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Agglomeration, Diversity and Regional Growth

The effects of poly-industrial versus mono-industrial agglomerations

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Abstract

The objective of this paper is to empirically examine the importance of the structure of agglomeration on productivity and growth. To accomplish this we will include the degree of co-agglomeration of similar industries as an explanatory variable in the empirical analysis, while simultaneously controlling for the degree of industry-specific agglomeration. To the best of our knowledge, the impact of co-agglomerated industries on productivity has not previously been investigated. The empirical analysis confirms a positive statistical relationship between interdependent and co-located industries on labour productivity.

JEL: R11, R12

Keywords: Co-agglomeration, productivity, growth

1. Introduction

Interest in the spatial distribution of economic activities has surged during the last two decades; propelled by trade liberalization, deregulation at national and international levels, and technological progress. The theoretical breakthroughs achieved in economic geography, where location basically is modeled as a function of trade costs and scale economies, have set off a wave of predominantly theoretical research in this strand of economics.

Although theories of economic geography primarily address issues of relevance for the spatial distribution of production, they also contain clear connections to growth. The endogenous growth theory constitutes the bridge between agglomerated production structures and growth. According to the latter theory, growth is primarily increasing in the in the accumulation of knowledge through spillover to other users, i.e. it is only partially excludable and appropriated by the firms investing in knowledge. Economic geography contends that proximity is essential in order to access spillovers, pecuniary and non- pecuniary, originating in the interaction between people, firms and institutions, through vertical and horizontal linkages. Furthermore, concentrated production also gives rise to external scale effects. Thus there would appear to be a clear link between growth and densely concentrated production. This has preciously been discussed in the theoretical literature (Fujita and Thisse, 2002).

However, empirical evidence regarding the positive effects of agglomeration on growth is, to say the least, scarce. An exception is Ciccone and Hall's (1996) study on the U.S., where they confer a positive relationship between the density of regional employment and labour productivity. Braunerhjelm and Borgman (2004) corroborated these results implementing regional data from Sweden, cross-tabulated on industries and regions.

A neglected aspect of these studies concerns the composition of geographically concentrated production structures, and its relevance for productivity and growth. For instance, does it matter whether a strong regional agglomeration is based on one industry or on several interrelated industries? One can think of reasons why specifiallized *mono-industrial agglomerations* may benefit productivity, such as a reduction of redundancy in research, reducing costs at the industry level, along with increased vertical specialization and exploitation of economies of scale. Moreover, knowledge spillovers emanating from the same industry may be easier to appropriate, yielding strong Marshall-Arrow-Romer (MAR) externalities.

There are also reasons to believe that *poly-industrial agglomerations* may prompt higher productivity and growth by providing a richer and more varied knowledge base from which innovations emerge.[2] That is, Jacobian inter-industry externalities may be more powerful then Marshall-Arrow-Romer externalities. Furthermore, a diversified production structure may also diminish a region's vulnerability to exogenous shocks. A classical case of the importance of combining different technologies would be the Wright brothers, who utilised inputs from three technological fields; the bicycle, the combustion engine and dragon flying, when they constructed the first (flying) aircraft.

The objective of this paper is to empirically examine the importance of the structure of agglomeration on productivity and growth. To achieve this we will include in the empirical analysis the degree of co-agglomeration of similar industries as an explanatory variable, while simultaneously controlling for the degree of industry-specific agglomeration. To the best of our knowledge, the impact of co-agglomerated industries on productivity has not previously been investigated.

The next section contains a brief survey of previous research while section three presents the data, the variables used in the empirical analysis and the hypotheses to be tested. Thereafter the econometric model is introduced followed by a discussion of the results. Section five summarizes and concludes.

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[2] See Audretsch and Feldman, (1996) and Feldman and Audretsch (1998). A particular angle related to these ideas is advanced in Florida's (2002) work on the importance of heterogeneity to spur creativity.

2. Location and growth: Previous research

The economic analyses of regionally concentrated production structures can broadly be classified into two veins in the literature. The first is based on the neo-classical paradigm and can be traced back to Marshall's explanation of why production tends to concentrate in certain regions.[3] The second thread in the literature adheres more to the evolutionary school , originally focussing on technological trajectories, relying on path dependency, economies of scale and lock-in effects. Although there is considerable difference between them, to some extent they both share the intellectual platform. We will focus on the link to growth in this brief literature survey.

Perhaps the first attempt to rigorously address the issue of agglomeration and growth was undertaken by a group of economists in the 1950s. The well-known concept of "growth poles" was coined by Perroux (1955) where spatially concentrated milieus were considered to be of importance to the entire economy's growth performance. A few years later, and based on Perroux, Kaldor (1961) claimed that early growth in these core regions had initiated private and social dynamics that were based on increasing returns to scale, which generated self-perpetuating mechanisms in location. Myrdal (1957) and Hirschman (1958) argued that locally bounded spillovers, along with other market forces, tended to increase inequalities between regions due to "cumulative causation". The advantages of locating in growth regions were mirrored by amplified disadvantages in peripheral regions and a continuous diminishing of the "trickle-down" effects. Similar thoughts have been presented in the urban economics vein of the literature (Jacobs 1969, Blacks and Henderson 1999, Acs 2002, Fujita and Thisse 2002).

