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Abstract

This paper uses a novel measure and detailed plant-level Portuguese data to reexamine the Marshallian hypothesis that specialization and the vertical disintegration of firms should be greater in areas where an industry concentrates. Our measure of firm specialization and vertical disintegration employs a Herfindhal index constructed with occupational shares for all workers within the firm. Controlling for firm size and sector of activity, we find that vertical disintegration is around three percent higher in areas where industries agglomerate. Sensitivity tests reveal that this positive relation is remarkably robust across different specifications.

JEL classification: R12, R39, L25

1 Introduction

How does the scale of production at a location affect the organization of production at this location? Interest in this central question dates back to Smith (1776) who asserted that occupational specialization (or the division of labor) within the firm is "limited by the extent of the market."[1] In his celebrated 1890 text, *Principles of Economics*, Alfred Marshall advanced a related theorem about industrial concentration across space, suggesting that firm specialization and vertical disintegration should be greater in areas where an industry concentrates:

> When an industry has thus chosen a locality for itself, it is likely to stay there long: so great are the advantages which people following the same skilled trade get from near neighbourhood to one another. [...] And presently subsidiary trades grow up in the neighbourhood, supplying it with implements and materials, organizing its traffic, and in many ways conducing to the economy of its material [Marshall (1890), book IV, chapter X].

[1] Recall the well-known example of the division of labor in pin manufacture with which Adam Smith opens *The Wealth of Nations*. When pin manufacture is in a primitive stage of development the whole and undivided process of production of a pin within the firm is carried out by one person. With increases in the extent of markets, however, it becomes increasingly feasible to divide the labor of pin making into a sequence of specialized tasks attended to by detailed workers within the firm. Thus, a transformation of pin making firms comes about, and the labor process is fragmented into several activities, such as drawing, straightening, cutting, pointing, grinding, head-making, whitening, and so on. With increasing volume of output, the division of labor within the firm tends to become increasingly more finely grained.

Marshall's notion that industrial localization would engender vertical disintegration and spur the emergence of a wide variety of specialized suppliers in the area infuses a large body of theorethical work, from the "new economic geography" to modern theories of growth and international trade [see for example Rivera-Batiz (1988), Krugman (1991), Arthur (1994), Venables (1996), Rodríguez-Clare (1996) and Hanson (1996)]. This theorethical research emphasizes the importance of industry-specific external economies.

Less progress has been made in the empirical verification of the Marshallian hypothesis. Within the literature on industrial districts, many case studies illustrate the presence of specialized suppliers and firm vertical disintegration in particular areas and industries [for surveys see Piore & Sabel (1984) and Markusen (1996)]. Yet, the issue of whether these cases have wider relevance remains an open empirical question.

As noted by Rosenthal & Strange (2004), Holmes (1999) represents the only systematic statistical study addressing the Marshallian hypothesis to date. The author found a positive correlation between localization of an industry and firm vertical disintegration for the U.S. manufacturing sector. To measure localization, Holmes (1999) used 1987 employment data at the establishment level. Vertical disintegration was measured using a Purchased Input Intensity (PII) index (the ratio of purchased inputs to output), a measure derived from Adelman's (1955) index of firm vertical disintegration. Yet, the lack of establishment level data for the PII index forced the author to aggregate up the employment data set. The spatial level of aggregation for the 459 industries used in his study varies considerably. For more than 50 percent of the industries the spatial breakdown has 10 or less areas.[2] Beyond this practical constraint, Adelman's (1955) index of firm vertical disintegration has significant theoretical limitations. Above all, the index is sensitive to the stage of the production process. The earlier disintegration occurs in the process, the less sensitive the index becomes to changes in the degree of firm integration.

In this paper we use a novel measure and establishment- (plant-) level Portuguese data to evaluate the proposition that the vertical disintegration of firms should be greater in areas where an industry concentrates. Our approach addresses the essential problem associated with Holmes's (1999) empirical analysis. First, because we have access to detailed establishment data for all regions and industries, we are able to use the plant as the unit of observation. We also know the occupation of every employee in each establishment. This allows us to compute an alternative, improved measure of vertical disintegration based on the occupational specialization within the establishment. Applied to Portuguese data, after controlling for firm size and sector, we find that firms' vertical disintegration is about three percent higher in areas where industries agglomerate.

