivity gap between each firm and the sector's leader in the beginning of the period.

At the regional level, variables were added to test the importance of the spatial dimension over the rate of productivity growth. Dummy variables for states were included to test whether regional factors influenced the mean rate of productivity growth in each city. In addition, the log of each city's population was added as a proxy of urban scale, similarly to Henderson (1986). In our case, however, the proxy has a dynamic perspective, given that it expected to measure the impact of urban scale on productivity growth, not on productivity levels.

At the group level, variables were introduced in an intercept-as-outcomes model. It is important to keep in mind that significant coefficients for the dummy variables mean that a firm's location has an impact on its rate of productivity growth after controlling for individual factors such as output growth, schooling and productivity gap, as well as for the scale of the urban centre in which the firm is located.

The estimation of the extended multilevel Verdoorn, which includes human capital and catching-up variables, will follow four stages, from a basic ANOVA, to the Intercept as Outcome model.⁴ The full equation with a random varying intercept has the form:

$$p_{ij} = \gamma_{00} + \gamma_{10}(dq_{ij}) + \gamma_{20}(lgap_{ij}) + \gamma_{30}(lschool_{ij}) + \gamma_{01} lpop_j + \gamma_{0n} regions + u_{0j} + r_{ij},$$

where p_{ij} is the rate of productivity growth of firm i in group j , dq_{ij} is the rate of output growth, $lgap_{ij}$ is each firm's productivity gap, $lschool_{ij}$ is the average number of schooling years, $lpop_j$ is the log of the population of group j , u_{0j} is the residual error of level 2 and r_{ij} is the error of level 1. The equation also includes one dummy for each administrative region of the country, except São Paulo (base dummy).

Model 1.1: Variance decomposition (ANOVA)

$$\text{Level 1: } p_{ij} = \beta_{0j} + r_{ij}$$

$$\text{Level 2: } \beta_{0j} = \gamma_{00} + u_{0j}$$

Model 1.2: Classic Verdoorn

⁴ This step-by-step approach has two main advantages. First, it allows us to evaluate the relevance of the hierarchical model to Verdoorn's Law equation by comparing changes in the variance components of each level at each stage. Secondly, it makes the distinction between the fixed and the random part of the model clearer.

$$\text{Level 1: } p_{ij} = \beta_{0j} + \beta_{1j}(dq_{ij}) + r_{ij}$$

$$\text{Level 2: } \beta_{0j} = \gamma_{00} + u_{0j}; \beta_{1j} = \gamma_{10}$$

Model 1.3: Extended Verdoorn (human capital and catch-up)

$$p_{ij} = \beta_{0j} + \beta_{1j}(dq_{ij}) + \beta_{2j}(lgap_j) + \beta_{3j}(lschool_j) + r_{ij}$$

$$\text{Level 1: } \beta_{0j} = \gamma_{00} + u_{0j}$$

$$\text{Level 2: } \beta_{1j} = \gamma_{10}; \beta_{2j} = \gamma_{20}; \beta_{3j} = \gamma_{30}$$

Model 1.4: Extended Multilevel Verdoorn

$$p_{ij} = \beta_{0j} + \beta_{1j}(dq_{ij}) + \beta_{2j}(lgap_j) + \beta_{3j}(lschool_j) + r_{ij}$$

$$\text{Level 1: } \beta_{0j} = \gamma_{00} + \gamma_{01}(lpop_j) + \gamma_{0n}(\text{regional dummies}) + u_{0j}$$

$$\text{Level 2: } \beta_{1j} = \gamma_{10}; \beta_{2j} = \gamma_{20}; \beta_{3j} = \gamma_{30}$$

To avoid the possibility of spurious correlation between p_{ij} and q_{ij} , Model 1.4b replaces the rate of productivity growth, which is replaced by the rate of employment growth (e_{ij}). The estimated equation, is then:

$$e_{ij} = \beta_{0j} + \beta_{1j}(dq_{ij}) + \beta_{2j}(lgap_j) + \beta_{3j}(lschool_j) + r_{ij}$$

It is important to note that only the intercept coefficient β_{0j} is allowed to vary randomly in models 1.1 to 1.4. For the time being, we assume that the impact of the remaining level-1 variables $lschool$ and $lgap$ is homogenous across cities.