[3] These are access to skilled labour, specialized intermediate products, and technological spillovers.

Marshallian forces and economies of scale constituted the main basis in Krugman's (1991a,b) seminal contributions in the early 1990s, where he extended the then "new" international trade model to include the spatial distribution of economic activities between two countries.[4] This thread was followed by an impressive amount of research that, in one way or another, modified and/or enriched previous models (Fujita et al, 1999). However, the link between growth and spatial concentration has only more recently been developed (Waltz 1996, Baldwin 1999, Martin and Ottaviano 1999, 2001, Baldwin, Martin and Ottaviano 2001, Fuijta and Thisse, 2002). The most frequently imposed mechanism to enhance growth is through the migration of knowledge, embodied in individuals or firms.[5]

A somewhat different approach builds on the works of Arthur (1990) and David and Rosenbloom (1990), originally developed to explain the evolution of technological trajectories. They claimed that evolution is rooted in path dependency, increasing returns to scale and the irreversibility, or lock-in effects, which occur after a certain level, or diffusion, has been reached, in a technology regime. Obviously, there appears to be close parallels to the emergence of regionally agglomerated production structures and growth. In particular, Arthur (1988) shows that in the case of an unbounded agglomeration, the initial random decision process will eventually evolve into a situation where a single location site of production emerges and continues to grow.

Paired to this are the ideas advanced in the organizational ecology literature (Carrol 1988, Hannan and Freeman 1989, Staber, 1997). Density is shown to affect founding rates of an organizational population (e.g., a given type of firm) through institutional processes. However, growth is not unbounded since at some point it will become counterbalanced by competition within and between populations. More precisely, these

[4] See Puga (1999) and Davies (1999) for a criticism of the underlying assumptions.
[5] Empirical evidence as regards the importance of skilled labour for growth are however weak (Jones 1995, Greenwood and Jovanovic, 1998). Acs et al (2004) argue that the explanation has to do with poor modelling of the diffusion of knowledge.

models define locational (gross) benefits as composed of geographical and agglomeration benefits, matched by costs distributed on the same two categories (Artur 1988, 1990, Maggioni 2002). The geographical factors refer to the quality of local factors of production, the efficiency of specialised suppliers, the quality of urban and industrial infrastructures, etc. Agglomeration factors depend on the number of incumbents and their interaction. [6]

As the number of firms increase in a sparsely populated region , benefits initally increase due to agglomeration economies, but at some point turn negative when congestion and competition more than counterbalances for agglomeration economies. Increase in costs is related to the limited pool of local inputs, leading to upward pressure on prices, plus other negative externalities that tend to appear.[7] Hence, each additional firm that enters a geographic agglomeration, or cluster of firms, increases the net average profitability of locating in the cluster only up to a threshold. After that point, any new entrant lowers the average net benefits available to themselves and to each resident firm.

Contemporaneously as these models were developed, several studies empirically examined the degree of geographical concentration in production. Krugman (1991) used locational Gini-coefficients to quantify the degree of agglomeration of industries in the U.S. Three years later Ellison and Glaeser (1994) presented an alternative index of geographic concentration which takes as its points of departure the importance of proximity to natural resources, input-output linkages and knowledge spillovers in the location of economic

[6] See also Porter (1990) who claims that productivity is increa[illegible] in strong vertical and horizontal links in the "diamond model". According to Porter, the availability of a pool of competent factor inputs is the most important ingredient in the diamond model.

[7] An alternative explanation for the convexity of the locational costs function for firm *f* runs as follows: the locational costs function is composed by a "fixed" and a "variable" component. The fixed part of the costs (geographic costs) decreases as the number of entrants increase; while the variable part increases (because of competition) as the number of entrants increase. The combination of these two effects produces an U-shaped (convex) cost curve as the interaction between fixed and variable costs of production in standard microeconomics textbooks. Correspondingly, there exists an inverted U-shaped benefit function.

activities. However their index did not differentiate between these factors when geographic concentration was measured.[8]

The empirical work of both Krugman and Ellison and Glaeser revealed a strong geographical concentration within the U.S. economy. These results were corroborated on studies applying the same method on data distributed on regions and industries in France (Maurel and Sedillot, 1999) and in Sweden (Braunerhjelm and Johansson 2003, Braunerhjelm and Borgman, 2004).

The first rigorous attempt to estimate the effect of geographically concentrated production structures on economic growth was Ciccone and Hall's (1996) study on the relationship between regional employment density and labour productivity growth. Implementing cross-sectional data for 1988, and controlling for education and capital intensity, they found a strong impact of employment density on labour productivity growth. In a follow-up study Ciccone (2002) concluded that similar effects pertained to Europe. More recently Braunerhjelm and Borgman (2004), using the Ellison and Glaeser index and controlling for education, regional industry specialisation, regional population, industry plant size and entry rate, found a positive correlation between the EG-index and labour productivity growth in the 1990s.

