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Human Capital, R&D and Regional Export Performance [1]

Urban Gråsjö (HTU/JIBS)

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Corresponding author: urban.grasjo@htu.se

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Human capital, R&D and Regional Export Performance

Urban Gråsjö[2]

Abstract

The main purpose of the study in this paper is to establish to what extent accessibility to R&D and human capital can explain regional export. This is done by estimating knowledge production functions, with export value and high valued exports in Swedish municipalities from 1997 to 1999 as outputs. In order to account for geographical proximity, the explanatory variables are expressed as accessibilities to R&D and human capital. The total accessibility is divided into three geographical levels; local (within the municipality), intra-regional and inter-regional accessibility to R&D and human capital. R&D conducted at universities and in companies is measured in man years and the numbers of people with at least three years of university studies measures the amount of human capital. The estimations are conducted with quantile regressions since the distributions of the dependent variables are highly skewed with a few very influential outliers. Due to problems with multicollinearity it is not easy to tell if the variations in the municipalities' exports are explained by human capital or company R&D. But the results in the paper indicate that accessibility to human capital has the greatest positive effects. The value of exported products is mainly affected by local accessibility to human capital (and company R&D). The intra- and inter-regional accessibilities play a more important roll when the number of high valued export products in Swedish municipalities is the output.

JEL Classifications: R11, O18

Keywords: knowledge production, R&D, human capital, exports, quantile regression

[2] University of Trollhättan/Uddevalla, P.O. Box 795, SE-451 26 Uddevalla, Sweden, urban.grasjo@htu.se

1. Introduction

Many studies of innovation tend to focus on the explanatory power of R&D expenditure (see Acs & Audretsch, 1989, among others). These studies use R&D expenditure or R&D effort as an input variable in a knowledge production function (Griliches, 1979). Other studies, following Lucas (1988), have identified the importance of human capital in economic growth (Glaeser et al 1995 and Gemmell 1996). Glaeser found that level of education is closely related to subsequent income and population growth. Simon (1998) also found a positive relationship between level of human capital and employment growth. There are however very few empirical studies that focus on the role of human capital in innovation and economic growth. Feldman (2000) assumes that highly educated people tend to produce more innovations and subsequent regional income and population growth. Following Jacobs (1961) and Lucas (1988), Florida & Lee (2001) showed that regional innovation (measured by the number of patents issued) is positively and significantly related to human capital (measured by the percentage of people with a bachelor's degree and above) and diversity.

The importance of geographical proximity on knowledge diffusion has been revealed in several studies (Jaffe, 1989; Jaffe et al., 1993; Feldman, 1994; Audretsch & Feldman, 1996). Closeness between agents and other members in the regional innovation system is more likely to offer greater opportunities to interact face to face, which will develop the potential of the innovation system. The theoretical explanation is that a great deal of new economic knowledge relevant in different innovation processes is hard to codify and is therefore not perfectly available. Thus, in most cases, face to face contacts are necessary for transferring tacit (complex) knowledge. There are several possible ways to measure geographical proximity. Karlsson & Manduchi (2001) have proposed an accessibility concept in order to incorporate geographical proximity. The accessibility measure is based on Weibull (1976) and is constructed according to two main principles. Firstly, the size of attractiveness in a destination has a positive effect on the propensity to travel. Secondly, the time distance to a destination affects the propensity to travel negatively.

In Gråsjö (2004) the accessibility concept was used in a knowledge production framework. The output of the knowledge production was the number of patent applications in Swedish municipalities from 1994 to 1999. In order to account for proximity, the explanatory variables were expressed as accessibilities to university and company R&D. The total accessibility was also decomposed into local, intra-regional and inter-regional accessibilities. The consensus in the literature is that both university and company R&D have positive effects on patent production (see Anselin et al. 1997; Acs et al 2002, among others). Acs et al (2002) use data based on 125 US Metropolitan Areas (MSAs) in a knowledge production framework with patents and new product innovations as dependent variables. Their empirical findings show a clear dominance of company R&D over university research. However, this dominance is not so accentuated for new product innovations. This pattern is also replicated for research spillovers from surrounding areas; university R&D being more important for new product innovations and company R&D being the dominant factor for patents. The empirical findings in Gråsjö (2004) do, to some extent, support the results in Acs et al (2002). Local accessibility to company R&D is undoubtedly the dominating variable explaining patent production in Sweden. But while Acs et al. (2002) find statistically significant effects of local university research for the MSAs in US, local accessibility to university R&D for Swedish municipalities is of no importance.