The regressions' results of each model (step) are summarised in Table 1. In the first model, the weighted least squares' mean rate of productivity growth is 0.051. The restricted maximum likelihood estimated variance components are 0.433 at the firm level and 0.037 at the city (group) level, both being statistically significant at 0.1%. From these values it is possible to calculate the intra-class correlation coefficient. This indicator measures the proportion of city-level variance of the rate of productivity growth between firms in the total variance. For this basic ANOVA model, the ICC is 8.6%. This value is well within the range of ICC's found in education studies, although closer to the lower end.⁵ More importantly, an estimated ICC of over 8% is sufficient to bias standard errors and to justify justify the

⁵ As discussed above, the debate on the size of the ICC coefficient is far from consensual. In our case specifically, the estimated ICC is satisfactory, even though there is no benchmark for studies of productivity change.

introduction of group-level variables, which will allow us to test the relevance of regional characteristics.

Table 1: Multilevel Verdoorn

Variable	Model 1.1	Model 1.2	Model 1.3	Model 1.4	Model 1.4b
Intercept	0.051*	-0.012**	-0.197*	-0.247*	0.248*
<i>lpop</i>				0.012*	-0.012*
<i>Southeast</i> ¹				-0.063*	0.063*
<i>Centre-west</i>				-0.038	0.038
<i>North</i>				-0.140*	0.140*
<i>Northeast</i>				-0.087*	0.087*
<i>South</i>				-0.070*	0.070*
dq		0.555*	0.551*	0.552*	0.448*
lgap			-0.052*	-0.054*	0.054*
lschool			0.059*	0.040**	-0.040**
Variance					
Region	0.037*	0.010*	0.010*	0.009*	0.009*
Individual	0.433*	0.225*	0.223*	0.222*	0.222*
%	8.55%	4.44%	4.48%	4.05%	4.05%
Deviance	25276.10	17006.57	16912.35	16912.08	16912.08

Legend: * significant at 0.01; ** significant at 0.05

Notes: ¹ The Southeast excludes the state of São Paulo.

The relevant explanatory variables are introduced from Model 1.2 onwards. It is important to note that all the estimated coefficients are highly significant. In Model 1.2, the rate of growth of firms' output is included as a level 1 predictor. In practice, each city's mean rate of growth of productivity is being predicted by the rate of growth of output of each city. In this model, u_{0j} is now the residual and its variance is the conditional variance after controlling for firms' output growth rates.

As expected, variances from both level 1 and 2 were reduced after the introduction of the first level 1 variable, showing that the rate of output growth explains part of both individual and regional variability. The residual city-level variance is now 0.01 and still highly significant, meaning that even controlling by their output growth rate, cities still vary significantly in their average rate of growth of productivity. The firm-level variance fell nearly 47%, an indication of goodness of fit of the model with the inclusion of the rate of growth of the output. At the group level, the introduction of the rate of growth of output in the model explained over 70% of the variance of the group level. This is not a completely unexpected result, given that the rate of output growth of a specific firm is connected to the

rate of growth of the region in which the firm is located. As can be seen in Model 1.2 in Table 1, the estimated Verdoorn coefficient was 0.56.

Model 1.3 shows an extended version of the Verdoorn equation to account for catching-up (productivity gap) and human capital (schooling) factors. Once more, all estimated coefficients are highly significant and have the expected signals. The catching-up coefficient (*lgap*) was -0.052 and has the correct sign, given that the productivity gap was measured by the ratio between each firm's productivity and the productivity of its sector's leader. Hence, two similar firms in terms of rate output growth and workforce qualification are taken under consideration, the one with a gap 50% smaller in relation to the sector's leader could achieve a rate of productivity growth almost 5% slower than the other one from 1996 to 2002.

It is important to note, however, that in spite of its significance, the size of the catching-up coefficient shows that the process of convergence associated with the productivity gap was rather slow for the period under consideration. An impact of a similar magnitude is found for the schooling variable, whose estimated coefficient was 0.06. Finally, another important outcome of Model 1.3 is that even after controlling for firm-level characteristics, the city-level variance still accounts for a sizable portion of the individual level variance.