3. Data, variables and hypotheses

All data refers to Sweden and are obtained from Statistics Sweden (SCB). The data covers the entire population and is sorted by year (1993, 1996, and 1999), region (70 labour market regions) and industriy (ISIC three-digit level). Due to constraints on the availability of data at

[8] See Duranton and Overman (2002) for a criticism of the Ellison-Glaeser method.

more disaggregated levels, on the service sectors, the analysis will be restricted to manufacturing industries.

There are some missing values in the database, implying that a variable has been assigned a value of zero. Missing values can be explained by several reasons, such as confidentiality or simply because Statistics Sweden failed to find information about a particular variable. There are however relatively few missing values and the magnitude of the database suggests that the conceivable bias, due to missing values, would be negligible.

The measurement of co-agglomeration

The Ellison and Glaeser index (henceforth called the EG-index) is one of the most frequently used measures of regionally concentrated production structures in economic geography (Ellison and Glaeser, 1994). Their co-agglomeration measure, which is an extended and modified version of their original index, presented a few years later (Ellison and Glaeser, 1997) has received considerably less attention. Ellison and Glaeser applied this index to the U.S. industries and analyzed whether industries are regionally concentrated because individual industries agglomerate, or, because different industries are co-agglomerated. They concluded that co-agglomeration does exist within industries that belong to a common aggregated industry class, but that there is a great deal of heterogeneity across industries.

The co-agglomeration index measures to what extent there is a correlation in the location choices of plants belonging to different industries, where the underlying mechanisms triggering co-location are assumed to originate in spillovers and natural advantages. Examples are, different electronic manufacturing industries that may co-locate to benefit from spillovers, or shipping and shipyards that both tend to locate near costal regions. The co-agglomeration index does not take input-output linkages explicitly into account, although

Ellison and Glaeser claim that many industries with strong input-output linkages were also co-agglomerated.

To construct the co-agglomeration index a number of *r* industries, which we believe would gain from co-location, are chosen. Let N_j represent the number of plants in the *j*th industry, while l_j is the *j*th industry's share of the total employment in those *r* industries and H_j is the plant Herfindahl index of the *j*th industry. We also derive the total Herfindal index,

$$H = \sum_{j=1}^{r} l_j^2 H_j$$

which represents the whole group of *r* industries. The region's share of employment in the *r* industries compared to the region's share of total employment is defined as,

$$G = \sum_i (s_i - x_i)^2 \qquad (1)$$

where s_i is region *i*'s share of the aggregate employment in the *r* industries, and x_i is the region's share of total aggregate employment.

With the help of each industry's individual EG-index, represented by $\hat{\gamma}_j$ (see Appendix 1) the Ellison and Glaeser co-agglomeration index (γ^c) is constructed in the following way;

$$\gamma^c \equiv \frac{\left[G \Big/ \left(1 - \sum_i x_i^2\right)\right] - H - \sum_{j=1}^{r} \hat{\gamma}_j l_j^2 (1 - H_j)}{1 - \sum_{j=1}^{r} l_j^2} \qquad (2)$$

where γ^c is an unbiased estimator of the tendency for a plant in industry *j* to locate near plants in the *r* industries, whereas $\hat{\gamma}_j$ is the estimate of the tendency for a plant in industry *j* to locate near other plants belonging to the same industry *j* . According to Ellison and Glaeser, values of γ^c above 0.05 imply high co-agglomeration among the *r* industries, whilst values of γ^c below 0.02 suggest that agglomeration predominantly takes place between plants belonging to the same industry. The co-agglomeration index is then rescaled by;

$$\lambda = \frac{\gamma^c}{\sum_j l_j \hat{\gamma}_j} \qquad (3)$$

where, according to Ellison and Glaeser, a value of λ close to 1 reflects an almost perfect correlation of spillovers (together with factors related to natural advantages) across the *r* industries. The interpretation is that co-agglomerating forces prevail over agglomerative forces. Conversely, a value of λ close to 0 suggests that spillovers and natural advantages are almost entirely specific to the *j*th industry.

Variables and hypotheses

The dependent variable is labour productivity (LPROD), defined as the value added per employee and delineated in millions of Swedish kronor.[9] This variable is calculated by aggregating all the value added, divided by the total number of employees, in one industry and region.

[9] Always expressed at the price level of 1999. Value added is calculated as the income of the business – the costs of the business +/- changes in stocks of goods.