In the next section we review measures of firm vertical disintegration and motivate our approach to accounting for firm specialization. In section 3, we discuss the measurement of localization of an industry. Section 4 present our main findings and implements several sensitivity tests, while section 5 concludes the paper.

[2] Holmes (1999) notes that these areas can be counties, metropolitan statistical areas, states, or even larger units. For example, the creamery butter industry is partitioned into only two areas: the state of Wisconsin and the rest of the United States.

2 Measuring Vertical Disintegration

The most commonly used measure of firm vertical disintegration is Adelman's (1955) index: the ratio of value added to sales [see Davies & Morris (1995) for a survey]. Limitations of this measure, however, have been pointed out over the years by Barnes (1955), Eckard (1979) and Maddigan (1981). The main problem is the sensitivity to the stage of the production process, well illustrated in Holmes (1999). Consider the following scenario. There are three firms, each one undertaking one of the three stages of a sequential production process. Additionally, suppose that all firms contribute the same amount of added value to the final product. Now, even though all the three firms are vertically integrated to the same extent, because sales increase as we move along the production chain, Adelman's (1955) index will result in a series of decreasing values. Another problem when implementing this measure is the dearth of adequate micro-level data sets. In most countries and regions, data on the value of inter-firm transactions are not available.

In this paper we take a different tack and construct an internal measure of firm vertical disintegration. The analysis is based on a comprehensive Portuguese manufacturing employer-employee data set, the *Quadros do Pessoal*.[3] The data set includes the universe of all plants in Portugal, with precise information on plant location, firm start-up date, sector of activity, actual employment, and characteristics of the workforce. Of particular interest is information on the occupation of entire workforce for each firm. Every worker is coded using the Portuguese National Classification of Occupations (CNP),

[3] This survey collects information for all the establishments operating in Portugal, except family businesses without wage-earning employees.

which follows the current International Standard Classification of Occupations (ISCO).[4] This allows us to construct an establishment-level measure of vertical integration based on occupational specialization within the establishment. If we compare two equally sized establishments in the same industry we would expect the establishment that undertakes more stages of production (the more integrated) to have a larger and more diversified mix of occupations.

In turn, to measure establishment vertical disintegration we propose a Herfindhal index constructed with the shares of workers on each occupation. That is,

$$H_i = \sum_{z=1}^{Z_i} \left(\frac{x_{zi}}{x_i} \right)^2 , \tag{1}$$

where x_{zi} denotes establishment's i employment in occupation z, x_i stands for total employment in establishment i, and Z_i is establishment's i total number of occupations.

To get some insight about the validity of our proposed measure we can apply this same logic to manufacturing sectors as a whole. Because subsectors tend to correspond to different production stages of sectors, if a correspondence exists between the occupations and the different phases of the productive process, then we would expect an increase in the Herfindhal index of occupations (calculated at the industry level) as we move from a broader to a finer definition of an industry. Table 1 shows the results of such exercise, by computing average Herfindhal indexes for different levels of aggregation of

[4] The ISCO is a tool for organizing jobs into a clearly defined set of groups according to the tasks and duties undertaken in the job.

the manufacturing sectors. Information is for the year of 2005, the most recent available year in our data set. We make use of the Portuguese Standard Industrial Classification system (CAE rev.2) at the 2-digit (22 industries), 3-digit (100 industries) and 5-digit (315 industries) levels.[5] Occupations are coded according to the Portuguese CNP at 6-digits, the more detailed level of disaggregation. At this level, we have 1,751 different occupations in the manufacturing sector as a whole for the year of 2005.

[insert Table 1 about here]

As can be seen in Table 1, the Herfindhal measure behaves as expected when we move from a broader to a finer definition of industries. Yet, comparing the Herfindhal in this manner can be misleading because the average gives equal importance to all sectors within each level of CAE rev.2. Hence, we also compared the Herfindhal of each subindustry with its parent in the industry.[6] We found that 81 of the 98 3-digit Herfindhal indexes for which the CAE rev.2 distinguish the 2 from the 3-digit levels are larger than their 2-digit counterparts (83 percent) and that these numbers are 246 out of 284 (87 percent) for the 5 versus 3-digit comparison.

