**Agglomeration economies and accounting framework**

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**Abstract:** *Higher average productivity of firms and workers in larger cities (or regions or countries) is attributed to agglomeration economies. Agglomeration economies arise from the possibility of thick input markets, thick labour markets, or learning from others. This paper deals with an accounting issue in total factor productivity (TFP) measurement related to thick input markets. We focus on the impact of the share of intermediate consumption on productivity measurement. The first concern is an overvaluation of TFP in the value added approach due to the Domar (EconJ, 1961) factor. A second issue is how the empirical results are dependent on the use of the TFP value-added based in city and regional studies.*

*We use the Domar factor, the inverse of value added share in gross production, as a multiplicative factor shifting "value added TFP" from complete "gross production TFP". The empirical analysis suggests that the value added share in gross production decreases with size for agriculture and services, and usual agglomeration economies are slightly overvalued. Unexpectedly, the Domar factor suggests undervaluation of the productivity in manufacturing and construction with the value added approach.*

*Two main conclusions emerge. Firstly, the price and quantity effects of thick input markets greatly differ among sectors. Secondly, the baseline of larger 2% size productivity for manufacturing in Melo et al. (RegSc&UrbEcon, 2009) is undervalued when intermediate inputs and gross production are considered.*

**Keywords:** *Agglomeration. Productivity, Domar factor, Size economies, Spanish regions, Spanish provinces*

**JEL codes:** R12, R34, O47

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**1 Introduction**

The omission of intermediate consumption in sector growth results in two kinds of empirical problems. The first concern is measurement because there is an overvaluation of TFP in the value-added approach due to the Domar factor, the inverse of value added share in gross production. The second issue is the way empirical results are dependent on the use of the value-added measure as the indicator of productivity, if the share of value added to gross production is not independent of other variables in the study, such as city size. In this, paper we analyze empirically the impact of using value added based measures in the empirical analysis of the size productivity of cities. We use the sample of 50 Spanish provinces in four sectors (agriculture, manufacturing, construction and services), for the period since 1985 to 1995. We use the Domar factor as a multiplicative factor shifting productivity measures using the value added approach. We do not estimate the productivity of the Spanish provinces, but the productivity differences explained by the Domar factor

Localization economies involve ‘clusters’ of firms benefitting them from expansion of their own industry, implying specialized production. Higher average productivity of firms and workers in larger cities is attributed to urbanization economies. Urbanization economies occur when expansion of a city benefits firms from the proximity of a variety of industries, leading to regional growth due to increases in diverse production. As both localization and urbanization economies result from factors beyond the control of the individual firms, agglomeration economies in a region are often modelled as external scale economies. Duranton and Puga (2004) distinguish among three sources of agglomeration economies: sharing, matching, and learning. The agglomeration economies arise from the possibility for similar firms to share suppliers (thick input markets), the existence of large workers and firms facilitating matching (thick labour markets), or the possibility to learn from the experiences and innovations of others.

To our knowledge, the literature has neglected an accounting issue related to thick input markets: the impact of the share of intermediate consumption on productivity measurement. A theoretically correct measure of TFP should include all the inputs and outputs involved in the production process. However, the use of value-added approaches is more usual. The preference for a gross production approach has been acknowledged explicitly in previous literature using value-added, as in Hulten and Schwab (1984) and Moomaw and Williams (1991), where the difficulty of obtaining gross output data limits them to a net output (value-added) approach. Thus, a lack of data is one of the reasons behind the measurement of productivity based on the value-added function. The other reason for productivity measurement based on the value-added approach is that intermediate consumption compensates itself in economy-wide production.

The relation between gross-production–based and value-added–based total factor productivity (TFP) measures is well established in the growth accounting literature. Bruno (1978), with microeconomic analysis, and Balk (2009), with only accounting identities, have shown that a simple relationship between both TFP indices can be derived, with the Domar (1961) factor relating them.

The spatial area represented by the term city can be rather fuzzy in practice, although empirical results are, in general, irrelevant to the spatial unit under study (Melo et al, 2998;, Combes et al, 2012). Hence, in our analysis 'cities' are the Spanish provinces. The empirical urbanization literature initiated with Sveikauskas (1975), and its models and empirical success are surveyed in Duranton and Puga (2004), Rosenthal and Strange (2004), Melo et al. (2009) and Cpmbes and Gobillon (2015). A fact firmly established is that firms and workers are, on average, more productive in larger cities due to urbanization economies. However, estimates of the elasticity of productivity with respect to city size vary remarkably, ranging between 0.02 and 0.10, depending, among other things, on the sector and the details of the estimation procedure (Melo et al., 2009). That is, a city that is 10% larger in population offers wages that are 0.2 to 1% higher; doubling city size, other things equal, means that the firm in the larger city are 2% to 10% more productive. Melo et al. (2009) report that service industries tend to derive considerably larger benefits from urban agglomeration, about 8% higher than the elasticity estimates for the aggregate economy, while there is no statistical difference between the effect of urbanization for manufacturing industries and the whole economy. The possibility of changing urbanization effects for different periods is explicitly analyzed also in Melo et al. (2009)

The empirical work involves regressing an outcome variable by location on a measure of agglomeration. In the early literature, the typical regression of choice involved using partial productivity measures as output per worker as the dependent variable and city population as the explanatory variable. Other analysis use wages, which are related to marginal productivities. The recent contribution of Duranton et al. (2012) focus on total factor productivity (value added based, as in most studies). A survey of issues related to the use of production techniques for the empirical analysis of agglomeration effects included production or cost systems, is Cohen and Morrison Paul (2009).

**2 Methodology**

Different econometric techniques have been used to capture agglomeration, some of which are fundamentally non-spatial (Glaeser et al, 1992; Ellison and Glaeser 1997; Cohen and Morrison Paul 2009) and some of which are explicitly spatial (Fingleton 2003) in their respective approaches. Because agglomeration economies are cost reductions that occur because economic activities concentrate, a productivity framework that extents to spatial features is appealing. Cohen and Morrison Paul (2009), Otsuka and Goto (2015) and Otsuka (2017) are recent presentations of the productivity approach to agglomeration economies.