The prime purpose is to estimate the relationship between labour productivity and poly-industrial agglomeration (POLY-AGGL),as defined by λ above. The difficulty is to determine which industries that should be included in this index. To some extent each region is likely to produce a unique set of industries working together and exploiting externalities. To model this would be extremely time consuming and requires data which is not readily available . Thus we settle with a poly-industrial agglomeration index for the manufacturing industries, defined as those industries at the three digit ISIC level belonging to the same two digit level. This is consistent with the theoretical prediction that similar industries locate together in order to extract spillovers between plants. Increased access to spillovers from related industries, rather than just from each individual industry, are expected to enhance value-added and production of firms. Thus, we hypothesize a positive impact of POLY-AGGL on labour productivity.

The poly-industrial agglomeration index treats the *r* industries included in the index the same regardless of whether we are analysing a region where the industries are densely located or their presence is hardly noticeable (since it is a nation-based measure). One might suspect that the plants located in regions where the *r* industries have dense production will benefit from the positive effects of co-location more than those plants in regions where production is scarce. We implement a set of control variables to take these effects into account. Firstly, we control for an industry's regional specialization through indexes (RSPEC); defined as the share of total employment in one region belonging to an industry *j* divided by the corresponding fraction on the national level. A stronger specialization should be positively correlated with the dependent variable, due to external economies of scale. However, since the dependent variable, labour productivity, has employment in industry *j* for each specific region as the denominator, a negative correlation cannot be ruled out.

Secondly, we integrate the poly-industrial agglomeration index with the regional specialisation index by simply multiplying the two variables (POLY-SPEC). This variable attributes extra weight to the poly-industrial agglomeration index in regions where one of the *r*-industry has particularly high employment.. A modified version of this measure will also be used (POLY-SPEC2), where the poly-industrial agglomeration index is multiplied by a specialisation index that embraces all *r* industries.[10] To avoid multicollinearity between POLY-AGGL, POLY-SPEC or POLY-SPEC2, they will be introduced separately into the regressions. All three indexes are expected to exhibit a positive influence on labour productivity.

In addition, we control for each industry's individual agglomeration, as captured by the EG-index, measuring regional concentration within an industry (MONO-AGGL). Theory, along with previous empirical evidence, indicates a positive relationship between the EG-index and labour productivity.

The remaining control variables relate to internal economies of scale (SIZE), knowledge intensity (EDU) and entrepreneurship (ENT). Internal economies of scale are defined as the average plant size of an industry in a specific region and SIZE is measured as the total number of employees in industry *j* and region *i*, divided by the number of plants in the same industry and region. By introducing the variable (EDU), that measures the share of all employees in industry *j* and region *i* that have a university/college education, we can quantify the "quality of labour" as a proxy for knowledge intensity. Both SIZE and EDU are expected to positively influence labour productivity.

The final control variable, entrepreneurship (ENT) is measured as the proportion of self-employed in industry *j* and region *i*. As firms begin on a small scale, this is used as a proxy for entrepreneurial activity, or recently established firms, within an industry

[10] The specialisation index for the *r* industries is defined as the share of total employment in one region that belong to the *r* industries, divided by the corresponding fraction on the national level.

and region. Drawing from recent empirical research, a positive correlation between ENT and labour productivity seems likely (e.g. Acs and Armington 2003, Audretsch and Keilbach, 2003). However, data limitations force us to proxy entrepreneurs by the proportion of self-employed but it is not evident that the entrepreneurial spirit is captured by that variable. Hence, it is difficult to *a priori* hypothesize the effect our method of measuring of entrepreneurship may have on labour productivity.

Industry dummies (IDUM) have also been implemented on the three-digit level in order to account for industry specific differences.

Econometric model and results

The model that will be used in order to study the relationship between poly-industrial agglomeration and labour productivity can be written as:

$$\begin{aligned} LPROD_{j,i,t} &= \alpha + \beta_1 POLY\text{–}AGGL_{j,t} + \beta_2 MONO\text{–}AGGL_{j,t} + \beta_3 RSPEC_{j,t,t} + \beta_4 SIZE_{j,i,t} \\ &+ \beta_5 EDU_{j,i,t} + \beta_6 ENT_{j,i,t} + \beta_7 IDUM_{j,t} + \varepsilon_{j,i,t} \end{aligned} \tag{4}$$

where index *j* denotes industry, *i* denotes region and *t* denotes time. The time period in the regression is 1996 to 1999. Fixed effects estimation techniques are applied, where we control for the three-digit industry specific differences by using industry dummies and for heteroskedasticity using Whites (1980) method. The error term is then assumed to exhibit standard properties. However, to ensure that the assumption of no autocorrelation does not distort the results, a regression using the generalized least-squares method, which accounts for autocorrelation, will also be estimated. Note also that β_1 refers to POLY-AGGL, POLY-SPEC or POLY-SPEC2 in the respective regressions, since these variables never appear in the same regression.