Models 1.4 and 1.4b proceed to include regional dummies to account for the impact of location on the rate of productivity growth. In addition, to isolate the effect of location even further, the natural logarithmic of the population of city in which each firm is located was included as an explanatory variable of the intercept equation. This variable works as a proxy for urban scale. As expected, the results show that the estimated coefficients from models 1.4 and 1.4b are symmetric. In addition, the estimated coefficients for the individual-level variables remained virtually unchanged in comparison with Model 1.3. The coefficients of the slope equation show a positive coefficient for *lpop*, indicating that, after controlling for individual-level variables and for location, positive externalities are associated with larger cities. This result does not offer support, at least at the micro level, for regional convergence between cities in regard to productivity change. If there are negative externalities associated with larger urban centres, there is no evidence that they outweigh the existing locational advantages, causing a negative impact on the rate of productivity growth.

The most crucial characteristic that surfaces from Table 1 does not come from any variable taken in isolation, but from the combination of all estimated coefficients. Significant

coefficients of the dummy variables mean that firms' location is an important determinant of productivity growth after controlling for individual attributes, represented by the productivity gap, schooling and rate of output growth variables, as well as the impact of urban scale, represented by each city's size. This is to say that if two hypothetical firms that are otherwise similar are taken under consideration, i.e., had the same productivity gap in relation to its sector leader, employed workers with the same average level of education, experienced the same rate of output growth in the period and were located in cities of similar size, the one located in the state of São Paulo will have enjoyed a faster rate of productivity growth.

These results allow us to argue that space represents a fundamental dimension to productive growth independently of each firm's individual characteristics and regardless of urban scale. This is an indication that the location of each firm is determinant for economic growth from a dynamic perspective, given that there is a specific environment associated with each city (and region) that allow firms to attain distinct levels of productivity growth.

In the next two models will test other two factors that can contribute to understand these regional disparities.

Model 2: Spatial Knowledge Spillovers

One of the advantages of hierarchical models is the ability to account for variables that have a distinct economic meaning depending on the level of aggregation. This is certainly the case of schooling when measured at the firm and at the city level. To test this particular characteristic, another slope-as-outcome model was estimated. In this case, a variable to measure the average level of schooling of each city was added as an explanatory variable of the slope coefficient, together with a dummy variable for the state of São Paulo. To allow a meaningful interpretation of the estimated level-2 coefficients, the schooling variable was centred on the grand mean.

The slope coefficients of the level-1 variables are fixed. The steps taken in the estimation of Models 2.1 to 2.3 are the same as models 1.1 to 1.3. The new model including the new variables is given by:

$$p_{ij} = \gamma_{00} + \gamma_{01}dummy_sp + \gamma_{02}lschoolc_j + \gamma_{0n}regions + \gamma_{20}(lgap_{ij}) + \gamma_{30}(lschool_{ij}) + \gamma_{10}(dq_{ij}) + u_{0j} + r_{ij}$$

Model 2.4: Spatial Knowledge Spillovers

Level 1:
$$p_{ij} = \beta_{0j} + \beta_{1j}(dq_{ij}) + \beta_{2j}(lgap_j) + \beta_{3j}(lschool_j) + r_{ij}$$

$$\text{Level 2: } \beta_{0j} = \gamma_{00} + \gamma_{01} \text{dummy_sp} + \gamma_{02} \text{lschoolc}_j + u_{0j}; \beta_{1j} = \gamma_{10}; \beta_{2j} = \gamma_{20}; \beta_{3j} = \gamma_{30}$$

Model 2.4b, like model 1.4b, replaces the rate of productivity growth by that of employment. Table 2 shows the results of the new model. As can be seen, at the firm level, the estimated coefficient for schooling was reduced by a factor of almost 39%, but remained significant. One possible explanation for this reduction is the coincidence between firms' high level of education amongst their workforce and cities' higher-than-average levels of schooling. The estimated coefficients of the remaining variables remained virtually unchanged. At the group level, the estimated coefficient for the average level of schooling of the city where firms are located showed a significant and large impact over the intercept of the extended Verdoorn function.