It may be argued that these results are driven by chance. To address this concern, we implemented a simple permutation test. The test builds on the idea that if the mix of occupations is the same in the sector and the subsectors then differences in Herfindhals should be attributed to chance alone. Hence,

[5] These are the numbers of industries we observe for this particular year.

[6] It should be noted here that for 2 industries the Portuguese Standard Industrial Classification system (CAE rev.2) does not distinguish the 3 from the 2-digit levels. The same occurs for 31 industries when we move from 5 to 3-digit. In these cases, by definition, the Herfindhal for the industry is identical to that of the subindustry.

to test this hypothesis, for each sector we randomly rearranged the assignment of existing occupations to workers. This procedure was implemented 1,000 times and the Herfindhal indexes for each subsector were calculated in each permutation of the data. Comparison of the actual Herfindhal values for the subsectors with those obtained by permutation allow us to infer the likelihood of obtaining a value as extreme (as high) as the one actually observed. Thus, we perform a one-sided test of hypothesis using as reference the empirical distribution of the Herfindhals obtained by the procedure described above. For 93 percent of the 81 3-digit industries for which the actual 3-digit Herfindhal indexes are larger than their 2-digit counterparts we reject the hypothesis at a 95 percent level of significance and the corresponding percentage for the 246 5-digit industries is 86 percent.

This industry-level analysis lends credibility to the idea that occupation data can be used to measure vertical disintegration. We now turn to the measurement of industry concentration, or localization.

3 Measuring Localization

Typically, measures of industry localization are based on employment. Some authors [such as Holmes (1999) and Wheeler (2006)] have used aggregate local employment while others calculate location quotients [see for example Kim (1995) and Holmes & Stevens (2002)]. These quotients summarize the extent to which industries are disproportionately represented in total employment (relative to the national level) across a collection of regions.

As argued in Figueiredo, Guimarães & Woodward (2007) the use of employment based indexes to measure localization is questionable. These measures broadly capture agglomeration, but they do not specifically measure Marshallian industry localization. The reason is that these kind of indicators encompass both firm internal scale economies and Marshallian external economies. Consider for example the employment location quotient. The quotient will be the same whether employment in a region results from a cluster of small establishments or from a single large establishment. Clearly, a large employment location quotient that results from one single large plant does not reflect external localization economies of any type. In this case, we do not have a cluster of firms and thus geographic concentration (as measured by employment-based measures) is entirely explained by internal returns to scale.

Figueiredo et al. (2007) proposed an alternative statistic for the measurement of localization that is derived from the probabilistic dartboard location model of Ellison & Glaeser (1997). This statistic expurgates the effect of internal scale economies from the localization measure. Thus, it more closely reflects the firm externalities of Marshallian industrial districts. The statistic is similar to a location quotient where the numerator is replaced by the shares of each region in the total number of plants for an industry. Formally,

$$L_{jk} = \frac{(n_{jk}/n_k)}{(x_j/x)} \ , \tag{2}$$

where n_{jk} stands for the number of plants in location j and industry k and n_k is the total number of plants in industry k.[7] More recently, Guimarães, Figueiredo & Woodward (2008) extended this work and demonstrated how

[7] x_j and x are, respectively, total employment in region j and in the country. As shown in Figueiredo et al. (2007), the location quotient in (2) is not comparable across industries. In our regressions this problem is addressed by introducing industry fixed effects.

the framework of Ellison & Glaeser (1997) can also be used to derive statistical tests for the measure in (2).[8]

We are interested in testing whether firms inside areas of localization of an industry are more vertically disintegrated than more isolated firms. Therefore, in our empirical analysis, the identification of areas of localization is implemented by dichotomizing the location quotient between values above and below one.[9] To obviate the problem of having the own plant contributing to both sides of the regression we excluded the current plant from the calculation of the localization measure.[10] We calculate localization measures using the Portuguese *concelho* as the spatial unit of analysis.[11] Industries are classified according to the 3-digit (103 industries) classification of the Portuguese Standard Industrial Classification system (CAE rev.2).