I order to investigate the dynamics between poly-industrial agglomeration and labour productivity, we will also estimate a corresponding model in first differences. This will be specified as;

$$\Delta LPROD_{j,i} = \beta_1 \Delta POLY-AGGL_j + \beta_2 \Delta MONO-AGGL_j + \beta_3 \Delta RSPEC_{j,i} + \beta_4 \Delta SIZE_{j,i} + \beta_5 \Delta EDU_{j,i} + \beta_6 \Delta ENT_{j,i} + \varepsilon_{j,i} \quad (5)$$

where the first differences will be calculated according to the formula,

$$\Delta LPROD = LPROD_{1999} - LPROD_{1996} \quad (6)$$

Since equation 5 only consists of a single time period, fixed effect estimation, controlling for industry heterogeneity, cannot be used, as it would cancel out all variation in the poly-industrial agglomeration variable. However,all time invariant heterogeneity is controlled for as we are using first differences. Equation 5 will be estimated with OLS technique, correcting the standard errors using Whites (1980) method.

The degree and structure of agglomeration

Table 1 shows the extent of mono-industrial agglomeration ($\hat{\gamma}_j$), co-agglomeration (γ^c) and the relationship between co-agglomeration and mono-industrial agglomeration, which we denote as poly-industrial agglomeration (λ) for Swedish manufacturing industries during the years 1993, 1996 and 1999 (see equation 2). The co-agglomeration indexes are calculated using industries at the three-digit ISIC level that belong to the same two-digit industry. Mono-industrial agglomeration is measured through EG-index for each specific two-digit industry.[11]

From Table 1 it is obvious that co-agglomeration exists between related manufacturing industries for each of the three years. The sub-industries of textile, wearing apparel and leather industries (ISIC 32) plus those of the manufacture of wood and wood products, including furniture (ISIC 33), have a value of γ^c which exceeds the limit for high concentration, as defined by Ellison and Glaeser. The industries also exhibit a λ close to 1, which indicates that poly-industrial agglomerative forces dominate over mono-industrial agglomeration.[12] The manufacture of non-metallic mineral products (ISIC 36) also exhibits stable values of co-agglomeration during the same time period. With regard to the relative importance of poly-industrial agglomeration, the value indicates a moderate impact (λ is 0.6) compared to the previous industries. An interesting observation is that neither of these industries are considered high-tech or knowledge intensive and are all heavily dependent on natural raw material for production.

On the opposite side of the spectrum can be found the manufacture of chemicals and chemical, petroleum, coal, rubber and plastic products (ISIC 35), which ,along with, the manufacture of paper and paper products, printing and publishing (ISIC 34) exhibit no clear co-agglomeration or of poly-industrial agglomeration patterns. Note that some of these industries are knowledge intensive when compared to other manufacturing industries.[13]

A study of the food, beverage, tobacco industry (ISIC 31) and the basic metal industries (ISIC 37) reveal that λ can be quite volatile at times. The former display a domination of mono-industrial agglomeration during 1993 and 1996, but then the index

[11] Exactly which three digit industries that are included in the co-agglomeration index for each two digit industry is presented in the Appendix 2, table A1.

[12] In fact it is even larger than 1 for the textile, wearing apparel and leather industries in 1999. This is possible since the index, even though it's defined limits for the interpretation lies between 0 and 1, does not have to display a value within the interval by construction as can also be seen in Ellison and Glaeser (1997) and Bertinelli and Decrop (2005).

increases to 0.522 during 1999 suggesting a growing importance of poly-industrial agglomeration forces. In the basic metal industry the opposite pattern is observed; initially poly-industrial forces dominated but declined considerably in 1996 and 1999. For all three year the index of co-agglomerative concentration, γ^c, is much more stable and shows negligible concentration regarding the food, beverage and tobacco industries whereas it display a strong, though not extreme, concentration for the basic metal industries. This is consistent with results found by Bertinelli and Decrop (2005), who also noted that λ was very volatile in some industries, over time. In the case of the basic metal industries (ISIC 37) the changes in the index are influenced by the small size of the industry, 6 000 employees in 1999, which even makes the more robust mono-industrial agglomeration measure quite volatile. Between 1993 and 1999 there is an increase from 0.08 to 0.593.[14]

Regression results

Table 2 shows the regression results for the manufacturing industries at the three-digit level for the years 1996 and 1999.[15] The dependent variable is always value added per employee and all the variables are defined in levels. The t-statistics are shown within parenthesis (z-statistics in regression 2).[16] The first regression uses POLY-AGGL as the main independent variable and implements the full set of control variables. The second regression contains the same variables, but is estimated using the generalized least-squares method that accounts for autocorrelation. The third regression excludes RSPEC and MONO-AGGL to investigate their effect on POLY-AGGL. In the fourth regression POLY-SPEC is used as a main independent variable, while excluding RSPEC to avoid multicollinearity. Finally, regression five replaces POLY-SPEC with POLY-SPEC2. Judging from the correlation matrices (see Appendix 2,

[13] For ranking of average knowledge intensity, see appendix

[14] There also seem to be a connection between the ranking of the industry two digit EG-index for 1999 and the co-agglomeration of its sub-industries, with the notable exception of basic metal industries (ISIC 37).