Table 2: spatial knowledge spillovers

Variable	Model 2.1	Model 2.2	Model 2.3	Model 2.4	Model 2.4b
Intercept	0.051*	-0.012**	-0.197*	-0.184*	0.184*
<i>lschoolc</i>				0.113*	-0.113*
<i>São Paulo</i>				0.064*	-0.064*
<i>dq</i>		0.555*	0.551*	0.552*	0.448*
<i>lgap</i>			-0.052*	-0.054*	0.054*
lschool			0.059*	0.034**	-0.034**
Variance					
Region	0.037*	0.010*	0.010*	0.009*	0.009*
Individual	0.433*	0.225*	0.223*	0.222*	0.222*
%	8.55%	4.44%			
Deviance	25276.10	17006.57	16912.35	16886.39	16886.39

Legend: * significant at 0.01; ** significant at 0.05

These results suggest that there is a significant impact caused by knowledge spillovers in regions with higher levels of education. The level of schooling of a firm's employees has a positive impact on its rate of productivity growth, regardless of where the firm is located. However, if two firms similar in terms of output growth and productivity gap, whose workforces have the same average level of schooling, the firm located in a city with a higher average level of education will experience a faster rate of productivity growth. As can be seen in Model 2.4b in Table 2, a given firm's autonomous rate of productivity growth is 11% higher than a similar firm located in a city whose schooling level is 50% lower, all other individual attributes being similar.

This is to say that firms located in cities that have higher average levels of schooling can reach a higher path of productivity growth independently of each firm's own level of schooling. The effect of knowledge spillovers is similar to the 'frog pond' theory, used in biology and adapted to education studies to evaluate whether students with a high IQ tend to under-perform if the average IQ in the class is low (Hox, 2002). In the case of schooling variable, the results showed that higher level of education amongst employees has a significant positive impact on the autonomous rate of productivity growth, -0.034 in Model 2.4b, or roughly 2/3 of the importance of the productivity gap variable. This result is in line with human capital theories, which reinforces the importance of the investment on education at the individual level. However, the addition of the schooling variable as a determinant of the intercept term of the equation shows that the importance of education is even higher if firms are located in a city where the average level of schooling is above than the national average. In fact, the estimated coefficient for the group level is more than three times higher than the coefficient of the individual level. This means that a firm can reach an even higher path of productivity growth if it is immersed in an environment where the average level of education is also high.

It is also important to note that these results add a regional perspective to the human capital theory, given that it stresses the fundamental role played by the level of regional development. This is to say that the environment in which firms are embedded is as (or more) important as firms' own attributes from the perspective of educational development.

Model 3: Urban externalities: services density and industrial concentration

Having tested the importance of regional factors to firms' rate of productivity growth with intercepts-as-outcomes models, the third model proceeds to allow the slope to vary at the group level. In this case the regressions aim to test two important factors. First, if agglomeration economies allow firms located in some cities to reach a higher path of productivity growth (higher intercept). Secondly, it is possible to test if agglomeration economies are associated with a stronger connection between the rate of growth of productivity and that of output (Verdoorn coefficient).

Two variables are included in the group level. The first is the share of the services sector on the total employment of each city. This variable is also an indication for urban scale, but, more importantly, it is a proxy for the urban diversity. In this sense, the variable

should capture Jacobian agglomeration economies. The second variable is the relative share of industrial employment of each city in relation to the national share. This variable is meant to capture indirectly Marshallian agglomeration economies. Urban economists have addressed this matter extensively. Following the results obtained by Glaeser et al. (1992), the variable measuring urban diversity is expected to have a stronger impact on the rate of productivity growth.

Hence, the next regressions are carried out for a modified model that includes that proxy urban externalities stemming from the availability of services and the relative concentration of manufacturing activities in each city. The first steps of the estimation remain as the previous two models. Hence, the estimated model is a slope and intercept-as-outcomes, given by the equation:

$$p_{ij} = \gamma_{00} + \gamma_{01} \ln serv_j + \gamma_{02} \ln ind_j + \gamma_{0n} regions + \gamma_{20}(\ln gap_{ij}) + \gamma_{30}(\ln school_{ij}) + \gamma_{10}(dq_{ij}) + \gamma_{11}(q_{ij})(\ln serv_j) + \gamma_{11}(dq_{ij})(\ln ind_j) + u_{0j} + (q_{ij})u_{1j} + r_{ij} ,$$

where $\ln serv_j$ and $\ln ind_j$ are the natural logarithmic of the services density and industrial concentration variables, respectively. All the other variables remain unchanged. The impact of level 1 variables is assumed to be constant across regions.