The main methodological tool in the sources of growth approach to productivity change consists of a production function with constant returns to scale for each industry with output expressed as a function of capital, labour, and intermediate input inputs and the level of technology. The production function for the industry i in city j gives the quantity of output, say Yij, as a function of capital, Kij, labour, Lij, intermediate inputs , Mij, and the level of technology, Aij, where all inputs are measured as service flows rather than stocks:

(1) Yij=f(Aij,Lij,Kij,Mij)

An economy-wide aggregate production function gives GDP as a function of aggregate capital and labour inputs, so that intermediate inputs – goods produced by one sector and sold to another – are excluded. The aggregate value-added function for city j is then

(2) Vj=g(Aj,Lj,Kj)

where V is real aggregate value-added, K is capital services, L is labour input.

The former function is also used for specific sectors. Hulten and Schwab (1984) assume that technical change in (1) is value-added augmenting, and thus Yij=f(g(Aij,Lij,Kij),Mij). The sectoral value-added function takes the form

(3) Vij=g(AVij,Lij,Kij)

Equations (1) and (3) define industry-level productivity growth in terms of industry gross output or in terms of industry value-added. The gross production function (1) collects information about all conventional inputs. This represents an advantage over (3) the value-added function, at least for explicit production factors. The theoretical appeal of the gross production approach to TFP measurement in (2) favours TFPY over TFPVA in (5). The theoretical superiority has an empirical counterpart in providing an explicit role for intermediate goods in allocating economic growth, and in identifying the sources of growth at the industry level. This provides a more detailed understanding of the forces driving aggregate trends. The above discussion is a mere nicety if TFPY and TFPVA measures lead to similar figures for productivity growth, but the analysis is important because this is not the case.

In the agglomeration literature, as an example Rosenthal and Strange (2004), is usual to model the technology levels 'A' as multiplicative shifters explained by different spillovers, starting at the firm level as 'micro-foundations' of agglomeration economies. Focusing on cities (or regions), equation (1) can be written as

(4) Yij= Aij(X-ij,Gj,Si) f(Lij,Kij,Mij)

where X-ij are spillovers from other cities or sectors, Gj are characteristics of city j, and Si are sector i variables .

Equation (3) can be modelled in a similar way

 (5) Vij = AVii(X-ij,Gj,Si) gi(Li,Ki)

On the other hand, equation (2) is

(6) Vj= Aj(X-j,Gj)g(Lj,Kj)

where sector variables are cancelled (although the industry composition of city j can contribute via Gj).

As examples, Segarra and Arcarons (1999), Pedraja et al. (1999), Maudos et al. (2000), Delgado and Alvarez (2004) use the value-added approach to compare manufacturing or other sector productivity in the Spanish regions, using different techniques as growth accounting, stochastic frontiers and DEA-Malmquist, in the framework of equation (5). On the contrary, Alvarez et al. (2006) use value added with Spanish provinces, but in an aggregate analysis, as in equation (6).

Cohen and Morrison Paul (2009) emphasize the production approach to agglomeration as the analysis of the causes modelled as 'Aij', which shift the frontier using production or cost models. The same paper examines the consequences of the multiplicative nature of the Aij, imposing neutrality of the productivity effect, in equations of the types (4) to (6). Otsuka and Goto (2015) and Otsuka (2017) focus on the same issues naming it the Solow residual approach, comprising the time variation of 'Aij' and a scale effect.

A simpler approach considering internal constant returns to scale and a simple accounting factor relating equations (1) and (3), or equations (4) and (5), has been overlooked in the literature: the Domar (1961) factor.

When total cost equals total revenue (constant returns to scale) and the proper VA deflator (Divisia) is used, several authors, and summarized in Balk (2009), have shown that

(7) TFPVi = TFPYi/(Vi/Yi)= TFPYi/Wi= Di TFPYi

where TFPVi is TFP value added based, TFPYi is TFP gross output based, Wi is the share of value added in gross output, and Di (=1/Wi) is a multiplicative effect called the Domar factor.

Although it is analyzed mainly in a growth accounting framework, the Domar factor can be used in an inter-firm (city, region,...) comparison. The analysis by Bruno (1978) can be embedded in the framework above. In the spirit of the survey by Cohen and Morrison (2009), we are explaining (part of) AVi. Then, we have

(8) AVij ∝ Aij /Wij = Dij Aij

where we indicate with ∝ that the productivity value added based and the productivity gross output added based are proportional in the product of a normalizing constant and the Domar factor

If the share of intermediate consumptions, or "outsourcing", increases (decreases) with urban size, then higher (smaller) productivity in large cities is measured with value added, even if TFP is the same gross-production based. This implies that part of agglomeration economies could be explained by the Domar factor. Explaining the changes of the Domar factor, we can think of two opposite effects of thick input markets. Firstly, there is a price effect with more input of good quality and less expensive, which tends the share of intermediate consumption in gross production to decrease. Secondly, there is a quantity effect, which facilitates outsourcing and the use of higher levels of external inputs, increasing the share of intermediate consumption in gross output.

The previous ideas can be tested in a simple model. In average, the share of value added in gross output changes with city size according to the coefficient bi in the following regression:

 (9) Wij = ai + bi log(SIZEji/SIZEg)

The share of value added (Wi) is regressed on city size, normalized by its geometrical mean. SIZEj is the population of the city j where the firm (sector) is established, and SIZEg is the geometric mean of city size. The parameter ai is given the interpretation of value added share in the geometric mean of SIZE, and the implied mean value added share change when population doubles is given by (bi log(2)) . The implied productivity growth due to changes in the Domar factor when value added is used and population doubles can be calculated as log(ai/(ai+bi log(2)).