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[8] Later, in the empirical analysis, we will use the statistic,

$$W_{jk} = \frac{J\left[\log(L_{jk})\right]^2}{(J-2)n_{jk}^{-1} + \widetilde{n_k}} \ ,$$

to check whether the plant counts based location quotient in (2) provides evidence of localization in excess of what would be expected to arise randomly. In the above formula $\widetilde{n_k}$ is the mean of all n_{jk}^{-1} for industry k. The statistic is asymptotically distributed as chi-square with one degree of freedom.

[9] In addition to this localization dummy variable, later on, as part of our sensitivity tests, we will also use the location quotient directly in the regression as in Holmes (1999).

[10] That is, we computed the following plant count location quotient to construct the dummy variable that enters in our regressions:

$$L_{ijk} = \frac{(n_{jk}-1)/(n_k-1)}{(x_j - x_i)/(x - x_i)}) \ .$$

[11] We restrict analysis to continental Portugal. The *concelho* is a Portuguese administrative region roughly equivalent to the U.S. county. In continental Portugal there are 278 *concelhos* with an average area of 320.3 square kilometers.

4 Empirical Results

4.1 Main Results

Table 2 presents our main results. The dependent variable is the logarithm of the establishment-level Herfindhal index in (1) and the localization variable is the dummy variable described above. We used panel data for the period 2002-2005.[12] Besides fixed effects for industry and year, in column (1), we also introduced a fixed effect for establishment size. This was done mainly because the range of variation of the Herfhindhal is constrained by the size of the establishment.[13] The models were estimated by ordinary least squares with a correction for the standard errors. This correction accounts for possible unobservable correlation between repeated observations (i.e., the same establishment in different years) and produces rather conservative t-statistics.[14]

The use of fixed effects for establishment size is desirable because it does not impose a functional structure in the relation. However, it has the adverse effect of removing all the singleton observations, a problem more likely to affect large establishments. Thus, we also ran the regression in column (2) of Table 1 where we include size directly as a regressor.

Both regressions produce similar results. As can be seen, controlling

[12]We choose this particular period of time because the *Quadros do Pessoal* data set does not report worker level data for the year of 2001. Another reason is that in 1999 the number of *concelhos* has been changed in continental Portugal.

[13]We also excluded from the regressions establishment with only one employee because in that case the Herfindhal is constrained to 1.

[14]We use cluster-robust standard errors [see Cameron & Trivedi (2005)]. In our application, this generates more conservative estimates than conventional heteroskedasticity-robust (White) standard errors.

for size and sector, we found that establishment's vertical disintegration is around 3 percent higher in areas where industries agglomerate.

[insert Table 2 about here]

4.2 Sensitivity Tests

We now implement several sensitivity tests to check the robustness of the positive relation shown above. There are two sets of tests. The first is for subsamples. Then, later, we will test for different variable specifications.

4.2.1 Tests for Subsamples

Vertical integration within the plant occurs where the different stages of production of one product are carried out in succession by the same plant and where the output of one stage serves as the input to the next. It can be argued that if one worker undertakes several of these different stages of production within the plant, then our index would fail to measure the extent of vertical disintegration. Workers are unambiguously assigned to one occupation by the CNP classification. This potential problem is more likely to occur in small establishments than in larger ones. Thus, in our first test, we broke the sample in two different classes of establishment size: below or equal to the median and above the median.[15] Regressions for these two subsamples are shown in Table 3, columns (1) and (2). As can be seen in this table, the relationship still holds for the large size subsample and the estimated coefficient on the localization dummy is in line with that in the main regression in Table 2.

[15] The median value for the size of the establishments in our sample is six workers.

[insert Table 3 about here]

Another potential drawback of our analysis is that younger firms may have not reached their optimal structure of occupations and this may bias the results. Ono (2003) puts forward the argument that firms need time to develop their ties with business partners and find their optimal matches. Thus, our second test separates establishments according to their firm's age. Columns (3) and (4) of Table 3 show that the relationship holds for both establishments pertaining to the younger firms (with an age below or equal to the median) and to more mature firms (above median age).[16] Again, the estimated coefficients on the localization dummy are in line with that in the main regression in Table 2.

