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Returns to Scale for EU Regional Manufacturing

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Abstract

Recent theoretical advances have emphasised the importance of localised increasing returns to scale in understanding both the regional growth and agglomeration processes. However, considerable empirical controversy still exists over whether returns to scale are constant or increasing. Consequently, this study aims to provide some new estimates of the degree of returns to scale for EU regional manufacturing. It does so within the framework of the Verdoorn law. Unlike previous studies, issues of specification of fundamental importance to recent theoretical developments are brought to attention. Overall, the paper concludes that localised increasing returns in EU regional manufacturing are substantial.

Keywords: increasing returns, Verdoorn law, manufacturing, productivity growth, spatial econometrics

JEL Classification: O18, O33, R11

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1. Introduction

An understanding of whether or not regional production within the European Union (EU) is subject to increasing returns to scale is crucial for policymakers and economists alike. For both, it is crucial for an assessment of the potential impact of continuing integration on the economic geography of the EU, with implications both for social cohesion and the future evolution of regional policy. For economists, it is further important from a theoretical viewpoint, especially in view of developments in growth theory over the past two decades and the emergence of a new field of "geographical economics" that aims to model the centripetal and centrifugal forces that underlie the spatial distribution of economic activity.

To elaborate, it has traditionally been the case that economists' models of growth at both the national and regional levels have been based upon the assumption of constant returns to scale, as have models of the spatial distribution of activity based upon the static concept of comparative advantage. Thus, the neoclassical model of Solow (1956) and Swan (1956) provides the traditional growth model and, in this model, the existence of constant returns to scale, combined with an associated pure public good treatment of technology, implies a stable process in which all regions should converge to the same steady-state growth path. Furthermore, by increasing the mobility of both capital and labour, regional integration should eliminate not only growth rate differences between regions, but also long-run differences in levels of income per capita and productivity, so that a process of absolute convergence results. Likewise, when its assumption of no factor mobility is relaxed, the classic Heckscher-Ohlin model implies that interregional differences in underlying factor endowments should disappear, thereby engendering an associated convergence in regional production structures.

However, since the mid-1980s, there has been a sustained theoretical effort to replace the assumption of constant returns to scale with that of increasing returns to scale. In growth theory, this effort has been driven by a recognition that growth is endogenous rather than exogenous, and, in particular, by the argument that it is the result of decisions made by economic agents rather than technological progress arriving as "manna from heaven." Thus, technological progress, and, therefore, economic growth, has been modelled as both the accidental, and indirect, outcome of decisions to invest in capital accumulation (Romer, 1986) and the intentional outcome of decisions to invest in the production of new technologies (Romer, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1998). In both cases, fundamental to the story of endogenous growth is the existence of knowledge spillovers, leading to the existence of increasing returns, as, without increasing returns, growth would dry-up in the absence of an exogenous driving force. Meanwhile, with respect to the spatial distribution of economic activity, it has been realised that this is often difficult to explain using the static notion of comparative advantage. Thus, without increasing returns, it is difficult to explain why dense agglomerations of economic activity continue to exist even when the historical reasons that led to their establishment have disappeared, and this is the case at many different spatial levels (Krugman, 1991). Indeed, a "problem of backyard capitalism" arises by which it would be expected that every household would produce a fully diversified range of commodities in its own backyard so that the distribution of economic activity was uniform across geographic space. It is this realisation of the importance of increasing returns in explaining the spatial distribution of activity that has led to the development of geographical economics by, *inter alia*, Fujita, Krugman and Venables (see, for example, Fujita, Krugman, and Venables, 1999). Along with this have gone policy implications shared with endogenous growth theory, for the existence of regional increasing returns implies that integration brings, at least the potential of, intensified forces for divergence in regional production structures, growth rates, income per capita and productivity levels.

However, although the above developments mean that the potential role of increasing returns in driving spatial processes of growth and distribution is now the subject of widespread research interest, it is important to point out that the modern emphasis on increasing returns in such processes is actually considerably predated by a related literature. Thus, there is a notable literature inspired by Myrdal (1957) and Kaldor (1966, 1970) that pinpoints increasing returns to scale as the source of "circular and cumulative" processes in space, where increasing returns are given a wide interpretation so as to incorporate not only conventional static sources, but also the dynamic sources of knowledge spillovers and induced technological progress that mainstream endogenous growth theory has picked-up on. In this literature, increasing returns are captured by the so-called Verdoorn law, which asserts the existence of a positive relationship between either labour productivity or total factor productivity (TFP) growth and output growth.[1] The estimation of this relationship then provides an explicit means of testing for increasing returns to scale, be it at the national level (Kaldor, 1966) or the regional level (McCombie and de Ridder, 1984).

Despite the sustained theoretical efforts to replace the assumption of constant returns to scale with that of increasing returns to scale that have been outlined above, it is interesting to note that the empirical subject of whether or not returns to scale are constant or increasing at the regional level is far from being resolved. Hence, whilst many geographical economists have been content to refer to the “backyard capitalism” argument as providing sufficient proof of the existence of localised increasing returns, actual empirical work on the subject is far from arriving at a consensus. Studies estimating regional production functions, for example, have traditionally found either constant returns or very small increasing returns (Moroney, 1970; Griliches and Ringstad, 1971; Douglas, 1976), whilst findings of cross-regional convergence are often interpreted as being consistent with the traditional Solow-Swan model and, therefore, constant returns to scale (see, *inter alia*, Barro and Sala-i-Martin, 1991, 1992; Mankiw, Romer and Weil, 1992). Furthermore, whilst time-series estimation of industry production functions (expressed in terms of growth rates) have been found to indicate the existence of substantial externalities in production (Caballero and Lyons, 1992), these have been subject to criticism by, for example, Basu (1995). Finally, there has, at the national level, been a distinct absence of “scale effects”, whereby, even if increasing

[1] For a collection of some of the latest developments in this literature see McCombie *et al* (2002).

returns were only small at this level, we would expect a distinctive positive relationship in the data between country population sizes and productivity levels for countries at the same level of development. There is no evidence of support of this conjecture (Jones, 2002).

In this context, the Verdoorn law literature mentioned above is important. This is because, as indicated, the law provides an interesting means of testing for significant increasing returns at the regional level. Indeed, previous work estimating this law for the European regions has found evidence of substantial increasing returns (Fingleton and McCombie, 1998; Pons-Novell and Viladecans-Marsal, 1999).[2] However, at the same time as providing support for the key assumption of both endogenous growth theory and geographical economics, these studies provide a challenge to both of these theoretical literatures. This is because by specifying the Verdoorn law with output growth as the regressor, they hold true to the Kaldorian origins of the law in seeing the regional growth and agglomeration processes as being fundamentally demand-driven. By contrast, both endogenous growth theory and geographical economics are neoclassical approaches and, therefore, much more supply-oriented in their focus (Roberts and Setterfield, 2006). Still, this does not mean that Fingleton and McCombie (1998) and Pons-Novell and Viladecans-Marsal (1999) are necessarily correct in their Kaldorian specification of the law. Indeed, in this context, there is an old controversy surrounding the issue of endogeneity and the proper specification of the law that both sets of authors abstract from (see Kaldor, 1975; Rowthorn, 1975a, 1975b). There is, furthermore, a paradox in the specification of the law, confirmed by Fingleton and McCombie (1998), which raises doubt over the findings of substantial increasing returns for the European regions. This is the so-called "static-dynamic Verdoorn law paradox" of McCombie (1981). In particular, it has previously been found that when the law is respecified from being in terms of growth rates (the dynamic version of the law) to being in terms of log levels (the static version of the law), constant or decreasing rather than increasing returns to scale are found. This is despite both versions of the law being estimated using a common dataset.

[2] Evidence of substantial increasing returns have also been found in other regional samples, not to mention in cross-country and cross-industry data (McCombie *et al*, 2002).

Given the controversy surrounding the empirical question of whether or not returns to scale at the regional level are constant or increasing and the theoretical and policy importance of this question, this paper aims to provide some new estimates of the degree of returns to the scale for European regional manufacturing. Although it does so in the context of the Verdoorn law framework that has been previously been used by both Fingleton and McCombie (1998) and Pons-Novell and Viladecans-Marsal (1999), the paper represents a considerable advance on the work of both of these sets of authors. First, the paper explicitly considers both the Verdoorn law controversy concerning endogeneity in the specification of the law and the static-dynamic Verdoorn law paradox on the grounds of the relevance of both to modern theoretical and policy debates. In particular, with respect to the former, both specifications of the law with output growth and factor inputs are estimated, and instrumental variable (IV) techniques are employed. Meanwhile, with respect to the latter, a possible resolution to the paradox suggested by McCombie and Roberts (2006) is tested. This suggestion implies that the static, but not the dynamic, version of the Verdoorn law is mis-specified because of the existence of a spatial aggregation bias. Secondly, rather than just estimating the simple Verdoorn law with a single regressor and no consideration of capital accumulation, an augmented specification is estimated in which total factor productivity growth is the dependent variable and in which the independent influence of both technological diffusion and agglomeration economies arising from the density of production in a region are taken into account. Thirdly, and finally, estimation of the Verdoorn law is conducted within a spatial econometric framework. Although the studies of both Fingleton and McCombie (1998) and Pons-Novell and Viladecans-Marsal (1999) are also set within such a framework, the spatial econometric approach adopted in this study is both more sophisticated and theoretically driven. Indeed, in itself, it represents a contribution to the spatial econometric literature with the estimation of a new spatial specification presented in the results reported.