[15] Industry dummies is not presented but can be supplied upon request.

table A3) the regressions do not seem to suffer from multicollinearlity between the independent variables.

As can be seen from regression 1, our "core" explanatory variable (POLY-AGGL) has a positive and significant relationship with labour productivity; this is also true for agglomeration (MONO-AGGL) and regional specialisation (RSPEC). This implies that agglomeration based on inter-industry co-location appears to associated with stronger productivity effects as compared to mono-industrial, industry-specific agglomerations. In addition, the human capital content of labour (EDU) and the variable related to internal economies of scale (SIZE), are shown to positively correlate with labour productivity. Entrepreneurship (ENT), approximated using self-employed, turns out to be negatively correlated with labour productivity. However we suspect that the quality of data and lags in the substantiation of effects may influence the variable.[17]

Regression 2 verifies, as expected, that autocorrelation does not –- affect the estimates significantly. The most visible change when controlling for autocorrelation, which is also true for the intercept, is that entrepreneurship (ENT) becomes insignificant. Overall the difference in estimates and significance levels are marginal compared with regression 1. This could be attributed partly to the industry fixed effects, which are obtained by implementing time invariant dummies. However, even without these dummy variables the estimated autocorrelation coefficient is only 0.11 and a Durbin Watson test fails to reject the null hypothesis of no serial correlation, both with and without industry dummies.[18] We therefore conclude that autocorrelation does not have a significant impact on the results.

From regression 3 it is clear that the results are fairly stable even when RSPEC and MONO-AGGL are excluded. None of the remaining variables lose significance or

[16] The z-statistic is a normalized version of the t-statistic.
[17] Withdrawing this variable (ENT) from regressions does not induce any significant changes on the other variables.
[18] The result of these tests will not be presented, but can be supplied upon request.

changes signs. As shown in regression 4 and 5, the positive relationships remain when the POLY-AGGL variable is interacted with the two measures of regional specialisation. In fact, judging from the magnitude of the coefficients, the interacted variables appear to mimic RSPEC. This is not surprising, especially for POLY-SPEC which consists of the interaction of RSPEC and POLY-AGGL, since there is much more variation in the former variable (remember that RSPEC varies between industries and regions, while POLY-AGGL only varies between industries).

One might suspect that not only the relative industry presence in a region affects the labour productivity, but also the absolute. To control for this we have re-run the regressions with the total number of employees of an industry in a region both as a compliment and as a substitute to the specialization index. However, no significant changes occurred. The regressions were also re-run without the three digit industries belonging to the aggregated Manufacture of Food, Beverages and Tobacco industry (ISIC 31). The reason for this is that this industry has by far the most volatile poly-agglomeration index over the time period. When doing this the coefficient for POLY-AGGL was still positive, and significant when controlling for autocorrelation, otherwise insignificant.[19]

As regards the dynamic relationship between poly-industrial agglomeration and labour productivity, Table 3 shows the results of the regressions using variables containing first differences. From regression 1 it is clear that the positive correlation between the poly-industrial agglomeration index, describing the co-agglomerative forces relative to the agglomerative forces, and value added per employee remain when the variables are specified in first differences. Industry-specific concentration (MONO-AGGL) also displays a significant and positive correlation with labour productivity growth. However, none of the other variables gain significance in the regression.

[19] The result of these complementary regression results will not be presented, but can be supplied upon request.

Regression 2 confirms that the results are robust, even when the regional specialisation index and the mono-industrial agglomeration variables are excluded. The poly-industrial agglomeration variable is still positive and significant, although the coefficient reaches a somewhat higher value than in the first regression. Entrepreneurship (ENT) also attains weak significance, although there is not a great change in the t-value for the variable.

Regression 3 also yields results that are in line with the two previous regressions. As before, none of the explanatory variables; economies of scale (SIZE), education (EDU) and entrepreneurship (ENT), where the latter mimics its size and significance from regression 1, are significant. Only mono-industrial agglomeration attains significance. The insignificant value of the interaction of the poly-industrial agglomeration and regional specialization (POLY-SPEC) can be explained by the fact that this variable is strongly influenced by the regional specialisation variable, which displayed virtually no correlation with labour productivity growth in regression 1. Finally, the modified interaction variable in regression 4 (POLY-SPEC2), consisting of a weighted regional specialisation index interacted with the co-agglomeration index, becomes (weakly) significant. Industry-specific agglomeration (MONO-AGGL) is also positive and significant, while no effect was found for the remaining control variables. Hence, a change in regional specialization does not in itself signal productivity changes; it has to be complemented with either a balanced increase in specialization of all *r-i*ndustries or industry-specific agglomeration.