As in Holmes (1999), we also split our sample according to the Ellison & Glaeser's (1997) index.[17] In Table 3, column (5), we show regressions for the industries in the top half of the Ellison & Glaeser's (1997) measure. Results for the other half, the least geographically concentrated industries, are in column (6).[18] We obtain estimates in line with Holmes (1999). For the most concentrated industries, the coefficient is much larger than in the main regression in Table 2, and it goes to zero for the least concentrated ones. As argued by Holmes (1999), this pattern provides some evidence that increased opportunity for vertical disintegration may be a factor that explains why some industries concentrate in space. Establishments in dispersed industries

[16] The median age for the firms in our sample is eleven years.

[17] For the reason discussed in section 3, we computed the Ellison & Glaeser's (1997) index using counts of plants instead of employment. This count based version of the Ellison & Glaeser's (1997) index is discussed in Guimarães, Figueiredo & Woodward (2007).

[18] The concentration measure has been calculated using data for the year of 2005.

do not specialize even when they locate in areas of agglomeration of their industry.

4.2.2 Tests for Different Variable Definitions

In this subsection we test the robustness of the relationship by employing alternative definitions for the main right and left-hand side variables in the regression. To start with, we checked whether changes in the definition of the right-hand side variable affected our main results. In the first test [Table 4, column (1)], we used the 5-digit (325 industries) classification of the Portuguese Standard Industrial Classification system (CAE rev.2) to calculate the location quotient. This regression allows us to test if the relation still holds when we use a finer classification of industries. Then, in Column (2), we implemented a second experiment by making use of the statistical test discussed earlier to define our localization dummy variable. Now, instead of dichotomizing the location quotient above and below unity, we coded the variable as one only when the quotient passed the one-sided test at the 95 percent level of significance. This statistical test allows for a stricter definition of areas of localization because it accounts for spurious geographic concentration (that is, concentration that occurs by chance alone). Finally, in Table 4, column (3), we make a third experiment by entering the logarithm of the plant count location quotient directly as a regressor instead of the localization dummy variable.[19]

We also performed similar robustness checks for the left-hand side vari-

[19] A continuous employment quotient as in Holmes & Stevens (2002) was also tried. Results are not reported because they are very similar to those obtained with the plant count continuous version shown in Table 4.

able. As indicated before, our measure of vertical disintegration relies on the 6-digit level of the Portuguese National Classification of Occupations (CNP). Because the *Quadros do Pessoal* data set is collected by means of a self-reported questionnaire it may be argued that with the 6-digit classification system for occupations there is more room for coding errors and ambiguities. If that were the case, the Herfindhal index could reflect more variability than that implied by the actual division of labor within the establishment. To check if this potential problem is biasing our results, in the regression in column (5) of Table 4, we computed the Herfindhal index using the 3-digit level of the CNP (116 job groups) instead of the 6-digit (1,891 groups) used so far.[20] At this coarser level of aggregation we loose precision but room for coding errors and ambiguities is smaller.

A criticism leveled by Eckard (1979) to establishment-based measures of vertical disintegration is that they ignore multiplant firms. In this case, vertical disintegration may occur within a firm but across establishments. Again, this situation results in measurement error that could bias our estimates. Accounting for this type of disintegration requires information linking establishments with firms. Because we have this information, in the last column of Table 4 we used the logarithm of a Herfindhal at the firm level as our left-hand side variable.[21]

[insert Table 4 about here]

As can be seen in Table 4, the positive relationship between vertical disin-

[20]These are the numbers of occupations groups in the manufacturing sector we observe for the 2002-2005 period.

[21]All establishments of a firm were lumped together if they belonged to the same industry and were located in the same *concelho*.

tegration and localization of an industry still holds across specifications. The magnitude of the coefficients for the localization variable and the quality of the adjustment are also quite similar for the different specifications. The only exception is the regression that employs a coarser definition of occupations. In that case, the estimated coefficient is slightly higher but the quality of the adjustment falls considerably. Note also that the coefficient of the regression with the continuous location quotient is not comparable with the others.