The structure of the rest of this paper is as follows. The next section introduces the Verdoorn law as a means of testing for increasing returns to scale. In so doing, it examines both the theoretical basis of the law and its augmentation. It also discusses both the Verdoorn law controversy regarding the question of endogeneity and the static-dynamic Verdoorn law paradox. Following this, spatial econometric issues in the estimation of the law are considered and our preferred spatial econometric model introduced. The econometric results obtained are then presented and discussed. The final section offers some concluding thoughts.

2. The Verdoorn law - theoretical framework, controversy and a paradox

2.1. The Verdoorn law and its theoretical framework

The traditional Verdoorn law

Traditionally, the Verdoorn law has been estimated as a linear relationship between labour productivity growth and output growth (Kaldor, 1966):

$$p_j = c_1 + b_1 q_j \qquad (1)$$

where p and q are the growth rates of manufacturing labour productivity and output respectively of region, or country, j. The coefficient b_1 is the Verdoorn coefficient and it traditionally takes a value of 0.5 (Kaldor, 1966), with Fingleton and McCombie (1998) and Pons-Novell and Viladecans-Marsal (1999) obtaining estimates of 0.575 and 0.628 respectively for their samples of European regions.[3]

Notoriously absent from the above the specification of the Verdoorn law, however, is the growth of the capital stock (McCombie and de Ridder, 1984). Neither Fingleton and McCombie (1998) nor Pons-Novell and Viladecans-Marsal (1999) include this because of an absence of data on gross investment, relying instead on the explicit or implicit hypothesis that the capital-output ratio is constant. To examine the consequences of this

[3] Fingleton and McCombie (1998) use a sample of 178 NUTS2 regions for the period 1979-1999, whilst Pons-Novell and Viladecans-Marsal (1999) use a sample of 74 NUTS1 regions for the period 1984-1992.

absence, assume that the Verdoorn law is derived from a Cobb-Douglas production function of the form:[4]

$$Q_j = K_j^a (Ae^{\lambda t} L_j)^{(1-a)} \qquad (2)$$

where Q, K, and L are the levels of output, capital, and labour respectively. Meanwhile, λ is the rate of technological progress and a and $(1-a)$ are production function parameters, which under the assumption of constant returns to scale, equal the shares of K and L in Q respectively.

A key assumption of the Verdoorn law is that the rate of technological progress is largely endogenously determined.[5] This can occur, for example, through localised knowledge spillovers emanating from learning-by-doing or induced technological change. To capture this, specify λ as:

$$\lambda = \tilde{\lambda} + \pi\big(ak + (1-a)\ell\big) \qquad (3)$$

where the lower case variables denote exponential growth rates, so that a faster growth of the (weighted) factor inputs leads to faster TFP growth.

Substituting equation (3) into equation (2) gives:

$$Q_j = K_j^{\alpha} (Ae^{\lambda' t} L_j)^{\beta} \qquad (4)$$

where α and β are the observed output elasticities of capital and labour respectively, ($\alpha + \beta > 1$); and $\alpha = (1+(1-a)\pi)a = va$ and $\beta = (1+(1-a)\pi)(1-a) = v(1-a)$ where v is the degree of returns to scale. Note, however, that v is more encompassing that the traditional definition of returns to scale as it also includes the effect of the induced rate

[4] The assumption that the Verdoorn law is derived from a Cobb-Douglas production function is not innocuous, as we shall see in Section 2.3.
[5] This assumption is shared with endogenous growth theory.

of technological change, $\phi(ak + (1\text{-}a)\ell)$. The rate of exogenous technological change is given by: $\lambda' = \tilde{\lambda}/v$.

Consequently, taking logarithms of equation (4), differentiating with respect to time, and rearranging gives:

$$p_j = \lambda' + \frac{\beta - 1}{\beta} q_j + \frac{\alpha}{\beta} k_j \qquad (5)$$

Given the hypothesis that $q_i = k_i$, then the Verdoorn law, from equation (5) is:

$$p_j = \lambda' + \frac{(\alpha + \beta - 1)}{\beta} q_j \qquad (6)$$

If the output elasticities are equal ($\alpha = \beta$), which is not an implausible assumption for manufacturing, a Verdoorn coefficient of 0.5 implies a degree of returns to scale of 1.33, which is large by any standard. Ideally, therefore, the growth of the capital stock should be explicitly included in the Verdoorn equation and, as noted above, the sole reason why it is not is due to the absence of data on investment from which estimates of the capital stock can be calculated.[6]

Augmenting the Verdoorn Law

Since the work of Fingleton and McCombie (1998) and Pons-Novell and Viladecans-Marsal (1999), data on gross investment has become available for the European regions, allowing for the construction of a measure of k.[7] Given this, the use of OLS to estimate equation (5) seems inappropriate because it is likely that k is endogenous, being largely

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[6] Using cross-country data, Kaldor (1967) included the gross investment-output ratio as a proxy for k, but found it made little difference to the estimates of either the Verdoorn coefficient or v. However, the investment-output ratio is a poor proxy for k, as it essentially assumes that there is no capital scrapping or deprecation.

[7] For a description of the data used in this paper and the construction of the capital stock estimates, see the data appendix.

determined by the growth of output (Kaldor, 1970). To tackle this, the Verdoorn law can be respecified as:

$$tfp_j = \frac{\beta\lambda'}{v} + \left(1 - \frac{1}{v}\right) q_j \qquad (7)$$

where $tfp = q - a\,k - (1\text{-}a)\ell$ is the growth of total factor productivity (TFP).

Equation (7) is a more flexible form of the production relationship than that derived from the Cobb-Douglas production function, as it allows for the factor shares, and, therefore, the underlying production technology, to vary both between regions and over time.

However, even this “simple” Verdoorn law attributes all of the cross-sectional variation in productivity growth to induced knowledge spillovers and technological change resulting from increasing returns, broadly defined. Yet, consistent with endogenous growth theory (see, for example, Barro and Sala-i-Martin, 2004, chapter 8), part of the variation in tfp_j could equally be due to the diffusion of innovations from high-technology to low technology regions. Furthermore, in equation (7), the realisation of increasing returns is clearly demand-driven through output growth, but recent theoretical advances looking to combine insights from endogenous growth theory with those from geographical economics (Baldwin, 1999; Baldwin and Martin, 2003), suggest that the density of production within a region might be a source of dynamic agglomeration economies and, therefore, increasing returns. It follows that variation in the density of production might also help to explain the variation in tfp_j.

To capture the above possibilities, the Verdoorn law is augmented as follows:

$$tfp_j = \frac{\beta\lambda'}{v} + \left(1 - \frac{1}{v}\right) q_j + \zeta_1 \ln D_j + \theta_1 \ln TFP_0 \qquad (8)$$

where $\ln TFP_0$ is the log of the initial level of TFP for region j and is intended as a proxy for the initial level of technology. Of course, if the diffusion hypothesis is correct then $\theta < 0$ should hold.[8] Meanwhile, $\ln D_j$ is the log of region j's output density (D_j), where $D_j = Q_j/H_j$ with H_j being the area of region j in sq. km.[9]

Equation (8) implies that the density of production within region j has an effect on its steady-state growth path, and, because it is specified as a relationship between TFP growth and output growth, we label it the *dynamic Verdoorn law*. However, an alternative is to define D_j as only having a "level effect" as is done in, for example, the empirical work of Ciccone (2002) and Ciccone and Hall (1996). In this case, D_j only affects the *level*, and not the long-run growth rate, of TFP. This does not, however, affect the specification of equation (7), i.e. the non-augmented dynamic Verdoorn law, merely its interpretation. In fact, in this case, it is not possible to directly test for the independent influence of agglomeration economies arising from the density of production. To see this, assume, as before, that the underlying functional form is provided by a Cobb-Douglas production function. However, this time, it takes the form:[10]

$$\frac{Q_j}{H_j} = \left(\frac{K_j}{H_j}\right)^{\alpha}\left(Ae^{\lambda' t}\,\frac{L_j}{H_j}\right)^{\beta} \tag{9}$$

Consequently, the Verdoorn law in log-level form (which, it will be recalled we term the *static Verdoorn law*) is now given by:

[8] Fingleton and McCombie (1998) also attempt to proxy for the initial level of technology. However, given their lack of capital stock estimates, they make use of the initial level of labour productivity. This is less satisfactory than the initial level of TFP because variations in labour productivity might equally be attributable to variations in the capital-labour ratio, thereby leading to Solow-Swan style conditional convergence rather than technological diffusion.