Spatial autocorrelation

Since the regressions are based on data sorted by spatial units, the question arises as to whether the development in one region spills over to a nearby region. If this was the case, then the observations cannot be claimed to be independent. To control for this we have calculated the Moran statistic (Moran, 1950) for the residuals from regression 1 in table 2 and table 3. However, this can only be done when an industry exists in all regions in one year. This condition is fulfilled in ten cases in the two regressions. In nine of these the Moran statistic indicates that we cannot reject the null hypothesis of no spatial autocorrelation.[20] Since this test does not include all industries, we have re-run the regression, using regional dummies controlling for regional effects, with no significant impact on the main results. We therefore conclude that impact of spatial autocorrelation on the results is negligible.

6. Conclusions

This paper demonstrates that the Swedish manufacturing industry shows clear signs of co-agglomeration during the 1990's, albeit with considerable differences discernable across industries. In two of the eight industries *poly-industrial* agglomeration forces, related to inter-industry spillovers and the location of natural resources – seem dominant over intra-industry *mono-industrial* agglomeration forces. Hence, diversified Jacobian externalities seem more important than Marshall-Arrow-Romer externalities. Also, the extent of poly-industrial agglomeration was shown to fluctuate considerably over time.

Of more importance is that the regression analysis provides evidence that poly-industrial agglomeration is positively correlated with labour productivity, irrespective of whether the variable was specified in terms of levels or differences. Thus, poly-industrial agglomeration of industries augments the positive effects associated with industry specific agglomeration. It also has a much more robust relationship with labour productivity than regional specialization, which has little or no correlation with labour productivity.

The interpretation is that poly-industrial agglomerations, where different but interlinked industries have co-agglomerated, exert a stronger positive relationship with productivity in each industry, as compared to pure mono-industrial and industry-specific

[20] Which industries that were included in the test, and the exact result, is available upon request.

agglomerations. In other words, productivity, which eventually translates into growth, benefits from the diversity of industries located in the same region. These findings have obvious policy-implications where a host of regional developers are pre-occupied with the development of highly specialized ICT, or biotechnology clusters.

Table 1: Measures of co-agglomeration (γ^c), poly-industrial agglomeration (λ) at the three-digit level (1993, 1996 and 1999) and mono-industrial agglomeration ($\hat{\gamma}_j$) for two digit industries (1999), manufacturing industries.

Rank λ 1999	Industry	ISIC code	1993		1996		1999		1999
			γ^c	λ	γ^c	λ	γ^c	λ	$\hat{\gamma}_j$
1	Textile, Wearing Apparel and Leather Industries	32	0.129	0.954	0.141	0.920	0.182	1.018	0.168
2	Manufacture of Wood and Wood Products, Including Furniture	33	0.062	0.977	0.066	0.984	0.069	0.971	0.062
3	Manufacture of Non-Metallic Mineral Products, except Products of Petroleum and Coal	36	0.036	0.611	0.044	0.656	0.048	0.632	0.050
4	Manufacture of Food, Beverages and Tobacco	31	-0.002	-0.226	-0.004	-0.782	0.006	0.522	0.009
5	Manufacture of Fabricated Metal Products, Machinery and Equipment	38	0.004	0.193	0.003	0.098	0.004	0.121	0.009
6	Basic Metal Industries	37	0.056	0.598	0.083	0.096	0.080	0.096	0.593
7	Manufacture of Chemicals and Chemical, Petroleum, Coal, Rubbr and Plastic Products	35	0.001	0.012	-0.013	-0.191	-0.012	-0.172	0.007
8	Manufacture of Paper and Paper Products, Printing and Publishing	34	-0.017	-0.613	-0.017	-0.612	-0.018	-0.569	0.004

Source: Statistics Sweden and own calculations.

Table 2: Regression results. Manufacturing industry, three-digit level, year 1996 and 1999. Variables using level data.

	1	2	3	4	5
POLY-AGGL	0.038**	0.041***	0.057***		
	(2.04)	(3.42)	(2.96)		
POLY-SPEC				0.002***	
				(4.62)	
POLY-SPEC2					0.002***
					(4.78)
RSPEC	0.002***	0.002***			
	(6.09)	(6.52)			
MONO-AGGL	0.992***	0.957***		1.084***	1.087***
	(3.77)	(3.93)		(3.97)	(4.06)
SIZE	0.001***	0.001***	0.001***	0.001***	0.001***
	(2.95)	(4.37)	(4.42)	(4.43)	(4.42)
EDU	0.246*	0.316***	0.253**	0.261**	0.253**
	(1.98)	(4.39)	(2.01)	(2.06)	(2.01)
ENT	-0.066**	-0.019	-0.097***	-0.081**	-0.086***
	(-2.06)	(-0.81)	(-3.12)	(-2.58)	(-2.76)
CONSTANT	0. 264***	0.094	0.352***	0.281***	0.282***
	(11.42)	(1.61)	(22.17)	(12.26)	(12.32)
$\bar{R}^2$	0.65		0.65	0.66	0.66
F	18.73	787.42[†]	12.28	21.13	19.09
OBSERVATIONS	2099	2098	2099	2099	2099

Note: *=P<0.10; **=P<0.05; ***=P<0.01
[†] = Wald test statistics

Table 3: Regression results. Manufacturing industry, three digit level, change between year 1996 and 1999.