Model 3.4: Urban externalities

$$\text{Level 1: } p_{ij} = \beta_{0j} + \beta_{1j}(dq_{ij}) + \beta_{2j}(\ln gap_j) + \beta_{3j}(\ln school_j) + r_{ij}$$

$$\text{Level 2: } \beta_{0j} = \gamma_{00} + \gamma_{01} \ln serv_j + \gamma_{02} \ln ind_j + \gamma_{0n} regions + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} \ln serv_j + \gamma_{12} \ln ind_j + u_{1j}; \beta_{2j} = \gamma_{20}; \beta_{3j} = \gamma_{30}$$

The results of the new set of estimations are summarised in Table 3 below. Model 3.4 adds new explanatory variables to the slope and intercept and Model 3.4b uses employment growth as the dependent variable. The estimated coefficients for the region dummies remain virtually unchanged in comparison with Table 1, with the exception that the coefficient for the centre-west regions is now significant, at 10%. The coefficients for the gap and schooling variables changed slightly, but their signs and significance remain unchanged.

The Verdoorn coefficient is slightly higher than the previous models. However, in this model the variables $\ln serv$ and $\ln ind$ were centred to allow for a meaningful economic

interpretation of the coefficients. In Model 3.4, the estimated Verdoorn coefficient refers to that from cities whose share of the services sector in total employment and relative share of the industrial sector equals the sample's average.

Table 3: urban externalities

Variable	Model 3.1	Model 3.2	Model 3.3	Model 3.4	Model 3.4b
Intercept	0.051*	-0.012**	-0.197*	-0.117*	0.117*
<i>Southeast</i> ¹				-0.064*	0.064*
<i>Centre-west</i>				-0.136*	0.136*
<i>North</i>				-0.054***	0.054***
<i>Northeast</i>				-0.088*	0.088*
<i>South</i>				-0.046*	0.046*
<i>lserv</i>				0.186*	-0.186*
<i>lind</i>				-0.013**	0.013**
dq		0.555*	0.551*	0.579*	0.421*
<i>lserv</i>				0.129*	-0.129*
<i>lind</i>				-0.026*	0.026*
lgap			-0.052*	-0.050*	0.050*
lschool			0.059*	0.038**	0.038**
Variance					
Region	0.037*	0.010*	0.010*	0.008*	0.008*
Individual	0.433*	0.225*	0.223*	0.213*	0.213*
%	8.55%	4.44%			
Deviance	25276.10	17006.57	16912.35	16766.15	16766.15

Legend: * significant at 0.01; ** significant at 0.05; *** significant at 0.10

Notes: ¹The southeast excludes the state of São Paulo.

The estimated coefficients for the newly introduced variables are quite remarkable. The coefficient for the services density is positive and high for both the intercept and the slope. The higher the services' sector share in a given city, the higher the rate of growth of the autonomous productivity and the stronger the connection between productivity growth and output growth. This result reinforces the notion that urbanization economies, or *Jacobian* externalities, have a strong impact on the growth dynamic of firms and, consequently, on regional growth. These economies are associated with positive externalities derived from the urban scale and with the availability of services in a given region. This finding is in line with the results obtained by Glaeser et al. (1992), in which productivity growth was proxied by the rate of growth of wages.

Opposite results were found for the industrial concentration variable. Although on a smaller scale, the estimated coefficients show that the higher the concentration of industrial activities in relation to the national average, the lower the rate of productivity growth and the

weaker the connection between productivity and output growth. These results suggest that there are negative externalities associated with higher concentration of industrial activities.

Finally, the results from Table 3 suggest that the best possible scenario, in terms of growth dynamic, would be found by a firm located in a large city in the state of São Paulo, characterised by a large services sector and a below-than-average share of the industrial sector in the local economy.