A more direct approach involves the Domar factor as the dependent variable

(10) Dij = i + i log(SIZEj)

where the possibility of normalizing SIZEj is irrelevant, because the same structural effect i is constant along the regression line. Normalizing log(SIZEji/SIZEg) as in equation (9) gives i, the interpretation of the Domar factor at the geometric mean of SIZE. This is not a main issue in this paper because the interest is not the comparison of productivity measures but explaining biases in productivity measurement because of the accounting framework. The implied productivity increase with city size changes respect to any city size benchmark SIZEB due to the Domar factor is

(11) AVij = i log(SIZEj/SIZEB)

For the purpose of our discussion, a Domar factor effect on productivity is formulated in equation (10) as an empirical relationship where the inverse of value added shares in gross production increases (decreases) with the logarithm of city size, whatever it is measured, if the coefficient i>0 (i <0).

Suppose that we use a panel data approach to model equation (10) as in

(12) Yit = i + i Xit + uit

where we have changed the notation to a standard panel approach in order to reduce the number of sub indices. In this equation Yjt denotes the Domar factor for sector i (index omitted) of province j in year t; Xjt denotes the natural log of province size j in year t, and uit is a random residual which may be heteroskedastic, possibly correlated among provinces and serially correlated in different ways for the different provinces.

Elhorst (2014) surveys the theory and methods for fixing equation (12) by means of dynamic spatial panel econometrics. The main empirical problem is that there is not any obvious choice for the matrix of spatial correlations W, in our case. Spatial dependence could arise due to geographical vicinity, or to close levels of economic development, or to omitted factors possibly related also to urban size. Harris et al. (2011) find that differently constructed W matrices produce different estimates of spatial spillovers.

Hence avoiding the problems of spatial panel econometrics, we follow an alternative approach, based on a simple t-test. This is the Fama and MacBeth (1973) method for testing the capital asset pricing model in finance using data of different firms or stocks as individual units. We can formulate the statistical hypothesis as a purely empirical relationship. We are interested in testing the null hypothesis that the coefficient is zero against the alternative hypothesis that it is different from zero, as a two-side test because the coefficient  can be positive or negative. Then, cross-section regressions for different years and sectors are to be estimated separately and t-tests are to be applied to the resulting coefficients. Ibragimov and Müller (2010) provide a theoretical justification of this test and analyze several application settings.

**3. Empirical Analysis**

The following section analyzes empirically the relationships (10) and (11) for the main sectors of the Spanish provinces and the manufacturing subsectors of the Spanish regions.

Firstly, the model is tested using data from Alcaide Inchausti and Alcaide Guindo (2000) for the 50 Spanish provinces (Ceuta and Melilla are excluded), the years 1985 to 1995. For more recent years, it seems that a constant ratio between value added and gross production have been used for each province. The model is estimated for the following industries: agriculture, construction, manufacturing, and services. As our measures of city size we have used population and employment, both in number of persons and in density (per area) form.

It is thought that using a population- or employment-based measure of agglomeration as the dependent variable of interest makes little difference to the results, given the high correlation between the two. Following Ciccone and Hall (1996), employment density has been favoured relative to population because density-based measures of agglomeration. This is because density -based measures are more robust to size differences due to mere geographical or administrative zoning. It is clear that economic data are often available only for administrative divisions. The advantage of using density-based measures is that they better characterize the economic meaning of spatial units, proxying for urban amenities and potential congestion costs. However, Melo et al. (2009) do not find any difference in measuring urban agglomeration with employment density instead of total urban size; the coefficients are statistically not different from zero in both cases.

Our specification requires us to estimate relationship (10), adding an error tem vj without including other explanatory variables. The point is that the only coefficient of interest to us is ibecause equation (10) is our statistical hypothesis for the Domar-city size relationship. The problem of omitted variables or any other specification error is irrelevant to us, because we are only interested in the marginal regression of the Domar factor on the logarithm of city size. The Domar-city size relationship (10) is defined for this marginal distribution.

 Our statistical test for the null hypothesis that the coefficient i in equation (10) is zero against the alternative hypothesis that it is different from zero is a simple t-test. For each year t, we perform a regression to estimate equation (10) using the 50 provinces to obtain an estimate of it. We then use a t-statistic to test the null hypothesis that the estimates it of i come from a population with mean i = 0 against the alternative hypothesis that the mean is different from zero. This test is valid provided that the it for different times are close to statically independent. Changes in city size, whatever it is measured, are very small, but changes in the Domar factor provide enough variation.

Tables A1 to A4 show the results of each year regression for agriculture, manufacturing, construction, and services. The coefficients of city size are quite similar for the four constructed urbanization variables for the years analyzed, as expected from the previous literature. The t-test we employ is based on the estimates i in Tables A1 to A4. The estimates and results of the t-tests are presented in Table 1. The implied Domar productivity deviation is measured with respect to doubling city size.

Table 1. Domar Factor versus Province Size. t-Tests.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | ***Agriculture*** |  |  |  |
| **Size measure** | **Coeff** | **Std Dev** | **t-Student** |  **Domar bias** |
| Population | 0.040 | 0.013 | 9.79 | 2.7% |
| Pop. Density | 0.029 | 0.010 | 9.66 | 2.0% |
| Employment | 0.054 | 0.013 | 13.90 | 3.8% |
| Empl. Density | 0.036 | 0.009 | 12.92 | 2.5% |
|  | ***Manufacturing*** |  |  |  |
| **Size measure** | **Coeff** | **Std Dev** | **t-Student** |  **Domar bias** |
| Population | -0.030 | 0.015 | -6.59 | -2.1% |
| Pop. Density | -0.035 | 0.008 | -15.51 | -2.5% |
| Employment | -0.048 | 0.013 | -12.21 | -3.3% |
| Empl. Density | -0.044 | 0.007 | -21.67 | -3.1% |
|  | ***Construction*** |  |  |  |
| **Size measure** | **Coeff** | **Std Dev** | **t-Student** |  **Domar bias** |
| Population | -0.036 | 0.017 | -6.98 | -2.5% |
| Pop. Density | -0.034 | 0.016 | -6.79 | -2.3% |
| Employment | -0.041 | 0.019 | -6.94 | -2.8% |
| Empl. Density | -0.035 | 0.017 | -6.77 | -2.4% |
|  | ***Services*** |  |  |  |
| **Size measure** | **Coeff** | **Std Dev** | **t-Student** |  **Domar bias** |
| Population | 0.017 | 0.003 | 20.06 | 1.2% |
| Pop. Density | 0.018 | 0.003 | 17.19 | 1.3% |
| Employment | 0.021 | 0.004 | 18.76 | 1.4% |
| Empl. Density | 0.019 | 0.004 | 16.71 | 1.3% |

Even if one is to doubt about the independence of the cross-section samples, these estimates provide guidance about the over(under) valuation of the productivity of cities using the value added approach. Although the significance of the estimates can be under suspicion, the estimates and the implied productivity deviations are unbiased. Because of the cross-section regression, the only problem is the possible correlation among the residuals for different provinces for each time period t. Although an estimate using spatial correction would be more efficient, ordinary least squares estimates t are unbiased as required for the test of the marginal significance of the Domar-city size relationship.