This raises a number of questions: Is university R&D still ineffective if another output is used in the knowledge production process and is local company R&D still the dominating explanatory variable? Is accessibility to R&D the appropriate input variable or is accessibility to human capital (measured by people with a bachelor's degree and above) a better choice? Is there any evidence for productive knowledge flows between municipalities if other variables than patents and R&D efforts are used as outputs and inputs in the innovation process?

Although patents (granted patents as well as patent applications) are commonly used as proxies for the output of the innovation process, they do not by them selves generate economic growth. The classical definition of an innovation stresses introduction on the market. Thus, market penetration (or commercialization) distinguishes invention from innovation. If a firm also succeeds in introducing a product on the export market it implies a successful market penetration. Therefore export value or exports of high valued products could be useful measures of the innovative capacity in a region. Even though exports are not usually used as an output of an innovation process, it is a widespread agreement that knowledge is one of the crucial ingredients of innovation and in turn the main bases of international competitiveness and hence of successful export performance. Knowledge is therefore part of a good circle leading to innovation, competitiveness and exports. Exports and trade in their turn are major vehicles for the sharing and transfer of international knowledge.

The relation between export competitiveness and knowledge can also be found in empirical studies where proxies for product quality and variety are incorporated by using measures of innovation such as R&D investments and patents (see Fagerberg 1988; Greenhalgh et al 1994 among others). Greenhalgh et al (1994) explore the role of innovation in the determination of net exports and export prices on industry groups covering both manufacturers and services in the United Kingdom. Their empirical findings support the view that R&D has a significant effect on the balance of trade.

Furthermore, developed regions, with a long standing tradition of research, marketing, entrepreneurial organization, etc. have accumulated a stock of knowledge that allows them to be more dynamic in the creation of products with market potential. However, as much of the knowledge (tacit or non tacit) generated in one region can be enjoyed by other regions with similar characteristics, the capacity to export will be determined not only by the region's stock of knowledge but also by other regions' knowledge. One empirical work where export is used as an output in a knowledge production process is Breschi & Palma (1999). In the paper, they evaluate to which extent localised knowledge spillovers can affect trade performance in high technology industries in Italy. Their empirical findings imply that local knowledge spillovers appear to positively affect the trade performance in the industrial automation and instruments sectors.

This paper focuses on how knowledge and knowledge diffusion affects exports on regional level and the main questions are:

- To what extent can accessibility to university and company R&D explain exports (measured by export value or exports of high valued products) in Swedish municipalities?
- Is it R&D effort or is it the presence of a well educated population that best explains the exporting performance (measured by export value or exports of high valued products) of a municipality?

In order to answer these questions a knowledge production function is estimated both on aggregated level and on industry sector level. The model used for the knowledge production function and the accessibility concept is presented in the next section. Section 3 presents the data and section 4 contains a discussion of the choice of an appropriate estimation method and some pre-estimation tests. In section 5 the estimation results from the regressions are presented. The paper ends with the main conclusions of the empirical findings.

2. Model

The conceptual framework for analyzing geographic spillovers is based on the knowledge production function of Griliches (1979). In order to examine the influence of knowledge flows on the output of regional innovation systems, it is possible to use the number of patents in each region as an endogenous variable, regressed against the R&D effort from companies and universities (see Jaffe, 1989; Feldman & Florida, 1994, among others). In this paper, the accessibility to R&D and human capital are used instead of R&D effort. Furthermore, instead of patents, export value and number of high valued export products are used as outputs. The method with accessibilities in knowledge production has been used in a series of papers, (see e.g. Gråsjö, 2004; Andersson & Ejermo, 2004a,b; Andersson & Karlsson, 2005).

The accessibility of location *i* to it self and to *n-1* surrounding locations is defined as the sum of its internal accessibility to a given opportunity *X* and its accessibility to the same opportunity in other locations (not only neighbours),

$$A_i^X = x_1 f(c_{i1}) + \ldots + x_i f(c_{ii}) + \ldots + x_n f(c_{in}) \tag{2.1}$$

where A_i^X is the total accessibility of location *i*. x_i is a measure of an opportunity *X*, which can be an opportunity such as R&D efforts in universities and companies. *f(c)* is the distance decay function that determines how the accessibility value is related to the cost of reaching the opportunity. A common approximation of *f(c)* is to apply an exponential function, and then it takes the following form,

$$f(c_{ij}) = \exp\{-\omega t_{ij}\} \tag{2.2}$$

where t_{ij} is the time distance between location *i* and *j,* and ω is a time sensitivity parameter. The value of ω in (2.2) depends on if the interaction is local, intra-regional (between locations in a region), or inter-regional (location *i* and *j* in different regions). It is apparent that the accessibility value may improve in two ways, either by an increase in the size of the opportunity, x_j, or by a reduction in the time distance between location *i* and *j*. If the total accessibility to a specific opportunity is decomposed into local, intra-regional and inter-regional, then

$$A_i^X = A_{iL}^X + A_{iR}^X + A_{iOR}^X \tag{2.3}$$

where

$A_{iL}^X = x_i \exp\{-\omega_L t_{ii}\}$, local accessibility to opportunity *X* for location *i*