5. Final remarks

The regressions confirmed once more the Verdoorn Law thus providing further evidence that increasing returns to scale are pervasive in the manufacturing industry. The size of the estimated coefficients is remarkably similar to those presented in other studies. More importantly however, the regressions showed that space matters to productivity growth. The extended Verdoorn model showed that, after controlling for firms' characteristics, there are regional factors that impact decisively their rate of productivity growth. This is to say that if we analyse similar firms that are located in cities that are equivalent in terms of size, those located in the South and Southeast of the country will have experienced faster productivity growth. The second model produced further evidence of the importance of education for productivity change. After controlling for human capital at the firm level, the results showed that firms similar experienced faster productivity growth in cities where the average level of schooling was higher. This result represents an important point of contact with Urban Economics theory. The existence of knowledge spillovers can be an indicator that there are significant externalities related to the labour market in urban agglomerations. Firms located in larger cities may be benefiting from factors such as a better pool of labour or from the facilitation of face-to-face interaction.

Finally, the third model showed that, from a dynamic point of view, urbanisation economies, not localisation economies, impact positively firms' rate of productivity growth. Urbanisation economies were associated with higher levels of productivity growth *and* with a stronger connection between productivity and output growth. Localisation economies, proxied by the relative share of the industrial sectors, proved to be slightly harmful for both. In conclusion, hierarchical linear models offer an alternative way to build on the existing literature on cumulative growth and Verdoorn's Law.

References

- Abramovitz, M. (1986). Catching Up, Forging Ahead, and Falling Behind. *The Journal of Economic History*, 46(2), 385-406.
- Anas, A. (2001). Book review: The spatial economy. *Regional Science and Urban Economics*, 31, 601-615.
- Angeriz, A., McCombie, J. S. L., & Roberts, M. (2006). Some New Estimates of Returns to Scale for EU Regional Manufacturing, 1986-2002. *CCEPP Working Paper, Land Economy Department, WP03-06*.
- Anselin, L. (1988). *Spatial econometrics: Methods and Models*. Dordrecht: Kluwer.
- Becker, G. S. (1962). Investment in Human Capital: A Theoretical Analysis. *The Journal of Political Economy*, 70(5), 9-49.
- Cardoso, A. R. (1999). Firms' Wage Policies and the Rise in Labor Market Inequality: The Case of Portugal. *Industrial and Labor Relations Review*, 53(1), 87-102.
- Cardoso, A. R. (2000). Wage differentials across firms: an application of multilevel modelling. *Journal of Applied Econometrics*, 15(4), 343-354.
- David, P. A. (1999). Krugman's economic geography of development: NEGs, POGs, and naked models in space. *International Regional Science Review*, 22(2), 162.
- Dosi, G. (1988). *Technical change and economic theory*. London: Printer.
- Dosi, G., Pavitt, K., & Soete, L. (1990). *The economics of technical change and international trade: Harvester Wheatsheaf*.
- Dymski, G. A. (1996). On Krugman's model of economic geography. *Geoforum*, 27(4), 439-452.
- Fingleton, B. (2000). Spatial econometrics, economic geography, dynamics and equilibrium: a 'third way'. *Environment and Planning A*, 32(8), 1481-1498.
- Fingleton, B. (2001a). Equilibrium and Economic Growth: Spatial Econometric Models and Simulations. *Journal of Regional Science*, 41(1), 117-147.
- Fingleton, B. (2001b). Theoretical economic geography and spatial econometrics: dynamic perspectives. *Journal of Economic Geography*, 1(2), 201.
- Fingleton, B. (2003a). Externalities, Economic Geography, And Spatial Econometrics: Conceptual And Modelling Developments. *International Regional Science Review*, 26(2), 197-207.
- Fingleton, B. (2003b). Increasing returns: evidence from local wage rates in Great Britain. *Oxford Economic Papers*, 55(4), 716-739.
- Fingleton, B. (2005). Towards applied geographical economics: modelling relative wage rates, incomes and prices for the regions of Great Britain. *Applied Economics*, 37(21), 2417-2428.
- Fingleton, B., & McCombie, J. S. L. (1998). Increasing returns and economic growth: some evidence for manufacturing from the European Union regions. *Oxford Economic Papers*, 50(1), 89-105.
- Fujita, M., Venables, A. J., & Krugman, P. (1999). *The Spatial Economy: cities, regions, and international trade*. London, England.: MIT Press.
- Glaeser, E. L. (1999). Learning in Cities. *Journal of Urban Economics*, 46(2), 254-277.
- Glaeser, E. L., Kallal, H. D., Scheinkman, J. A., & Shleifer, A. (1992). Growth in Cities. *The Journal of Political Economy*, 100(6), 1126-1152.
- Glaeser, E. L., & Maré, D. C. (2001). Cities and Skills. *Journal of Labor Economics*, 19(2), 316-342.
- Goldstein, H. (1995). *Multilevel Statistical Models*. London: Edward Arnold.
- Henderson, V. (1986). Efficiency of resource usage and city size. *Journal of Urban Economics*, 19(1), 47-70.
- Henderson, V., Kuncoro, A., & Turner, M. (1995). Industrial Development in Cities. *Journal of Political Economy*, 103(5), 1067-1090.
- Hox, J. J. (1995). *Applied Multilevel Analysis*: TT-Publikaties Amsterdam.
- Jacobs, J. (1969). *The Economy of Cities* New York: Vintage Books.