[9] The level of output is taken to be that of the initial level to avoid the possibility of reverse causation from TFP growth to lnD_j. Using the average density of production over the period made little difference to the results obtained.

[10] For expositional ease, any possible technological diffusion effect is ignored.

$$\ln TFP_j = \left(\ln A + \left(\frac{\beta}{\nu} \right) \lambda' t \right) + \left(1 - \frac{1}{\nu} \right) \ln Q_j + \left(\frac{1 - \alpha - \beta}{\nu} \right) \ln H_j \qquad (10)$$

Consequently, if there are increasing returns to scale, the greater the density of production is (i.e., the lower H_j is, *ceteris paribus*), the higher the level of TFP will be. With constant returns to scale, though, the density of production has no effect.

As H is constant over time, however, note that, when expressed in growth rate (i.e.: dynamic*)* form, the Verdoorn law given by equation (10) is the same as equation (7). This has a relevant consequence when D_j only has a level effect, as in this case the dynamic Verdoorn Law does not allow the separate influence of agglomeration economies to be disentangled from that of increasing returns, interpreted more generally.

2.2. Endogeneity and the Verdoorn law controversy

The specification of the augmented dynamic Verdoorn law in equation (8) holds true to the Kaldorian origins of the law. Thus, q_j is specified as an exogenous and independent determinant of tfp_j, so that demand growth is seen as the fundamental driving force behind the regional growth and agglomeration processes. However, the specification by Kaldor (1966) of the law (in its original guise of equation (1)), was criticised by Rowthorn (1975a). In particular, Rowthorn argued that, in the context of the argument that Kaldor was using the law, q_j was endogenous to employment growth, which implies that, in our augmented specification, q_j is endogenous to tfp_j. On these grounds, Rowthorn (1975a) advocated respecifying equation (1) as $p_j = c_2 + b_2 \ell_j$ where ℓ is the growth of employment in region j. In terms of our augmented dynamic Verdoorn law, this is equivalent to respecifying equation (8) as:

$$tfp_j = \beta\lambda' + (\nu - 1)\ tfi_j + \zeta_2 \ln D_j + \theta_2 \ln TFP_{0,j} \qquad (11)$$

where $tfi = a\,k - (1-a)\ell$ denotes the growth of total factor inputs in region j.

In respecifying the law, Rowthorn found that, using the same dataset as Kaldor (1966), he could not reject the hypothesis of constant returns to scale. This is equivalent to finding a coefficient on tfi_j in equation (11) that is not significantly different from zero Kaldor (1966), on the other hand, found significant increasing returns to scale using equation (1), which is identical to finding a coefficient on q_j in equation (8) that is significantly greater than zero.[11]

The reason for the divergence in the implied estimates of ν obtained by Kaldor and Rowthorn can, however, be easily understood. It occurs because the relationship between the two slope coefficients in the original Kaldorian and Rowthorn specifications of the dynamic Verdoorn law is given by $(1-\hat{b}_1)(1+\hat{b}_2) = R^2$. Given that Kaldor (1966) and many subsequent studies have found $\hat{b}_1 = 0.5$ (implying increasing returns) and that, in cross-sectional data, R^2 usually presents a reasonably good fit of 0.5, it follows that $(1+\hat{b}_2) \approx 1 \Rightarrow \hat{b}_2 = 0$ (implying constant returns). In the case of the augmented specifications, this indicates that the true estimate of ν will lie between the (lower bound) estimate obtained from equation (11) and the (upper bound) estimate obtained from equation (8).

Although Kaldor (1975) argued that Rowthorn (1975a) had misinterpreted his original argument behind the use of the Verdoorn law and although there are persuasive reasons for believing that regional growth is demand driven (Thirlwall, 1980), the above discussion is clearly of modern relevance. In particular, given that they build on conventional production functions, endogenous growth models suggest that causation runs from the growth of factor inputs to output growth, i.e., from the supply-side of the economy to the demand-side. By contrast, we know that the Kaldorian origins of the Verdoorn law suggest the opposite. However, even here, there is acknowledgement that the regional growth and agglomeration processes are circular and cumulative with feedback from productivity growth to output growth (Dixon and Thirlwall, 1975). This

[11] Kaldor's original sample consisted of 12 advanced countries for the early post-Second World War period. Rowthorn used the same sample as Kaldor with the exception that he dropped Japan on the grounds that it was an outlier.

being the case, the use of OLS to estimate either equation (8) or equation (11) will be subject to simultaneity bias. Consequently, an instrumental variable (IV) estimator should be used (Rowthorn, 1975b) and, ideally, this should help to bring about a convergence of the estimates of v obtained from the two specifications.

Even the use of an IV estimator, however, has not proved to be without its problems. Thus, in a previous study with non-regional data, McCombie (1981) advocated using Durbin's ranking method where the instrument is the rank of the regressor. This raises two problems. First, it implies that whereas in equation (8) the instrument is the rank of q_j, in equation (11) it is the rank of tfi_j. Second, if more than one instrument is used, the model is over-identified. In both cases, the method of normalisation, i.e., whether q_j or tfi_j is chosen as the regressor, affects the estimates. Hence, the difference in the estimates of the degree of returns to scale still remains. McCombie and de Ridder (1984) found that, for the US states, both specifications gave estimates of substantial increasing returns to scale, although the Kaldorian specification of the Verdoorn law gave a larger figure. Here the explicit inclusion of the growth of the capital stock meant that the R^2 was sufficiently good that, consistent with Wold's proximity theorem (Wold and Faxer, 1957), the estimates of v converged.

2.3. The Static-Dynamic Verdoorn law Paradox

Equations (8) and (10) give, what have been referred to as, the *dynamic* Verdoorn law and the *static* Verdoorn law respectively. In particular, ignoring both the possibility of technological diffusion and agglomeration economies arising from the density of production, the dynamic Verdoorn law can be derived from its static counterpart by differentiating with respect to time. This being the case, it might be expected that the estimation of the following two equations would give identical estimates of v:

$$tfp_j = \frac{\beta\lambda'}{v} + \left(1 - \frac{1}{v}\right) q_j \qquad (12)$$

$$\ln TFP_j = \left(\ln A + \left(\frac{\beta}{v}\right)\lambda' t\right) + \left(1 - \frac{1}{v}\right)\ln Q_j \qquad (13)$$

However, this has not been found to be the case in previous studies, including those for the European regions (Fingleton and McCombie, 1998).[12] In particular, it has been found that whereas dynamic specifications of the Verdoorn law give estimates of ν significantly greater than unity, static specifications do not. This is a puzzle, notwithstanding the different assumptions underlying any error terms appended to static and dynamic specifications of the law. Consequently, there has previously been found to exist a paradox in the estimation of the Verdoorn law, namely, the static-dynamic Verdoorn law paradox (McCombie, 1981).

A possible explanation for the above paradox is provided by McCombie and Roberts (2006) through the concept of *spatial aggregation bias*. They argue that the ideal unit of observation is not the (administrative) region (of which the NUTS1 regions used in this paper are examples), but, what they term, the Functional Economic Area (FEA). The FEA is the area over which substantial agglomeration economies occur and is likely to be determined by various factors, such as journey to work patterns, for instance. These authors suggest that any particular region is likely to consist of a number of FEAs, with the larger regions containing proportionately more. The spatial aggregation error occurs because the data for each region are the values of output, employment, and capital for each constituent FEA summed *arithmetically*. This potentially biases (the static) estimates of ν obtained from equation (13) towards constant returns to scale. To see this, assume that the true specification of the Verdoorn law for an FEA is given in static form by $L_{ij} = BQ_{ij}^{\gamma}$ where i denotes the particular FEA, j is the region in which it is located.[13,14] The underlying assumption is that $\gamma = 0.5$ and so at the FEA level it is immaterial whether the law is estimated in static or dynamic form. For expositional ease, assume that all of the FEAs are the same size and that the smallest region contains

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[12] Although note that Fingleton and McCombie (1998) do not estimate versions of the Verdoorn law that allow for capital accumulation.

[13] To simplify the argument, we ignore the possibility of capital accumulation. Allowing for such accumulation does not affect the nature of the argument

[14] This is formally equivalent to: $P_{ij} = B^{-1}Q_{ij}^{(1-\gamma)}$, as by definition $P \equiv Q/L$ and $(1-\gamma)$ is the Verdoorn coefficient.

one FEA, the second smallest region two FEAs, and so on. Given these assumptions, the recorded levels of employment and output will take the form reported in Table 1.

TABLE 1 HERE

It can be seen that when the aggregate cross-regional data is used to estimate the static Verdoorn law, it will suggest constant returns to scale. Thus, if this is the correct explanation, the dynamic Verdoorn law (i.e. equation (12)) is the correct specification. Using simulation analysis, McCombie and Roberts (2006) show that this result is robust even when the sizes of the individual FEAs are allowed to vary, provided that they are relatively small compared with the size of the average region. They also show that time-series estimation of the static Verdoorn law will give an unbiased estimate of ν, provided the inherent problem of variations in capacity utilisation is solved. Furthermore, they demonstrate that a one-way fixed-effects (FE) estimation of the static Verdoorn law will lead to a biased estimate of ν, i.e., it will suggest constant returns to scale, by picking up the cross-section variation. However, the two-way FE estimator gives an unbiased estimate, as it also employs the time-series variation in the data.