	1	2	3	4
Δ POLY-AGGL	0.029***	0.042***		
	(2.95)	(4.49)		
Δ POLY-SPEC			-0.000	
			(-0.10)	
Δ POLY-SPEC2				0.002**
				(2.24)
Δ RSPEC	0.009			
	(0.06)			
Δ MONO-AGGL	0.906***		1.003***	0.968***
	(4.16)		(4.69)	(4.51)
Δ SIZE	-0.001	-0.001	-0.001	-0.001
	(-1.00)	(-1.08)	(-1.14)	(-1.14)
Δ EDU	0.166	0.240	0.164	0.166
	(0.69)	(1.04)	(0.69)	(0.70)
Δ ENT	0.083	1.07*	0.083	0.086
	(1.49)	(1.93)	(1.49)	(1.55)
$\bar{R}^2$	0.045	0.028	0.041	0.042
F	9.10	8.94	6.91	9.14
OBSERVATIONS	945	945	945	945

Note: *=P<0.10; **=P<0.05; ***=P<0.01

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Appendix 1

Definition of the industry specific Ellison and Glaeser index[21]

Starting with the share s_i which refers to region *i*'s share of the aggregate employment in industry *j*, and x_i which refers to the region's share of total aggregate employment, the industry's geographic concentration can be found by the formula

$$G = \sum_{i=1}^{M} (s_i - x_i)^2$$

where *i* refers to a specific region and M the number of regions in the country. The EG-index also factors in the size distribution of the plants within the industry though the Herfindahl index according to the formula

$$H = \sum_{k=1}^{N} z_k^2$$

where *k* refers to a specific plant, and z refers to the number of employees in each of the industry's N plants divided by the total number of employees in the industry. The final Ellison and Glaeser index can now be defined by

$$\hat{\gamma}_j \equiv \frac{G - (1 - \sum_{i=1}^{M} x_i^2) * H}{(1 - \sum_{i=1}^{M} x_i^2) * (1 - H)}$$

[21] For a more detailed description of the Ellison and Glaeser index, please refer to Ellison and Glaeser (1994).

Appendix 2

Table A1: Sub-industries (three digit level) belonging to the same aggregated industry (two digit level).

ISIC 2 Digit Code	2 Digit Industry	ISIC 3 Digit Code	3 Digit Industry
31	Manufacture of Food, Beverages and Tobacco	311	Food Products
		312	Food Products
		313	Beverages
		314	Tobacco
32	Textile, Wearing Apparel and Leather Industries	321	Textiles
		322	Wearing Apparel, Except Footwear
		323	Fur and leather
		324	Shoe industry
33	Manufacture of Wood and Wood Products, Including Furniture	331	Wood products
		332	Furniture, Except Metal
34	Manufacture of Paper and Paper Products, Printing and Publishing	341	Paper and Products
		342	Printing and Publishing
35	Manufacture of Chemicals and Chemical, Petroleum, Coal, Rubber and Plastic Products	351	Industrial Chemicals
		352	Other Chemicals
		354	Miscellaneous Petroleum and Coal products
		355	Rubber Products
		356	Plastic Products
36	Manufacture of Non-Metallic Mineral Products, except Products of Petroleum and Coal	361	Pottery, China, Earthenware
		362	Glass and Products
		369	Other Non-Metallic Mineral Products
37	Basic Metal Industries	371	Iron and Steel
		372	Non-Ferrous Metals
38	Manufacture of Fabricated Metal Products, Machinery and Equipment	381	Fabricated Metal Products
		382	Machinery, Except Electrical
		383	Machinery, Electric
		384	Transport Equipment
		385	Professional and Scientific Equipment

Table A2: Ranking of average percentage of employed in firms within an industry that have a university/college – or graduate – education. Manufacturing industry, two-digit industry level, 1996

Manufacuring industry	Average knowledge intensity
ISIC 35	5.4%
ISIC 34	4.5%
ISIC 38	4.1%
ISIC 36	2.9%
ISIC 32	2.3%
ISIC 39	2.2%
ISIC 31	2.1%
ISIC 37	1.7%
ISIC 33	1.5%

Table A3: Correlation matrix

	POLY-AGGL	POLY-SPEC	POLY-SPEC2	RSPEC	MONO-AGGL	SIZE	EDU	ENT
POLY-AGGL	1							
POLY-SPEC	0.429	1						
POLY-SPEC2	0.538	0.736	1					
RSPEC	0.010	0.708	0.460	1				
MONO-AGGL	0.331	0.145	0.191	0.040	1			
SIZE	-0.186	-0.029	-0.061	0.356	-0.066	1		
EDU	-0.124	-0.087	-0.091	0.027	-0.062	0.130	1	
ENT	0.488	0.116	0.200	-0.114	0.213	-0.210	-0.050	1