- Kaldor, N. (1975). Economic Growth and the Verdoorn Law - A Comment on Mr. Rowthorn's Article. *The Economic Journal*, 85, 891-896.
- Lösch, A. (1954). *The economics of location* (W. Woglom & W. Stolper, Trans.). New Haven: Yale University Press.
- Marshall, A. (1890). *Principles of Economics*. London: Macmillan and Co.
- Martin, R. (1999). The new 'geographical turn' in economics: some critical reflections. *Cambridge Journal of Economics*, 23(1), 65-91.
- Martin, R., & Sunley, P. (1996). Paul Krugman's Geographical Economics and Its Implications for Regional Development Theory: A Critical Assessment. *Economic Geography*, 72(3).
- McCombie, J. S. L., Pugno, M., & Soro, B. (2002). *Productivity Growth and Economic Performance: Essays on Verdoorn's Law*: Palgrave Macmillan.
- Mincer, J. (1974). *Schooling, Earnings, and Experience*: New York: Columbia University Press.
- Moerbeek, M., van Breukelen, G. J. P., & Berger, M. P. F. (2003). A comparison between traditional methods and multilevel regression for the analysis of multicenter intervention studies. *Journal of Clinical Epidemiology*, 56(4), 341-350.
- Neary, J. P. (2001). Of Hype and Hyperbolas: Introducing the New Economic Geography. *Journal of Economic Literature*, 39(2), 536-561.
- Pickett, K. E., & Pearl, M. (2001). Multilevel analyses of neighbourhood socioeconomic context and health outcomes: a critical review. *Journal of Epidemiology and Community Health*, 55(2), 111-122.
- Pons-Novell, J., & Viladecans-Marsal, E. (1999). Kaldor's Laws and Spatial Dependence: Evidence for the European Regions. *Regional Studies*, 33, 443-451.
- Raudenbush, S. W. (1988). Educational Applications of Hierarchical Linear Models: A Review. *Journal of Educational Statistics*, 13(2), 85-116.
- Raudenbush, S. W., & Bryk, A. S. (2002). *Hierarchical Linear Models: applications and data analysis methods*: Sage Publications Inc.
- Raudenbush, S. W., & Kasim, R. M. (1998). Cognitive Skill and Economic Inequality: Findings from the National Adult Literacy Survey. *Harvard Educational Review*, 68(1), 33-79.
- Sampson, R. J., Raudenbush, S. W., & Earls, F. (1997). Neighborhoods and violent crime: a multilevel study of collective efficacy. *Science*, 277(5328), 918-924.
- Schumpeter, J. A. (1939). *Business Cycles*. New York: McGraw Hill.
- Steenbergen, M. R., & Jones, B. S. (2002). Modeling Multilevel Data Structures. *American Journal of Political Science*, 46(1), 218-237.
- Verspagan, B. (1993). *Uneven Growth Between Interdependent Economies: An Evolutionary View on Technology Gaps, Trade, and Growth*. Aldershot: Avebury.
- Weber, A. (1929). *Theory of the Location of Industries*. Chicago: The University of Chicago Press Chicago.