Clearly, assuming that the static-dynamic Verdoorn law paradox is found to hold for the data set in this paper, it is important to test the above hypothesis concerning its explanation. This is especially the case, because the aforementioned hypothesis indicates significant increasing returns to scale do exist at an economically meaningful level of spatial aggregation, but it is only possible to pick-up correctly these increasing returns by the Verdoorn law estimated in dynamic form or by the law estimated in static form using an appropriate panel data estimator. Obviously, if this is found to be the case, it resolves some of the confusion in the empirical literature as to whether returns to scale are constant or increasing in a manner that favours endogenous growth theory and geographical economics, as well as the Kaldorian approach to growth.

This does, however, raise problems concerning the appropriate measure of the level of TFP to use as a proxy for the level of technology in equation (8). Clearly, if there are significant localised increasing returns, then TFP levels could differ because of this factor and so the variable should be adjusted to take account of this. If McCombie and Roberts (2006) are correct, then the corrected index for the initial period for any region should be:

$$TFP'_{0j} = \sum_i \left(\frac{Q_{0ij}}{K^{\alpha}_{0ij} L^{\beta}_{0ij}} \right) \omega_{0ij} \qquad (14)$$

where i denotes the FEA, j the region and ω is the appropriate weight of FEA i.[15] The difficulty, of course, is that the data for the FEAs are not available. Consequently, the procedure adopted below is to use two alternative proxies for TFP_{0j}. First, the initial TFP was calculated under the assumption that the returns to scale apply to the *whole* of region j's output, namely, $TFP^{*}_{0j} = Q_{0j} / K^{\alpha}_{0j} L^{\beta}_{0j}$ where α and β are the estimates implicit in the estimated Verdoorn coefficient. However, the use of the data for the whole region will bias the estimates of TFP downwards (if $\alpha + \beta > 1$) compared with the correct measure given by equation (14). Consequently, the initial TFP, calculated under the assumption of constant returns to scale ($TFP_{0j} = Q_{0j} / K^{a}_{0j} L^{(1-a)}_{0j}$), was also used in the regressions. The assumption is that these two measures provide the limits of the true measure of TFP.

3. Spatial econometric issues

3.1. The standard approach to spatial autocorrelation

As noted, both Fingleton and McCombie (1998) and Pons-Novell and Viladecans-Marsal (1999) make use of a spatial econometric framework in their estimation of the Verdoorn law for the European regions. Indeed, more generally in the use of regional data, it is now becoming standard to explicitly test for spatial effects in regression

[15] Such as $K^{\alpha}_{0ij} L^{\beta}_{0ij} / \sum_i K^{\alpha}_{0ij} L^{\beta}_{0ij}$ so that $TFP'_{0j} = \sum_i Q_{0ij} / \sum_i K^{\alpha}_{0ij} L^{\beta}_{0ij} > TFP^{*}_{0ij} = Q_{0j} / K^{\alpha}_{0j} L^{\beta}_{0j}$.

models.[16] In this context, it is useful to divide the econometric problems arising from the use of spatial data into two categories. First are problems of *spatial heterogeneity,* which reflect the fact that the parameters of interest may vary over space. Such problems are normally dealt with by the use of panel data style estimators. Second, there are problems posed by the existence of *spatial autocorrelation,* whereby the assumption of independently distributed error terms breaks down across spatial units. With the latter set of problems, a "testing-up" approach is normally adopted as a solution. Thus, it is fast becoming standard to estimate the model under consideration by OLS and then to test for spatial autocorrelation through the use of an appropriate diagnostic test such as one based on Moran's *I*. If spatial autocorrelation is found to be present then two alternative spatial specifications are considered with Lagrange Multiplier (LM) diagnostics being used to choose between them. Specifically, the two alternative spatial specifications are the spatial autoregressive model (SAR), otherwise known as the spatial lag model, and the spatial error model (SEM). However, contrary to the impression given by this testing-up procedure, it has been argued that the SAR and SEM are not mutually exclusive specifications. Rather, both are special cases of a more general set of equations in which they are nested (Florax and Folmer, 1992). Thus, consider the following general functional form for a spatial cross-section regression:

$$y = \boldsymbol{X}\delta + \eta \boldsymbol{W}y + \boldsymbol{WX}\rho + \varepsilon \qquad (15)$$

where $$\varepsilon = \xi \boldsymbol{W}\varepsilon + \mu$$

and y is the dependent variable, $\boldsymbol{X}$ is a matrix of non-stochastic regressors, δ the associated vector of coefficients, and ε is the error term. $\boldsymbol{W}$ is an *a priori* specified matrix of exogenous weights and is often either a contiguity matrix (with a value of 1 if the regions have adjoining boundaries, 0 otherwise) or is based on a distance decay function from the region under consideration to the other regions. η is the spatial autoregressive parameter, ρ is a vector of cross-correlation coefficients, and μ is vector

[16] Abreu, De Groot and Florax (2005) provide a survey of empirical growth work employing a spatial econometric framework.

of random errors with $E(\mu) = 0$ and $E(\mu\mu') = \sigma_\mu^2 \mathbf{I}$. Note that when the spatial weights matrix, $\boldsymbol{W}$, is applied to a variable, this is referred to as the spatial lag of the variable.

From this general specification, at least five restricted specifications can be identified:

(i) Ordinary-least squares

This is appropriate when the constraints $\eta = 0$, $\rho = (0,\ldots.0)'$ and $\xi = 0$ hold:

$$y = \boldsymbol{X}\delta + \mu \qquad (16)$$

This is the correct specification when there is no spatial autocorrelation, providing the standard assumptions underlying OLS hold.

(ii) The spatial autoregressive or spatial lag model (SAR)

Used when the constraints $\rho = (0,\ldots.0)'$ and $\xi = 0$ hold:

$$y = \boldsymbol{X}\delta + \eta \boldsymbol{W} y + \mu \qquad (17)$$

(iii) The spatial cross-regressive model

Occurs when the restrictions $\eta = 0$ and $\xi = 0$ are imposed:

$$y = \boldsymbol{X}\delta + \boldsymbol{W}\boldsymbol{X}\rho + \mu \qquad (18)$$

Note that in this model, the spatially lagged variables are the regressors and, in contrast to the SAR model, the spatial cross-regressive model can be estimated using OLS. In the case of our augmented dynamic Verdoorn law given by equation (8), this translates into including $\boldsymbol{W}q_j$, $\boldsymbol{W}\ln TFP_{0,j}$ and $\boldsymbol{W}\ln D_j$ as additional explanatory variables. Consequently, this can be interpreted as cross-regional spillovers to region j occurring and/or being affected by output growth, technology levels and levels of agglomeration in neighbouring regions. This contrasts with the SAR model, which is often interpreted as saying that spillovers occur directly through productivity growth. However, in this sense, the spatial cross-regressive model would seem preferable because it enables us to identify and estimate the separate contributions of the different independent variables to cross-regional spillovers. This allows, for instance, for testing of the hypothesis that higher productivity growth is more likely to be observed in region j if that region is surrounded by technologically advanced regions. From an economic theory perspective, this seems very plausible.

(iv) <u>The spatial Durbin model</u>

This combines the SAR and spatial cross-regressive specifications by using the single restriction $\xi = 0$:

$$y = \boldsymbol{X}\delta + \eta \boldsymbol{W}y + \boldsymbol{W}\boldsymbol{X}\rho + \mu \qquad (19)$$

hence, the spatially lagged variables are both the independent variables and the dependent variable. This specification, however, is likely to suffer from severe multicollinearity between $\boldsymbol{W}y$ and $\boldsymbol{W}\boldsymbol{X}$.

(v) <u>The spatial error model (SEM)</u>

This model results when $\eta = 0$ and $\rho = (0 \ldots 0)'$:

$$y = \boldsymbol{X}\delta + \xi \boldsymbol{W}\varepsilon + \mu \qquad (20)$$

Note that $(\xi \boldsymbol{W}y - \xi W\boldsymbol{X}\delta) = \xi \boldsymbol{W}\varepsilon$; therefore:

$$y = \boldsymbol{X}\delta + (\xi \boldsymbol{W}y - \xi W\boldsymbol{X}\delta) + \mu \qquad (21)$$

And then, equation (20) can also be expressed as:

$$y = \boldsymbol{X}\delta + (\boldsymbol{I} - \xi \boldsymbol{W})^{-1}\mu \qquad (22)$$

As mentioned, the SAR and SEM specifications are the most commonly applied in spatial econometric studies and, indeed, these are the specifications that Fingleton and McCombie (1998) and Pons-Novell and Viladecans-Marsal (1999) restrict themselves to in their estimation of the Verdoorn law. These specifications have been interpreted as capturing spatial autocorrelation of the "substantive" and "nuisance" variety respectively. Thus, whilst, as indicated, η in the SAR model has been given the economic interpretation of capturing the strength of cross-regional spillovers, ξ in the SEM model has been seen as capturing the spatial correlation of any omitted variable, such as human capital, for instance (Bernat, 1996).