For agriculture, the value added approach overvalues the productivity of Spanish provinces. Of course, agriculture is not usually considered in the urbanization literature. The results for agriculture involving province size can be probably explained according to intensification (and decreasing marginal productivity of inputs) and increasing production, following classical von Thünen developments because large cities imply large demand areas.

A decreasing value added share (or increasing Domar factor) with size is found also for the services sector. Although we can explain the results by means of the quantity effects of thick input markets, the very large productivity of cities in the services sectors, 8% above average in the Melo et al. (2009) survey, is overvalued in less than 1.5%.

On the contrary, for construction and manufacturing the value added approach undervalues the productivity of cities around 2.5-3%. These are very high, and perhaps unexpected, values. The explanation is the importance of the price effects in thick input markets, where inputs are very probably tradable but subject to transport costs. In Melo at al. (2009), manufacturing is the baseline.

It is interesting to delve into the empirical analysis by trying to solve the problem of the lack of independence of the different b for a given sector at different times. To this end, we will test on different industrial subsectors, although with a greater spatial aggregation, at the region level. Data is from the Industrial Firm Survey NACE1993 1993 to 2007 in Spain (Encuesta Industrial de Empresas). The 17 Spanish Autonomous Communities and 12 manufacturing subsectors are analysed for these years. Value added is measured as the difference between 'Ingresos Totales de Explotación', which is the output measure, and 'Consumos y trabajos realizados por otras empresas', the measure of intermediate consumption. The subsectors with the summary of results of the methodology described above are shown in Table 2. The size variables are the same as previously, population and employment, both in levels and in density. For each sector-year pair, a regression of cross-sectional section is made according to equation (10), with the 17 regional observations.

Table 2 shows the result of the test on the 15 years samples for the 12 sectors. For reasons of space the particular results are not presented in Appendix. Of course, the problem of non-independence remains here, as in the province analyses, but it is interesting the pattern of results.

Table 2. Domar Factor versus Region Size, by Sector. t-Tests.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sector** |  | **Population** | **Empl.** | **Pop. density** | **Empl. density** |
| 1 Food, beverages, tobacco (NACE1993 15,16) | Mean | -0.0525 | -0.0655 | -0.1210 | -0.1190 |
| t | -10.02 | -12.43 | -15.57 | -16.03 |
| Domar bias | -3.6% | -4.5% | -8.4% | -8.2% |
| 2 Textile, clothing, leather and footwear (NACE1993 17,18,19) | Mean | -0.0179 | -0.0094 | 0.0618 | 0.0629 |
| t | -3.72 | -1.88 | 13.25 | 13.83 |
| Domar bias | -1.2% | -0.7% | 4.3% | 4.4% |
| 3 Manufacture of wood and cork products (NACE1993 20) | Mean | -0.0501 | -0.0464 | 0.0446 | 0.0436 |
| t | -7.47 | -5.85 | 4.38 | 4.28 |
| Domar bias | -3.5% | -3.2% | 3.1% | 3.0% |
| 4 Paper, publishing, graphic arts, and recorded media (NACE1993 21,22) | Mean | -0.0480 | -0.0444 | 0.0803 | 0.0756 |
| t | -6.28 | -5.59 | 8.73 | 9.38 |
| Domar bias | -3.3% | -3.1% | 5.6% | 5.2% |
| 5 Chemical industry (NACE1993 24) | Mean | -0.0239 | -0.0178 | -0.0043 | 0.0007 |
| t | -3.38 | -2.28 | -0.36 | 0.06 |
| Domar bias | -1.7% | -1.2% | -0.3% | 0.1% |
| 6 Rubber and plastics (NACE1993 25) | Mean | -0.0605 | -0.0499 | -0.0442 | -0.0303 |
| t | -10.92 | -9.13 | -8.31 | -6.37 |
| Domar bias | -4.2% | -3.5% | -3.1% | -2.1% |
| 7 Miscellaneous non-metallic mineral products (NACE1993 26) | Mean | -0.0156 | -0.0090 | 0.0409 | 0.0422 |
| t | -3.84 | -2.31 | 6.91 | 7.70 |
| Domar bias | -1.1% | -0.6% | 2.8% | 2.9% |
| 8 Metallurgy and metal manufacture (NACE1993 27,28) | Mean | 0.0288 | 0.0198 | 0.0557 | 0.0429 |
| t | 3.05 | 2.20 | 10.20 | 8.60 |
| Domar bias | 2.0% | 1.4% | 3.9% | 3.0% |
| 9 Mechanical machinery and equipment (NACE1993 29) | Mean | -0.0424 | -0.0442 | 0.0694 | 0.0621 |
| t | -4.56 | -4.52 | 9.71 | 8.88 |
| Domar bias | -2.9% | -3.1% | 4.8% | 4.3% |
| 10 Electrical, electronic and optical equipment (NACE1993 30,31,32,33) | Mean | -0.0743 | -0.0821 | 0.0723 | 0.0601 |
| t | -11.45 | -13.75 | 13.60 | 12.96 |
| Domar bias | -5.2% | -5.7% | 5.0% | 4.2% |
| 11 Transport equipment (NACE1993 34,35) | Mean | -0.0668 | -0.0644 | 0.0529 | 0.0500 |
| t | -9.66 | -8.59 | 4.82 | 4.99 |
| Domar bias | -4.6% | -4.5% | 3.7% | 3.5% |
| 12 Miscellaneous manufacturing industries (NACE1993 36,37) | Mean | -0.0318 | -0.0280 | 0.0624 | 0.0601 |
| t | -13.26 | -11.97 | 10.26 | 10.15 |
| Domar bias | -2.2% | -1.9% | 4.3% | 4.2% |

It is common to observe negative results on the variables of size, and positive results on the variables of density. This result is remarkable because it differs from the empirical analysis at the city or provincial level in this paper. The most direct interpretation is either that the size of a large spatial economy reflects aspects other than population aggregation or that population density is a poor indicator of urbanization for regions. A comparison with the results presented in Table 1 suggests a preference for the first interpretation in relation to agglomeration economies. The interpretation of the results in the form of density remains to be explained.