5 Conclusion

Marshall's hypothesis that industry localization would prompt vertical disintegration and the emergence of specialized suppliers underlies a large body of recent theorethical work, from the "new economic geography" to modern theories of growth and international trade. These studies emphasize the importance of industry-specific external economies.

Less research has been done regarding the empirical verification of Marshall's central claim. Case studies of industrial districts often point to the presence of specialized suppliers and vertical disintegration of firms in particular areas. Yet rigorous statistical research is rare. Thus far, Holmes (1999) remains the only systematic empirical study to address the question.

Our paper posits a new measure of vertical disintegration and tests it against plant-level Portuguese data. The results provide evidence supporting Marshall's suggestion that vertical disintegration of firms should be greater in areas where an industry concentrates. Controlling for firm size and sector of activity, we found that firm vertical disintegration is around three percent higher in areas where industries agglomerate. Various sensitivity tests indicate that this positive relation is remarkably robust across specifications.

In an original approach, we develop an internal occupational measure of firm disintegration. This measure is a Herfindhal index constructed with the shares of workers on each occupation within the firm. It overcomes the long-standing problem associated with Adelman's (1955) measure of firm vertical disintegration: The earlier disintegration occurs in the production process the less sensitive the measure becomes to changes in the degree of firm integration. Indeed, there is no reason to believe that our index is sensitive to the stage of the production process. Moreover, because our measure is constructed with data on workers' occupations, increased availability of employer-employee data sets with spatial information should allow the extension of our approach to other countries and regions.

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Table 1: **Average Herfindhal Index Across Sectors**

CAE rev.2	2-digit	3-digit	5-digit
Herfindhal Index	6.3%	6.8%	9.1%
Number of Sectors	22	100	315

Table 2: **Regression Estimates**

	(1)	(2)
Localization Dummy	0.030 (7.7)	0.029 (7.2)
Log of Size	-	-0.311 (-133.1)
Fixed Effects		
Size	Yes	No
Industry	Yes	Yes
Year	Yes	Yes
R^2	42,0%	39.7%
N	167,921	167,921

Note: t-statistics associated with cluster-robust standard errors in parenthesis.

Table 3: **Regression Estimates for Subsamples**

	Classes of Size		Classes of Age		Most versus Least Concentrated Industries	
	(1) Small	(2) Large	(3) Young	(4) Old	(5) Most	(6) Least
Localization Dummy	0.024 (5.7)	0.030 (4.4)	0.031 (6.2)	0.028 (4.6)	0.047 (7.9)	0.009 (1.6)
Log of Size	-0.482 (-103.2)	-0.237 (-53.0)	-0.278 (-82.5)	-0.326 (-103.1)	-0.293 (-101.9)	-0.341 (-87.5)
Fixed Effects						
Industry	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
R^2	24.4%	28.4%	30.8%	43.1%	39.4%	40.5%
N	84,641	83,280	86,345	81,576	93,706	74,215

Note: t-statistics associated with cluster-robust standard errors in parenthesis.

Table 4: **Regression Estimates for Different Variable Definitions**

	(1) 5-digit Industry Classification	(2) Statistically Significant Location Quotients	(3) Continuous Location Quotient	(4) 3-digit Occupations Classification	(5) Herfindhal For Firms
Localization Variable	0.021 (5.0)	0.036 (8.8)	0.020 (11.0)	0.042 (11.6)	0.030 (7.3)
Log of Size	-0.308 (-134.2)	-0.311 (-132.9)	-0.315 (-134.2)	-0.201 (-103.8)	-0.308 (-133.7)
Fixed Effects					
Industry	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
R^2	41.3%	39.7%	40.2%	30.1%	40.0%
N	167,921	167,921	158,197	167,921	164,481

Note 1: t-statistics associated with cluster-robust standard errors in parenthesis.

Note 2: with the exception of column (3), the localization variable is a dummy. For column (3) we use the logarithm of the location quotient.

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