Given that both the SAR and SEM specifications are nested within the general spatial specification, equation (15), it follows that the standard testing-up procedure, which is used by Pons-Novell and Viladecans-Marsal (1999) is powerful when either LM_{SAR} *or* LM_{SEM} is significant. However, when both are significant, it is not necessarily legitimate to choose the one with the highest value for the LM statistic, as is generally done as part of the procedure. This is because the results would seem to suggest that *both* $\boldsymbol{W}y$ and $\boldsymbol{W}\varepsilon$ are statistically significant and are likely to be highly collinear. In other words, the appropriate restrictions discussed above are not met. It would thus seem unwise to base model selection on this criterion.

Ideally, the more appropriate statistical procedure would be the Hendry-style one of estimating the more general specification and "testing down". There are, however, two drawbacks with this strategy. First, if $\boldsymbol{W}y$ and $\boldsymbol{W}\varepsilon$ are highly collinear then the standard errors will be inflated and the presence of multicollinearity should be tested for. Second, and more seriously, using the same weights matrices in the general specification means that the estimated equation is not identified (Anselin, 1988). Yet, it is difficult to determine on theoretical grounds why the weights matrices should differ between $\boldsymbol{W}y$ and $\boldsymbol{W}\varepsilon$. The upshot of this is that we are sceptical about distinguishing between the quantitative impact of the two variables and attaching different economic interpretations to them, unless one is statistically insignificant. Thus, we would hesitate to interpret $\eta \neq$

0 as capturing a cross-regional spillover effect unless the estimate of ξ is statistically insignificant.

3.2. A new spatial specification

Notwithstanding the above conventional approach to the modelling of spatial effects, there is a further spatial specification nested within equation (15). This specification seems to have been ignored in the spatial econometrics literature. However, for reasons discussed below, it seems the *a priori* preferable specification.

(vi) The spatial cross-regressive error model (the spatial hybrid model)

This model involves the single restriction $\eta = 0$ and therefore takes the form:

$$y = \boldsymbol{X}\delta + \boldsymbol{WX}\rho + \xi\boldsymbol{W}\varepsilon + \mu \qquad (23)$$

This specification presents the advantage of explicitly modelling both the "substantive" and "nuisance" components of any possible spatial autocorrelation. In particular, whilst ***WX*** models the substantive component, the nuisance component is captured by $\boldsymbol{W}\varepsilon$.

4. The results for total manufacturing[17]

4.1 Estimation of the Kaldorian version of the augmented dynamic Verdoorn law

Table 2 starts by presenting cross-sectional results for the full-sample period of 1986-2002 for the Kaldorian version of the augmented dynamic Verdoorn law given in equation (8). It does so for all six of the specifications discussed in the previous

[17] All estimations reported in this section were carried out using *MatLab v 7.0* with the assistance of James Le Sage's spatial econometrics toolbox. With the exception of column 1 in table 2, all estimates were obtained using Maximum Likelihood (ML) procedures. For details of the ML procedures in this toolbox see Le Sage (1999), although note that in employing these procedures, estimates of both η and ξ were constrained to the range (-0.999, 0.999) instead of the default of (-1, 1). This was necessary to allow for the proper numerical evaluation of the concentrated log-likelihood function given the structure of the weights matrices used- in particular, given that a small number of regions in the sample were only contiguous with one other region.

section. In all cases, the measure of initial TFP adopted is that which makes no correction for increasing returns.[18] We later discuss the consequences of correcting for increasing returns in this measure, as well as presenting panel data results for our preferred spatial specification. In subsequent sections, we progress to results for the Rowthorn-style specification of the augmented dynamic Verdoorn law and to associated IV results. We also present results from estimation of the static Verdoorn law, considering both the static-dynamic Verdoorn law paradox and the resolution of this paradox suggested by McCombie and Roberts (2006).

From Table 2, it can be seen that all five spatial specifications gave similar results, which were close to the OLS estimates. The coefficient on q_j (i.e. the Verdoorn coefficient) ranged from 0.502 to 0.673, implying that $\hat{v}$ (the composite measure of returns to scale) varied from 2.199 to 3.060. The diffusion of innovations from the more to the relatively less advanced regions is an important source of TFP growth, as indicated by the significant negative coefficient on $lnTFP_0$ with the (conditional) speed of diffusion, ϕ, estimated as being between 1.42 and 2.24% per annum.[19] The density variable is also significant with a positive coefficient, suggesting that agglomeration economies produce dynamic intra-regional knowledge spillovers and therefore also have a role to play in explaining TFP growth. Moran's I confirms the presence of spatial autocorrelation in the OLS specification and therefore justifies our additional use of spatial econometric methods.

It is interesting to note the virtually identical coefficients and t-values associated with $\boldsymbol{W}tfp$ and $\boldsymbol{W}\varepsilon$ in the spatial autoregressive model (SAR) and the spatial error model (SEM) specifications respectively (Table 2, equations (ii) and (v)) This makes it very difficult to discriminate between the two specifications on statistical grounds. As noted, the normal "testing up" procedure has been to compare LM_{SAR} with LM_{SEM} , which would suggest that the SEM specification is to be preferred over the SAR in

[18] The estimates using increasing returns to scale are available on request. There was little difference in the estimates of increasing returns to scale, but the speed of diffusion was much slower.

[19] The estimate of ϕ is given by $\phi = -(\ln(1 - \theta_l T))/T$.

Table 2. We know, however, that this is not an appropriate test procedure if we accept that equation (15) is the general functional form.

As discussed above, we prefer, on theoretical grounds, either the spatial Durbin model, the spatial cross- regressive error model, or what we have termed the "spatial hybrid model" for short, to the SAR and SEM. This is because these specifications allow for the breaking down of the substantive component of any spatial autocorrelation, allowing an assessment of the channels through which cross-regional spillovers might occur. In particular, the different channels are captured by the coefficients on the spatially lagged independent variables. Nevertheless, the spatial Durbin and spatial hybrid specifications lead to a number of different conclusions. In the spatial Durbin model, a faster growth of output of the surrounding regions has no statistically significant effect on the region under consideration. However, there is a large and statistically significant effect in the spatial cross-regressive and spatial hybrid models. Thus, in these specifications, the gains from the Verdoorn effect through learning-by-doing and induced technical change are not completely localised to the region in question, but directly spill-over into surrounding regions. This does not, however, occur in the spatial Durbin specification.

Moreover, the spatial Durbin model suggests that if a region is surrounded by regions with high levels of TFP, i.e., advanced levels of technology, this has the effect of raising the region's rate of TFP growth. Thus, there is a spatially lagged diffusion of innovations effect that is more important, the more advanced is the technology in the neighbouring regions. In the spatial cross-regressive and spatial hybrid models, this effect is not statistically significant. There is, however, evidence in all three models of a cross-regional spillover effect from agglomeration economies as evidenced by the positive coefficient of *WlnD*, although the effect is larger in the spatial cross-regressive and spatial hybrid models.

As explained, our preferred model in these circumstances is the spatial hybrid model where the true spillovers come from the economic variables, i.e. ***WX***, and *not* ***Wy***. This specification explicitly tests for the substantive component of any spatial autocorrelation through the inclusion of $\boldsymbol{WX}$ while correcting for the nuisance component through $\boldsymbol{W\varepsilon}$. Meanwhile, the spatial Durbin model gives similar results, but is misspecified as $\boldsymbol{Wy}$ is, in effect, capturing the joint effect of $\boldsymbol{WX}$ and $\boldsymbol{W\varepsilon}$.

The reported $\bar{R}^2s$ of all the specifications are subject to an element of spurious regression due to the fact that q appears on both sides of the regression (it will be recalled that $tfp \equiv q - tfi)$. The $\bar{R}^2_{adj}$ in Table 2 is the $\bar{R}^2$ adjusted to remove this spurious correlation and is obtained by running the regression with tfi as the dependent variable. In the specification of the Verdoorn law simply as $tfp_j \equiv c_3 + b_3q_j$ and $tfi_j \equiv c_4 + b_4q_j$, the choice of the dependent variable makes no difference to either the estimate of the degree of returns to scale or its statistical significance (i.e. $\hat{b}_3 + \hat{b}_4 = 1$) and the two specifications are mirror images of each other.

However, this is not the case in equation (ii), the SAR model, and in equation (iv), the spatial Durbin model. This is because these equations include the spatially lagged dependent variable, which is $\mathbf{W}tfp$ and $\mathbf{W}tfi$ depending on the choice of dependent variable. This means that in each of these cases, the degree of returns to scale differs, depending upon whether tfp or tfi is the dependent variable. The two estimates of the degree of returns to scale for equation (ii) are 2.415 and 1.758 and for equation (iv) are 2.495 and 1.758.[20] Unfortunately, there does not seem to be any reason, either statistical or theoretical, for preferring either tfp or tfi as the dependent variable, but the disparities in the estimates are not large.