It should be noted that in sectors 1 (Food, beverages and tobacco) and 6 (Rubber and plastic), the pattern observed is negative, both with variables in levels and density. Finally, in sector 8 (Metallurgy and manufacture of metal products) the relationship between the Domar factor and size variables is positive.

Table 3a. Domar Factor versus Region Size, by Year 1993-1999. t-Tests.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Year** |  | **Population** | **Employment** | **Pop. density** | **Empl. density** |
| 1993 | Mean | -0.0355 | -0.0347 | 0.0374 | 0.0366 |
| t | -4.69 | -4.58 | 1.72 | 1.80 |
| Domar bias | -2.5% | -2.4% | 2.6% | 2.5% |
| 1994 | Mean | -0.0238 | -0.0252 | 0.0325 | 0.0296 |
| t | -1.78 | -1.83 | 1.46 | 1.42 |
| Domar bias | -1.7% | -1.7% | 2.3% | 2.1% |
| 1995 | Mean | -0.0275 | -0.0264 | 0.0178 | 0.0173 |
| t | -2.00 | -2.01 | 0.98 | 1.03 |
| Domar bias | -1.9% | -1.8% | 1.2% | 1.2% |
| 1996 | Mean | -0.0310 | -0.0299 | 0.0116 | 0.0119 |
| t | -2.36 | -2.22 | 0.65 | 0.71 |
| Domar bias | -2.1% | -2.1% | 0.8% | 0.8% |
| 1997 | Mean | -0.0325 | -0.0304 | 0.0191 | 0.0194 |
| t | -3.35 | -3.35 | 0.94 | 1.02 |
| Domar bias | -2.3% | -2.1% | 1.3% | 1.3% |
| 1998 | Mean | -0.0347 | -0.0355 | 0.0194 | 0.0174 |
| t | -3.36 | -3.34 | 0.92 | 0.87 |
| Domar bias | -2.4% | -2.5% | 1.3% | 1.2% |
| 1999 | Mean | -0.0368 | -0.0357 | 0.0194 | 0.0185 |
| t | -3.42 | -3.21 | 0.92 | 0.94 |
| Domar bias | -2.6% | -2.5% | 1.3% | 1.3% |

Table 3b. Domar Factor versus Region Size, by Year 2000-2007. t-Tests.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Year** |  | **Population** | **Employment** | **Pop. density** | **Empl. density** |
| 2000 | Mean | -0.0377 | -0.0397 | 0.0265 | 0.0222 |
| t | -4.21 | -4.41 | 1.51 | 1.36 |
| Domar bias | -2.6% | -2.7% | 1.8% | 1.5% |
| 2001 | Mean | -0.0427 | -0.0415 | 0.0380 | 0.0350 |
| t | -4.43 | -4.15 | 2.45 | 2.45 |
| Domar bias | -3.0% | -2.9% | 2.6% | 2.4% |
| 2002 | Mean | -0.0510 | -0.0504 | 0.0275 | 0.0258 |
|  | t | -5.02 | -4.75 | 1.48 | 1.51 |
|  | Domar bias | -3.5% | -3.5% | 1.9% | 1.8% |
| 2003 | Mean | -0.0436 | -0.0411 | 0.0395 | 0.0380 |
| t | -3.82 | -3.43 | 2.15 | 2.26 |
| Domar bias | -3.0% | -2.8% | 2.7% | 2.6% |
| 2004 | Mean | -0.0481 | -0.0463 | 0.0317 | 0.0303 |
| t | -5.04 | -4.55 | 1.86 | 1.95 |
| Domar bias | -3.3% | -3.2% | 2.2% | 2.1% |
| 2005 | Mean | -0.0376 | -0.0346 | 0.0469 | 0.0447 |
| t | -3.05 | -2.72 | 2.52 | 2.58 |
| Domar bias | -2.6% | -2.4% | 3.3% | 3.1% |
| 2006 | Mean | -0.0484 | -0.0455 | 0.0471 | 0.0448 |
| t | -5.37 | -4.34 | 2.57 | 2.58 |
| Domar bias | -3.4% | -3.2% | 3.3% | 3.1% |
| 2007 | Mean | -0.0378 | -0.0347 | 0.0494 | 0.0470 |
| t | -3.73 | -3.04 | 2.90 | 2.98 |
| Domar bias | -2.6% | -2.4% | 3.4% | 3.3% |

An overall result relevant to the manufacturing industry can be envisaged. Table 3 shows the results of the t test carried out for the different years with the samples of the coefficients obtained in the 12 sector regressions. We can assume that these sector samples are independent. We know that there are some subsectors with positive coefficients in size variables and some subsectors with negative coefficients in density variables. The results are negative and almost every year statistically significant for the size variables. The results are positive, but scarcely significant for the density variables.

We can accept that by doubling the size of the population or employment in a region, the measure of total factor productivity with the value-added approach underestimates the total factor productivity with respect to the approximation of total product. This bias is between 2% and 3.5%, which must be added to the 2% elasticity of size that is taken as a baseline in the studies of agglomeration economies.