A commonly neglected shortcoming of traditional spatial models, including the spatial specifications of the Verdoorn law of Fingleton and McCombie (1998) and Pons-Novell and Viladecans-Marsal (1999), concerns the weights matrix. Consider a particular region, j. The weight given to the cross-regional spillover effects of the neighbours of j in the above approach are equal, regardless of their absolute size in terms of output. The inclusion of $\boldsymbol{W}q_j$, for example, implies that the impact on region j of a neighbouring region's output growth is not independent of the size of that region,

[20] The full results with tfi as the dependent variable are available on request from the authors.

which is rather implausible. It is likely that the impact of the growth of a neighbouring region that is several times larger than that of another bordering region will have a greater effect on *j,* even if both neighbours are growing at the same rate. To allow for this, an alternative specification is to weight the relevant variable by Q_i/Q_j, where Q_j and Q_i are the outputs of region *j* and neighbouring region *i* respectively. Thus, we constructed a non-row standardised weights matrix $\boldsymbol{W_1}$ where $w_{j,i} = Q_i/Q_j$ if *j* and *i* are contiguous regions (and $j \neq i$) and $w_{j,i} = 0$ otherwise. This matrix was used to weight the growth of output, but not the other variables, in the spatial hybrid model. [21]

TABLE 2 HERE

Using $\boldsymbol{W_1}$ for output growth and the row-standardised contiguous weights matrix for the other regressors, Table 3 reports two different specifications of the spatial hybrid model. This is done for both cross-sectional and panel data.[22] In particular, the panel consists of three periods, 1986-1991, 1991-1996, 1996-2002. Whilst the cross-sectional data has the advantage of minimising bias attributable to cyclical fluctuations by allowing growth rates to be calculated over a longer period, the panel data has the advantage of permitting control for fixed effects. In Table 3, equations (i), (iii) and (v) impose constant returns to scale on $lnTFP_0$, while equations (ii), (iv) and (vi) correct the measure of initial TFP for increasing returns in the manner discussed in section 2.3.[23]

Table 3 presents the results obtained with these specifications, which regarding the main variables, are very similar to the ones estimated so far, both when applying cross-sectional data sets and when panel data sets are employed. Thus, all equations show

[21] An alternative is to row standardise $\boldsymbol{W_1}$ so that the relative sizes of the surrounding regions, rather than their absolute sizes are taken into account. This alternative procedure yielded similar results to those reported.

[22] For the panel data estimation we used the spatial FE estimators of Elhorst (2003), which are ML estimators. We appreciate J.Paul Elhorst's kind help, especially in making available his *MatLab* routines for the implementation of these estimators.

[23] In particular, an iterative procedure was employed whereby the equation under consideration was first estimated with the initial level of TFP calculated under the assumption of constant returns to scale. The estimate of ν obtained was then used to recalculate the initial level of TFP under the alternative assumption of increasing returns. This procedure was repeated until successive estimates of ν converged. In most cases, the convergence required a maximum of eight iterations, and, in many, less than four.

very large composite increasing returns, a statistically significant diffusion effect and a statistically significant, but quantitatively small, agglomeration effect, except for equation (vi), in which the latter is non-significant.. As we would expect, the quantitative impact of the diffusion effect is substantially smaller when we adjust $lnTFP_0$ for increasing returns. This can be seen by comparing equations (ii), (iv) and (vi) with equations (i), (iii) and (v) respectively. Note, however, that when using a contiguity matrix to assess the effect from the surrounding area due to increments in the output, we collect a significantly positive impact, whereas positive but non-significant coefficients result when this effect is weighted by the size of the adjoining region. Other differences resulting after this change are that while the weighted impact of initial total factor productivity and density, as reported in Table 2, showed positive and stable results, in Table 3 these effects show different signs according to distinct specifications. We also have an anomaly in the estimation of the intercept in the cross-sectional data equation (ii), whose large negative value is difficult to explain.

TABLE 3 HERE

4.2. Estimation of Rowthorn's specification of the dynamic Verdoorn law

Equation (11), it will be recalled, gives the Rowthorn-style specification of the dynamic Verdoorn law in which causation is hypothesised to run from the growth of inputs to the growth of output and demand rather than *vice versa*. Although a Rowthorn-style specification has not previously been estimated for the European regions, when such specifications have been estimated for other samples, they have been found to suggest constant returns to scale (McCombie and Thirlwall, 1994, Chapter 2).[24] Consequently, we estimated equation (11) for each of the specifications discussed in section 3. Although the results are not explicitly reported for reasons of space, they were, in all cases, found to suggest either constant ($\nu = 1$) or decreasing returns to scale ($\nu < 1$),

[24] The sole exception seems to be provided by McCombie and de Ridder (1984) for the US states, who found increasing returns using both Kaldorian and Rowthorn-style specifications of the Verdoorn law.

despite the corresponding Kaldorian specifications reported in Table 2 all suggesting increasing returns. Table 4 reports the results of equation (11) for the preferred spatial hybrid model.

TABLE 4 HERE

It can be seen that all the results also suggest $v < 1$, although in the case of equation (i) in Table 4 the null hypothesis of $v = 1$ cannot be rejected. If this is the correct specification of the law, the estimate of decreasing returns to scale could be due to a relatively fixed factor of production such as land. It can also be seen that, with the exception of the estimations which correct for decreasing returns to scale, both $\ln TFP_0$ and the density variable take on the expected signs in all of the specifications. Not all of the models, however, provide significant estimations of these parameters. Of the spatially lagged variables, $\boldsymbol{W}tfi$ is non significant except for the case of model (v). By contrast, $\boldsymbol{W}\ln TFP_0$ is (except in equation (v)) and takes on the expected sign, showing that regions benefit from close neighbours with higher levels of TFP. Finally, $\boldsymbol{W}\ln D_0$ implies that there are negative agglomeration effects from the surrounding regions, although the variable is not statistically significant in equations (iii) and (v).

4.3. IV estimation of the dynamic Verdoorn law

Given the dramatic differences obtained from the Kaldorian and Rowthorn-style specifications of the dynamic Verdoorn law, the assumption of exogeneity is clearly crucial in the estimation of v. In section 2.2, it was seen that, although arguing that the dynamic Verdoorn law is better specified with q_j as the regressor, the Kaldorian position does accept the possibility of simultaneity bias given the hypothesised circular and cumulative nature of the regional growth and agglomeration processes. Furthermore, even if a Solow-Swan style neoclassical perspective is adopted with no postulated feedback between tfp_j and tfi_j, it is doubtful if tfi_j can be assumed to be strictly exogenous. This is because TFP growth will affect factor returns and, in a system of open regional economies, this will stimulate interregional capital and labour flows.

Consequently, from either a neoclassical or a Kaldorian perspective, both equations (8) and (11) should be estimated by methods that take endogeneity into account and ideally the implied estimates of v should converge.

Given the above, we report estimates for the spatial hybrid specification for both equations (8) and (11) using the IV approach. In particular, following McCombie (1981), we adopted Durbin's ranking method, which uses the ranks of the endogenous variables as instruments.[25]

Another problem, however, is the difficulty of estimating the spatial hybrid model using IVs, as it was originally estimated using ML techniques (see footnote 18). We therefore report IV results for the spatial Durbin specifications of equations (8) and (11), but regard $\boldsymbol{W}tfp$ as a proxy for the spatial error term. It is therefore interpreted as merely capturing any residual spatial autocorrelation of the nuisance variety and as having no substantive economic meaning. The results are reported in Table 5.

TABLE 5 HERE

While there is some slight convergence in the estimates of v, it can be seen that the Kaldorian specification still gives an estimate of large increasing returns to scale, while the Rowthorn-style specification cannot reject the null of constant returns. As might be expected from the discussion of section 2.2, the problem is that two different instruments are being used in the above estimations and so the direction of normalisation (i.e. whether q_j or tfi_j is used as a regressor) still matters.

As an alternative procedure, we used the ranks of both q_j and tfi_j together in the IV estimation of the Kaldorian and Rowthorn-style specifications, but this made no significant difference to the estimates of returns to scale given by the two methods of

[25] Using an IV approach also has the advantage of not requiring the assumption of a normally distributed error term, as is the case with the ML results reported in preceding tables. This is significant because, using the Jarque-Bera test, the null of normality was frequently rejected for these results. More generally, however, the re-estimation of all the spatial specifications reported using IV techniques did not significantly alter any of the results obtained.

normalisation. Consequently, the IV estimates are close to those previously obtained and do not resolve the problem. However, *a priori,* in the regional case, it seems more plausible to agree with the Kaldorian position that output growth, which is determined by the type of good that the region produces and other demand factors, is the more appropriate regressor. In this case, the results suggest large increasing returns to scale.

4.4. Estimation of the static Verdoorn law and resolution of the static-dynamic Verdoorn law paradox

Given the variables $\ln TFP_0$ and $\ln D_0$, there is no static specification of the Verdoorn law that corresponds to our augmented dynamic Verdoorn law. Therefore, for our augmented law, we cannot test for the existence of the static-dynamic Verdoorn law paradox in the European regional data. However, whilst $\ln TFP_0$ and $\ln D_0$ have been found to be statistically significant and give economically meaningful results, their inclusion has not dramatically altered the implied estimates of v obtained. Consequently, we estimated static versions of the Kaldorian and Rowthorn-style specifications of the Verdoorn law excluding these variables, using our preferred spatial hybrid specification to control for spatial autocorrelation. The results are reported in Table 6 for the panel data.

From Table 6, it can be seen that the estimate of v using time effects (which has the effect of allowing for shifts in the production relationship) is, in both cases, consistent with constant returns to scale. This is equivalent to the use of pooled data, with a dummy variable to allow for exogenous technical change. Consequently, the estimates of the static Verdoorn law stand in marked contrast to the dynamic specification. In the case of the Rowthorn-style specification, both the static and dynamic estimates are in accord.

As we have seen, McCombie and Roberts (2006) have suggested that the most likely explanation for the static-dynamic paradox is the existence of spatial aggregation bias in the static estimates. According to this hypothesis, the use of a two-way estimator that captures both time and regional effects should give unbiased estimates of v similar to those obtained from the dynamic Verdoorn law. This is confirmed for the European data set under consideration. Estimates of the static Kaldorian specification presented in Table 6 exhibit substantial increasing returns to scale of a magnitude comparable to the estimates from the corresponding dynamic law.

TABLE 6 HERE

However, interestingly, the static Rowthorn-style specification estimated using both one-way and two-way fixed effects gives an estimate of constant returns to scale. This is not surprising, though. The two-way fixed effects gives a correct estimate of v, by capturing the within region variation of the data which is not subject to the aggregation problem. In the case here, we know that the within variation will approximate to the results using growth rates, and in the case of the Rowthorn-style specification, this gives constant or decreasing returns to scale. It is worth noting, however, that León-Ledesma (1999) found, using postwar Spanish regional data for manufacturing and two-way random effects estimators, that Rowthorn's static specification gave an estimate of increasing returns.

In the dynamic specification of both the Kaldorian and Rowthorn-style specifications, $\ln D_0$ was, with one exception, found to have a significant effect on the growth of TFP, suggesting significant (intra-regional) *dynamic* knowledge spillover effects from agglomeration. It is not, of course, possible to derive an estimable static specification of this model. However, an alternative hypothesis that is discussed in section 2.1 is that of agglomeration economies of the *static* variety which only have a "level effect" also exist. Consequently, using ML techniques, we estimated a respecification of equation (10) using time and regional fixed effects. This gave the following results:

$$\underset{}{lnTFP_D} = c + \underset{(13.65)}{0.623 lnQ_D} + \underset{(0.68)}{0.038 \boldsymbol{W} lnQ_D} + \underset{(7.97)}{0.453 \boldsymbol{W}\varepsilon} \quad \bar{R}^2_{adj} = 0.990$$

where TFP_D = TFP/H, and Q_D = Q/H where, it will be recalled, H is the area of the region in sq. kms. It can be seen that there is a large Verdoorn coefficient, which implies a substantial degree of composite increasing returns with v over 7. This forms the basis of an alternative explanation of the static-dynamic Verdoorn law paradox, namely that the conventional Cobb-Douglas production function is not the true underlying functional form of the Verdoorn law.

Estimating the Rowthorn-style specification gives

$$\underset{}{lnTFP_D = c} \underset{(-5.21)}{- 0.380 lnTFI_D} \underset{(-2.46)}{- 0.023\boldsymbol{W} lnTFI_D} \underset{(5.83)}{+ 0.361\boldsymbol{W}}\varepsilon \qquad \bar{R}^2_{adj} = 0.984$$

which implies a substantial degree of returns to scale of 1.85.

Consequently, the density specifications of both the static Kaldorian and Rowthorn-style models indicate the existence of substantial increasing returns to scale, although those of the Kaldorian model are perhaps implausibly large.[26]

5. Conclusion

This paper has revisited the estimation of the Verdoorn law by spatial economic techniques using EU regional data manufacturing. On theoretical grounds, the spatial hybrid model (or the spatial cross-regressive error model) was preferred as this enables the sources of cross-regional spillovers to be more closely investigated and tested. Unlike the previous studies for the EU of Fingleton and McCombie (1998) and Pons-Novell and Viladecans-Marsal (1999), estimates of the capital stock were calculated and used in the specification of the law. Our results with the Kaldorian specification of the Verdoorn law gave estimates of substantial increasing returns to scale, where the estimates also included the effect of induced technical change. It was also found that the coefficient of the logarithm of the initial level of TFP was negative and statistically significant. This suggests that the diffusion of innovations from the relatively more to the relatively less advanced regions was a significant explanatory factor in accounting for disparities in TFP growth. A density variable that was introduced to capture the

[26] Estimating these specifications using two-way fixed effects, by effectively washing out the cross-regional variation in *H,* gives precisely the same results as the two-way estimation of the static laws reported in Table 6.

effect of agglomeration economies on TFP *growth* also proved to be statistically significant, although its quantitative effect was small. These variables, when spatially lagged, often turned out to be significant suggesting significant cross-regional spillover effects, although, interestingly, spatially lagged output growth was not significant.

The alternative Rowthorn-style specification using the weighted growth of the total factor inputs as a regressor always suggested either decreasing or constant returns to scale and the use of an IV approach was not able to resolve the discrepancy between the two specifications. On theoretical grounds, the method of normalisation of the Kaldorian specification seems preferable and this is the specification we prefer.

It was also found that the EU regional data also gives rise to the static-dynamic Verdoorn law paradox. In particular, estimation of the Kaldorian specification of the Verdoorn law in static form suggests constant returns to scale prevail, whilst estimation in dynamic form suggests substantial increasing returns to scale. The conjecture of McCombie and Roberts (2006) that this is due to spatial aggregation bias is given support by the finding that the two-way estimation of the static relationships finds, as predicted, increasing returns in accord with the dynamic estimates. The static Rowthorn-style specification still did not refute the hypothesis of either constant or decreasing returns to scale.

Data Appendix

The data were taken from the Cambridge Econometrics regional database, supplemented and amended where necessary from national sources. Output is gross value added in constant 1995 prices and measured using a purchasing power standard exchange rate, whilst employment is the total number of hours worked. The analysis was confined to the NUTS1 regions, as this is the lowest level of spatial aggregation for which independent gross investment figures are available – at the NUTS2 level the gross investment measures for a large number of regions in the database are interpolated. This gave 59 regions, which are reported in Table A1.

The capital stocks were calculated by the perpetual inventory method, where the increase in the capital stock of a particular region in time *t* is given by $\Delta K_t = I_t - \delta K_{t-1}$, where I is gross investment and δ is the proportion of the capital stock lost through scrapping and depreciation. Hence $K_t = \Delta K_t + K_{t-1}$. This method requires a value for the base-year capital stock. In order to provide an estimate of this, we used the relationship

$$K_{t-1} = \frac{I_t}{k + 0.05}$$

where k is growth of the capital stock. However, as there is no data available for the growth of the capital stock, we approximated it by the growth of investment over the period 1981-1985. The sample-period was consequently 1986-2002 for the cross-sectional estimations, and for the panel data estimation, 1986-1991, 1991-1996, and 1996-2002. Similarly, the level of investment in the numerator is the average value over 1981-1985. There are no reliable data for wages at the regional level and so we used the national manufacturing factor shares in the calculation of the regional indices of total factor inputs and total factor productivity.