**4 Conclusions**

The empirical significance of the Domar factor as an accounting bias in measuring size productivity of cities is analyzed. The empirical analysis for the Spanish provinces for the period 1985-1995 suggests that the value added share in gross production decreases with city size (employment and population, in levels and density) for agriculture and services. Perhaps unexpectedly, the Domar factor suggests undervaluation of the productivity of Spanish provinces in manufacturing and construction with the value added approach.

Additional analysis of manufacturing at the regional level, for the 17 Spanish Autonomous Communities with subsector disaggregation confirms, on average, the province results with size variables in levels. On the contrary, there is the opposite result with the size variables in density form, although with low statistical significance. The results can vary greatly among manufacturing sectors.

The previous results suggest that the price and quantity effects of thick input markets can differ greatly among sectors, affecting measurement. In addition, we suggest that some theoretical developments beginning with the same functional form (Cobb-Douglas or CES) for the different regions are not accurate, because similar to intermediate consumption, labour shares are probably related to city size, due to thick input and thick labour markets.

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***Table A1 Domar factor regressions on province size. Agriculture***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Population* |  |  |  |  |  |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(POP)** | **Std Dev** |
| 85 | 0.009 | 1.482 | 0.020 | 0.016 | 0.025 |
| 86 | 0.017 | 1.474 | 0.020 | 0.022 | 0.025 |
| 87 | 0.026 | 1.468 | 0.020 | 0.028 | 0.025 |
| 88 | 0.038 | 1.460 | 0.019 | 0.033 | 0.024 |
| 89 | 0.053 | 1.452 | 0.019 | 0.038 | 0.023 |
| 90 | 0.071 | 1.442 | 0.018 | 0.043 | 0.022 |
| 91 | 0.091 | 1.433 | 0.018 | 0.048 | 0.022 |
| 92 | 0.106 | 1.416 | 0.018 | 0.052 | 0.022 |
| 93 | 0.117 | 1.400 | 0.018 | 0.055 | 0.022 |
| 94 | 0.113 | 1.390 | 0.017 | 0.052 | 0.021 |
| 95 | 0.098 | 1.383 | 0.018 | 0.049 | 0.021 |
| *Population density* |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(POP/AREA)** | **Std Dev** |
| 85 | 0.009 | 1.482 | 0.020 | 0.013 | 0.019 |
| 86 | 0.015 | 1.474 | 0.020 | 0.016 | 0.019 |
| 87 | 0.020 | 1.468 | 0.020 | 0.019 | 0.019 |
| 88 | 0.032 | 1.460 | 0.019 | 0.023 | 0.019 |
| 89 | 0.045 | 1.452 | 0.019 | 0.027 | 0.018 |
| 90 | 0.062 | 1.442 | 0.018 | 0.032 | 0.018 |
| 91 | 0.081 | 1.433 | 0.018 | 0.036 | 0.017 |
| 92 | 0.093 | 1.416 | 0.018 | 0.038 | 0.017 |
| 93 | 0.102 | 1.400 | 0.018 | 0.041 | 0.017 |
| 94 | 0.101 | 1.390 | 0.017 | 0.039 | 0.017 |
| 95 | 0.090 | 1.383 | 0.018 | 0.037 | 0.017 |
| *Employment* |  |  |  |  |  |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(EMP)** | **Std Dev** |
| 85 | 0.031 | 1.482 | 0.020 | 0.031 | 0.025 |
| 86 | 0.046 | 1.474 | 0.019 | 0.037 | 0.025 |
| 87 | 0.060 | 1.468 | 0.019 | 0.043 | 0.025 |
| 88 | 0.081 | 1.460 | 0.019 | 0.048 | 0.024 |
| 89 | 0.103 | 1.452 | 0.018 | 0.053 | 0.023 |
| 90 | 0.128 | 1.442 | 0.018 | 0.058 | 0.022 |
| 91 | 0.152 | 1.433 | 0.017 | 0.063 | 0.022 |
| 92 | 0.169 | 1.416 | 0.017 | 0.066 | 0.021 |
| 93 | 0.180 | 1.400 | 0.017 | 0.070 | 0.022 |
| 94 | 0.176 | 1.390 | 0.017 | 0.066 | 0.021 |
| 95 | 0.156 | 1.383 | 0.017 | 0.062 | 0.021 |
| *Employment density* |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(EMP/AREA)** | **Std Dev** |
| 85 | 0.023 | 1.482 | 0.020 | 0.020 | 0.019 |
| 86 | 0.033 | 1.474 | 0.019 | 0.024 | 0.019 |
| 87 | 0.042 | 1.468 | 0.020 | 0.027 | 0.019 |
| 88 | 0.058 | 1.460 | 0.019 | 0.031 | 0.018 |
| 89 | 0.077 | 1.452 | 0.018 | 0.035 | 0.018 |
| 90 | 0.098 | 1.442 | 0.018 | 0.039 | 0.017 |
| 91 | 0.119 | 1.433 | 0.018 | 0.043 | 0.017 |
| 92 | 0.132 | 1.416 | 0.018 | 0.045 | 0.017 |
| 93 | 0.140 | 1.400 | 0.018 | 0.047 | 0.017 |
| 94 | 0.139 | 1.390 | 0.017 | 0.045 | 0.016 |
| 95 | 0.126 | 1.383 | 0.017 | 0.043 | 0.016 |

 Table A2 Domar factor regressions on province size. Manufacturing

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Population* |  |  |  |  |  |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(POP)** | **Std Dev** |
| 85 | 0.004 | 2.867 | 0.037 | -0.020 | 0.047 |
| 86 | 0.013 | 2.838 | 0.039 | -0.039 | 0.049 |
| 87 | 0.012 | 2.864 | 0.038 | -0.036 | 0.048 |
| 88 | 0.010 | 2.862 | 0.039 | -0.034 | 0.049 |
| 89 | 0.007 | 2.852 | 0.040 | -0.028 | 0.049 |
| 90 | 0.014 | 2.851 | 0.039 | -0.040 | 0.048 |
| 91 | 0.010 | 2.837 | 0.038 | -0.032 | 0.047 |
| 92 | 0.029 | 2.908 | 0.041 | -0.060 | 0.050 |
| 93 | 0.006 | 2.950 | 0.042 | -0.028 | 0.052 |
| 94 | 0.002 | 3.021 | 0.042 | -0.016 | 0.052 |
| 95 | 0.000 | 3.102 | 0.047 | 0.000 | 0.057 |
| *Population density* |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(POP/AREA)** | **Std Dev** |
| 85 | 0.008 | 2.867 | 0.037 | -0.022 | 0.036 |
| 86 | 0.026 | 2.838 | 0.039 | -0.043 | 0.038 |
| 87 | 0.022 | 2.864 | 0.038 | -0.038 | 0.037 |
| 88 | 0.017 | 2.862 | 0.039 | -0.035 | 0.038 |
| 89 | 0.013 | 2.852 | 0.039 | -0.031 | 0.038 |
| 90 | 0.023 | 2.851 | 0.038 | -0.040 | 0.037 |
| 91 | 0.013 | 2.837 | 0.038 | -0.030 | 0.037 |
| 92 | 0.031 | 2.908 | 0.041 | -0.049 | 0.039 |
| 93 | 0.021 | 2.950 | 0.042 | -0.041 | 0.040 |
| 94 | 0.016 | 3.021 | 0.042 | -0.035 | 0.040 |
| 95 | 0.008 | 3.102 | 0.047 | -0.028 | 0.045 |
| *Employment* |  |  |  |  |  |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(EMP)** | **Std Dev** |
| 85 | 0.013 | 2.867 | 0.037 | -0.037 | 0.047 |
| 86 | 0.025 | 2.838 | 0.039 | -0.055 | 0.050 |
| 87 | 0.026 | 2.864 | 0.038 | -0.054 | 0.048 |
| 88 | 0.022 | 2.862 | 0.039 | -0.051 | 0.049 |
| 89 | 0.017 | 2.852 | 0.039 | -0.045 | 0.049 |
| 90 | 0.027 | 2.851 | 0.038 | -0.055 | 0.048 |
| 91 | 0.019 | 2.837 | 0.038 | -0.046 | 0.047 |
| 92 | 0.044 | 2.908 | 0.040 | -0.075 | 0.050 |
| 93 | 0.015 | 2.950 | 0.042 | -0.045 | 0.052 |
| 94 | 0.010 | 3.021 | 0.042 | -0.036 | 0.052 |
| 95 | 0.004 | 3.102 | 0.047 | -0.025 | 0.058 |
| *Employment density* |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(EMP/AREA)** | **Std Dev** |
| 85 | 0.016 | 2.867 | 0.037 | -0.031 | 0.036 |
| 86 | 0.036 | 2.838 | 0.039 | -0.050 | 0.037 |
| 87 | 0.034 | 2.864 | 0.038 | -0.047 | 0.036 |
| 88 | 0.027 | 2.862 | 0.039 | -0.043 | 0.037 |
| 89 | 0.022 | 2.852 | 0.039 | -0.039 | 0.037 |
| 90 | 0.034 | 2.851 | 0.038 | -0.047 | 0.036 |
| 91 | 0.021 | 2.837 | 0.038 | -0.036 | 0.036 |
| 92 | 0.041 | 2.908 | 0.041 | -0.055 | 0.038 |
| 93 | 0.030 | 2.950 | 0.042 | -0.049 | 0.040 |
| 94 | 0.027 | 3.021 | 0.042 | -0.046 | 0.040 |
| 95 | 0.018 | 3.102 | 0.046 | -0.041 | 0.044 |

 Table A3 Domar factor regressions on province size. Construction

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Population* |  |  |  |  |  |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(POP)** | **Std Dev** |
| 85 | 0.178 | 2.053 | 0.009 | -0.037 | 0.012 |
| 86 | 0.244 | 2.033 | 0.008 | -0.037 | 0.009 |
| 87 | 0.220 | 2.013 | 0.008 | -0.037 | 0.010 |
| 88 | 0.295 | 2.004 | 0.007 | -0.040 | 0.009 |
| 89 | 0.273 | 1.993 | 0.007 | -0.039 | 0.009 |
| 90 | 0.193 | 1.972 | 0.010 | -0.041 | 0.012 |
| 91 | 0.398 | 1.934 | 0.007 | -0.050 | 0.009 |
| 92 | 0.410 | 1.909 | 0.007 | -0.051 | 0.009 |
| 93 | 0.404 | 1.885 | 0.007 | -0.051 | 0.009 |
| 94 | 0.109 | 1.889 | 0.008 | -0.023 | 0.010 |
| 95 | 0.043 | 1.887 | 0.005 | 0.010 | 0.007 |
| *Population density* |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(POP/SUP)** | **Std Dev** |
| 85 | 0.293 | 2.053 | 0.009 | -0.037 | 0.008 |
| 86 | 0.375 | 2.033 | 0.007 | -0.036 | 0.007 |
| 87 | 0.313 | 2.013 | 0.008 | -0.035 | 0.007 |
| 88 | 0.439 | 2.004 | 0.006 | -0.038 | 0.006 |
| 89 | 0.452 | 1.993 | 0.007 | -0.039 | 0.006 |
| 90 | 0.275 | 1.972 | 0.009 | -0.039 | 0.009 |
| 91 | 0.525 | 1.934 | 0.006 | -0.045 | 0.006 |
| 92 | 0.530 | 1.909 | 0.006 | -0.045 | 0.006 |
| 93 | 0.514 | 1.885 | 0.007 | -0.046 | 0.006 |
| 94 | 0.125 | 1.889 | 0.008 | -0.019 | 0.007 |
| 95 | 0.087 | 1.887 | 0.005 | 0.011 | 0.005 |
| *Employment* |  |  |  |  |  |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(EMP)** | **Std Dev** |
| 85 | 0.208 | 2.053 | 0.009 | -0.041 | 0.012 |
| 86 | 0.312 | 2.033 | 0.007 | -0.043 | 0.009 |
| 87 | 0.299 | 2.013 | 0.008 | -0.044 | 0.010 |
| 88 | 0.380 | 2.004 | 0.007 | -0.046 | 0.009 |
| 89 | 0.339 | 1.993 | 0.007 | -0.044 | 0.009 |
| 90 | 0.258 | 1.972 | 0.010 | -0.049 | 0.012 |
| 91 | 0.471 | 1.934 | 0.007 | -0.055 | 0.008 |
| 92 | 0.485 | 1.909 | 0.007 | -0.056 | 0.008 |
| 93 | 0.478 | 1.885 | 0.007 | -0.057 | 0.009 |
| 94 | 0.139 | 1.889 | 0.008 | -0.026 | 0.010 |
| 95 | 0.066 | 1.887 | 0.005 | 0.012 | 0.007 |
| *Employment density* |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(EMP/SUP)** | **Std Dev** |
| 85 | 0.308 | 2.053 | 0.009 | -0.038 | 0.008 |
| 86 | 0.418 | 2.033 | 0.007 | -0.038 | 0.006 |
| 87 | 0.367 | 2.013 | 0.007 | -0.037 | 0.007 |
| 88 | 0.496 | 2.004 | 0.006 | -0.040 | 0.006 |
| 89 | 0.494 | 1.993 | 0.006 | -0.041 | 0.006 |
| 90 | 0.320 | 1.972 | 0.009 | -0.041 | 0.009 |
| 91 | 0.563 | 1.934 | 0.006 | -0.046 | 0.006 |
| 92 | 0.569 | 1.909 | 0.006 | -0.046 | 0.006 |
| 93 | 0.552 | 1.885 | 0.006 | -0.047 | 0.006 |
| 94 | 0.142 | 1.889 | 0.008 | -0.020 | 0.007 |
| 95 | 0.107 | 1.887 | 0.005 | 0.012 | 0.005 |