TABLE A1. The EU Regions

Austria	Ostosterreich	***Finland***		***Portugal***	Continental
	Sudosterreich	***France***	Ile de France	***Sweden***	
	Westosterreich		Bassin Parisien	***UK***	North East
			Nord-Pas de		
Belgium	Vlaams Gewest		Calais		North West
					Yorkshire and the
	Region Walonne		Est		Humber
Switzerland			Ouest		East Midlands
	Baden-				
Germany	Wurttemberg		Sud-Ouest		West Midlands
	Bayern		Centre-Est		Eastern
	Bremen		Mediterranee		London
	Hamburg	***Greece***	Voreia Ellada		South East
	Hessen		Kentriki Ellada		South West
	Niedersachsen		Attiki		Wales
	Nordrhein-		Nisia Aigaiou,		
	Westfalen		Kriti		Scotland
	Rheinland-Pfalz	***Ireland***			Northern Ireland
	Saarland	***Italy***	Nord Ovest		
	Schleswig-				
	Holstein		Nord Est		
Denmark			Centro		
Spain	Noroeste		Sud		
	Noreste		Isole		
	Madrid	***Netherlands***	Oost-Nederland		
	Centro		West-Nederland		
	Este		Zuid-Nederland		
	Sur				

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Table 1. The Verdoorn Law and Spatial Aggregation Bias

Region	Employment	Output
1	L_1	BQ_1^{γ}
2	$2L_1$	$2BQ_1^{\gamma}$
…	…	…
j	jL_1	jBQ_1^{γ}

Table 2: The augmented dynamic Verdoorn Law (Kaldorian version): Cross Sectional Data, 1986-2002

	(i) OLS	**(ii) SAR**	**(iii) SCM**	**(iv) Durbin Model**	**(v) SEM**	**(vi) SHM**
Constant	-0.001 (-0.47)	-0.005 (-2.37)	-0.003 (-0.94)	-0.003 (-1.05)	-0.001 (-0.38)	-0.003 (-0.73)
q	0.664 (7.95)	0.586 (8.54)	0.673 (7.96)	0.599 (8.06)	0.502 (6.81)	0.673 (8.73)
$lnTFP_0$	-0.016 (-2.61)	-0.016 (-3.17)	-0.026 (-3.40)	-0.027 (-4.20)	-0.022 (-3.34)	-0.026 (-4.55)
lnD_0	0.006 (4.76)	0.005 (5.61)	0.005 (4.60)	0.005 (4.48)	0.004 (3.44)	0.006 (5.60)
$\mathbf{W}q$			0.277 (2.79)	0.046 (0.40)		0.297 (3.40)
$\mathbf{W}lnTFP_0$			0.014 (1.36)	0.018 (2.09)		0.011 (1.11)
$\mathbf{W}lnD$			0.005 (2.93)	0.003 (1.69)		0.006 (3.95)
$\mathbf{W}tfp$		0.406 (4.77)		0.387 (3.16)		
$\mathbf{W}\varepsilon$					0.499 (4.62)	0.499 (4.63)
$\overline{R}^2$	0.582	0.663	0.666	0.671	0.675	0.757
$\overline{R}^2_{adj}$	0.454	0.593	0.540	0.634	0.552	0.666
Moran's I	3.02 [0.003]					
LM_{BP}	11.70 [0.009]					
LM_{SAR}	6.29 [0.012]					
LM_{SEM}	14.18 [0.000]					
v	2.975	2.415	3.058	2.495	2.119	3.060
ϕ	0.0143	0.0143	0.0216	0.0224	0.0189	0.0217

Notes: The figures in parentheses are t-ratios and the figures in square brackets probability values.
SAR is the spatial autoregressive model, SCM is the spatial cross-regressive model, SEM is the spatial error model, SHM is the spatial hybrid model.

Table 3: The augmented dynamic Verdoorn Law (Kaldorian version) –
The Spatial Hybrid Model

	Cross sectional		Panel Data: Time Effects		Panel Data: Spatial and Time Effects	
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Constant	0.002 (0.495)	-0.070 (-2.76)	n.a.	n.a.	n.a	n.a.
q	0.554 (7.45)	0.648 (8.40)	0.647 (13.14)	0.651 (13.48)	0.491 (10.93)	0.747 (16.52)
$lnTFP_0$	-0.026 (-4.24)		-0.015 (-2.82)		-0.085 (-9.49)	
$\ln TFP_o^*$		-0.002 (-2.21)		-0.001 (-1.48)		-0.022 (-8.78)
lnD_0	0.006 (4.84)	0.004 (3.65)	0.005 (5.03)	0.004 (4.01)	0.047 (5.09)	-0.005 (-0.69)
$\boldsymbol{W_1}\, q$	0.024 (1.66)	0.023 (1.15)	0.008 (0.88)	0.001 (0.09)	0.007 (1.00)	0.0003 (0.04)
$\boldsymbol{W} lnTFP_0$	0.010 (0.90)		0.004 (0.47)		0.037 (2.81)	
$W \ln TFP_o^*$		-0.001 (-1.38)		-0.003 (-2.85)		0.001 (0.24)
$\boldsymbol{W} lnD_0$	0.005 (2.88)	0.003 (2.07)	0.004 (3.38)	0.003 (2.25)	-0.039 (-3.71)	-0.026 (-2.70)
$\boldsymbol{W}\varepsilon$	0.532 (5.15)	0.299 (2.31)	0.401 (5.80)	0.300 (4.01)	0.487 (7.71)	0.417 (6.13)
$\overline{R}^2$	0.726	0.670	0.597	0.593	0.829	0.794
$\overline{R}^2_{adj}$	0.623	0.641	0.522	0.518	0.797	0.767
v	2.244	2.839	2.832	2.864	1.968	3.9449
ϕ	0.022	0.002	0.014	0.001	0.053	0.019

Note: n.a. denotes not applicable

Table 4: The augmented dynamic Verdoorn Law (Rowthorn-style version) -
The Spatial Hybrid Model

	Pooled Data		Panel Data: Time Effects		Panel Data: Time Effects and Spatial effects	
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Constant	0.016 (2.85)	-0.099 (-2.55)	n.a.	n.a.	n.a.	n.a.
tfi	-0.169 (-1.09)	-0.354 (-2.33)	-0.362 (-4.04)	-0.413 (-4.85)	-0.175 (-2.40)	-0.903 (10.19)
$lnTFP_0$	-0.031 (-3.43)		-0.013 (-1.72)		-0.124 (-11.83)	
$\ln TFP_o^*$		-0.004 (-0.71)		0.015 (3.72)		0.219 (9.01)
lnD_0	0.003 (1.58)	0.001 (0.40)	0.003 (1.82)	0.001 (0.54)	0.087 (8.04)	-0.200 (-7.75)
$\mathbf{W_1}tfi$	-0.002 (-0.08)	-0.031 (-1.00)	0.006 (0.364)	0.011 (0.74)	0.021 (2.04)	0.018 (1.46)
$\mathbf{W}lnTFP_0$	0.037 (2.61)		0.022 (2.09)		0.002 (0.12)	
$W \ln TFP_o^*$		0.038 (3.42)		0.013 (2.02)		0.067 (2.22)
$\mathbf{W}lnD_0$	-0.001 (-0.28)	-0.007 (-2.76)	-0.003 (-1.66)	-0.005 (-2.71)	-0.020 (-1.46)	-0.086 (-2.49)
$\mathbf{W}\varepsilon$	0.562 (5.67)	0.259 (1.94)	0.381 (5.42)	0.251 (3.25)	0.502 (8.11)	0.391 (5.61)
$\overline{R}^2$	0.477	0.372	0.264	0.301	0.725	0.658
$\overline{R}^2_{adj}$	0.505	0.407	0.431	0.412	0.787	0.618
v	0.831	0.646	0.638	0.587	0.825	0.097
ϕ	0.025	0.004	0.012	n.a	0.068	n.a.

Note: n.a. denotes not applicable.

Table 5: Dynamic Verdoorn Law; Durbin Model, Instrumental Variable Estimates: Cross-Sectional Data, 1986-2002

	Kaldorian specification		Rowthorn-style specification	
	(i)	(ii)	(iii)	(iv)
Constant	-0.002 (-0.75)	-0.047 (-2.24)	0.003 (0.61)	0.002 (0.56)
q	0.416 (3.88)		-0.010 (-0.05)	
tfi		0.540 (5.20)		-0.009 (-0.05)
$lnTFP_0$	-0.031 (4.26)	-0.003 (-1.61)	-0.040 (-3.84)	-0.040 (-3.87)
lnD	0.005 (3.86)	0.004 (3.09)	0.004 (2.08)	0.004 (2.10)
$\boldsymbol{W_1}q$	0.008 (0.40)		0.003 (0.08)	
$\boldsymbol{W_1}tfi$		0.006 (0.25)		0.004 (0.10)
$\boldsymbol{W}lnTFP_0$	0.028 (2.66)	-0.002 (-0.61)	0.044 (3.48)	0.921 (4.57)
$\boldsymbol{W}lnD$	0.001 (0.41)	0.002 (1.06)	-0.003 (-1.25)	-0.003 (-1.29)
$\boldsymbol{W}tfp$	0.635 (4.37)	0.387 (2.46)	0.877 (4.14)	0.921 (4.57)
v	1.713	2.176	0.990	0.991
ϕ	0.025	0.003	0.031	0.031

Table 6: The Static Laws

	Kaldorian specification		Rowthorn-style specification	
	(i) Time Effects	(ii) Time and Regional Effects	(i) Time Effects	(ii) Time and Regional Effects
lnQ	0.034 (1.88)	0.623 (13.66)		
$lnTFI$			-0.040 (-2.23)	-0.380 (-5.21)
$\boldsymbol{W}lnQ$	0.100 (3.00)	0.038 (0.68)		
$\boldsymbol{W}lnTFI$			0.038 (1.19)	-0.232 (-2.46)
$\boldsymbol{W}\varepsilon$	0.651 (15.33)	0.451 (7.91)	0.669 (16.37)	0.361 (5.82)
v	1.035	2.653	0.960	0.620
$\overline{R}^2$	0.527	0.909	0.548	0.845
$\overline{R}^2_{adj}$	0.950	0.990	0.952	0.983