 Table A4 Domar factor regressions on province size. Services

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Population* |  |  |  |  |  |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(POP)** | **Std Dev** |
| 85 | 0.106 | 1.345 | 0.006 | 0.018 | 0.008 |
| 86 | 0.133 | 1.331 | 0.007 | 0.024 | 0.009 |
| 87 | 0.131 | 1.350 | 0.006 | 0.020 | 0.007 |
| 88 | 0.130 | 1.346 | 0.006 | 0.018 | 0.007 |
| 89 | 0.139 | 1.347 | 0.005 | 0.017 | 0.006 |
| 90 | 0.085 | 1.351 | 0.005 | 0.014 | 0.006 |
| 91 | 0.156 | 1.357 | 0.005 | 0.017 | 0.006 |
| 92 | 0.176 | 1.361 | 0.004 | 0.017 | 0.005 |
| 93 | 0.170 | 1.366 | 0.004 | 0.016 | 0.005 |
| 94 | 0.129 | 1.368 | 0.005 | 0.015 | 0.006 |
| 95 | 0.120 | 1.371 | 0.005 | 0.014 | 0.006 |
| *Population density* |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(POP/SUP)** | **Std Dev** |
| 85 | 0.215 | 1.345 | 0.006 | 0.020 | 0.006 |
| 86 | 0.267 | 1.331 | 0.006 | 0.026 | 0.006 |
| 87 | 0.241 | 1.350 | 0.006 | 0.021 | 0.005 |
| 88 | 0.237 | 1.346 | 0.005 | 0.019 | 0.005 |
| 89 | 0.236 | 1.347 | 0.005 | 0.018 | 0.005 |
| 90 | 0.149 | 1.351 | 0.005 | 0.014 | 0.005 |
| 91 | 0.254 | 1.357 | 0.004 | 0.017 | 0.004 |
| 92 | 0.272 | 1.361 | 0.004 | 0.017 | 0.004 |
| 93 | 0.273 | 1.366 | 0.004 | 0.016 | 0.004 |
| 94 | 0.236 | 1.368 | 0.004 | 0.016 | 0.004 |
| 95 | 0.216 | 1.371 | 0.004 | 0.015 | 0.004 |
| *Employment* |  |  |  |  |  |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(EMP)** | **Std Dev** |
| 85 | 0.156 | 1.345 | 0.006 | 0.023 | 0.008 |
| 86 | 0.204 | 1.331 | 0.007 | 0.030 | 0.009 |
| 87 | 0.182 | 1.350 | 0.006 | 0.024 | 0.007 |
| 88 | 0.181 | 1.346 | 0.005 | 0.022 | 0.007 |
| 89 | 0.196 | 1.347 | 0.005 | 0.021 | 0.006 |
| 90 | 0.125 | 1.351 | 0.005 | 0.017 | 0.006 |
| 91 | 0.213 | 1.357 | 0.004 | 0.020 | 0.005 |
| 92 | 0.223 | 1.361 | 0.004 | 0.020 | 0.005 |
| 93 | 0.229 | 1.366 | 0.004 | 0.019 | 0.005 |
| 94 | 0.185 | 1.368 | 0.004 | 0.018 | 0.005 |
| 95 | 0.184 | 1.371 | 0.004 | 0.018 | 0.005 |
| *Employment density* |
| **YEAR** | **R2** | **Intercept** | **Std Dev** | **log(EMP/SUP)** | **Std Dev** |
| 85 | 0.257 | 1.345 | 0.006 | 0.022 | 0.005 |
| 86 | 0.327 | 1.331 | 0.006 | 0.029 | 0.006 |
| 87 | 0.280 | 1.350 | 0.005 | 0.022 | 0.005 |
| 88 | 0.276 | 1.346 | 0.005 | 0.021 | 0.005 |
| 89 | 0.280 | 1.347 | 0.005 | 0.019 | 0.004 |
| 90 | 0.181 | 1.351 | 0.005 | 0.015 | 0.005 |
| 91 | 0.296 | 1.357 | 0.004 | 0.018 | 0.004 |
| 92 | 0.303 | 1.361 | 0.004 | 0.018 | 0.004 |
| 93 | 0.316 | 1.366 | 0.004 | 0.017 | 0.004 |
| 94 | 0.280 | 1.368 | 0.004 | 0.017 | 0.004 |
| 95 | 0.268 | 1.371 | 0.004 | 0.017 | 0.004 |