$A_{iR}^X = \sum_{r \in R,\ r \neq i} x_r \exp\{-\omega_R t_{ir}\}$, intra-regional accessibility to opportunity *X* for location *i*

$A_{iOR}^{X} = \sum_{k \notin R} x_k \exp\{-\omega_{OR} t_{ik}\}$, inter-regional accessibility to opportunity X for location i

j defines locations within the own region R, and k defines locations in other regions.

The accessibility concept expressed in Equation (2.3) has several advantages. Firstly, it incorporates "global" spillovers and does not only account for the impact from neighbours or locations within a certain distance band. Secondly, the separation of the total effect into local, intra-regional and inter-regional spillovers captures potential productive knowledge flows between locations and makes the inferential aspects more clear. Thirdly, distance is often measured by the physical distance, but a better way to measure it is to use the time it takes to travel between different locations (Beckman, 2000). Time distances are also crucial when it comes to attend to business meetings and also to spatial borders of labour markets (see Johansson & Klaesson, 2001, for the Swedish case).

The opportunities used in this paper are population with at least three years of university studies (a bachelor's degree and above) and conducted R&D work in Swedish universities and companies. When the accessibility variables are calculated they can be entered in a knowledge production function. The standard choice of the functional form is often a version of Cobb-Douglas. However, it could be argued that the various accessibilities are most probably substitutes and hence the implication of Cobb-Douglas that one zero in inputs is enough for zero output does not make sense. Therefore an additive linear functional form is used to model the knowledge production,

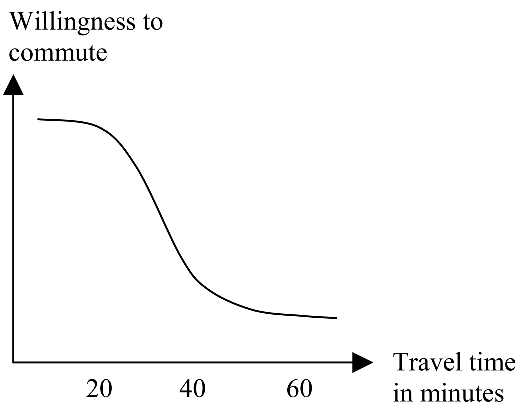
$$y_i = \alpha + A_{iL}^{X}\beta_1 + A_{iR}^{X}\beta_2 + A_{iOR}^{X}\beta_3 + u_i \qquad (2.4)$$

As dependent variables 1) the export value and 2) the number of exported products with a price greater than 1000 SEK per kg in municipality i are used. With 1000 SEK per kg as a cut off value, approximately 13% of the products are above this limit. Local (intra-municipal), intra-regional and inter-regional accessibility to 1) university R&D, 2) company R&D and 3) people with a at least three years of university studies are the explanatory variables.[3] Intuitively, the number of high valued export products is a better ouput measure of a knowledge production process than total export value. Hence, the innovative achievement is greater if a municipality has for instance two export products with a total value of 5000 SEK instead of one export product with a value of 5000 SEK. In addition, two dummy variables measuring the size of the population in the municipalities are included in the model. These variables enable a comparison between municipalities with a large (D_1), medium sized (D_2) and a small population. The hypothesis is that municipalities with large populations have an economic activity that exceeds smaller municipalities' and this ought to affect the output. In the accessibility calculations the time sensitivity parameter value ω_L is set to 0.02, ω_R to 0.1 and ω_{OR} to 0.05. Johansson, Klaesson & Olsson (2003) estimated these values by using data on commuting flows within and between Swedish municipalities in 1990 and 1998. It may perhaps look strange that the intra-regional accessibilities have the highest parameter value (ω_R = 0.1). But the intra-regional commuting trips, which are in the time span from approximately 15 to 45 minutes, are the ones that are most time sensitive. That is, increased

[3] Breschi & Palma (1999) have estimated a some what similar function. As a dependent variable they used share of exports of region i in high-tech sector j and as explanatory variables 1) share of patents in region i in high-tech sector j and 2) share of patents in neighboring regions in high-tech sector j, where neighboring regions mean regions sharing a boundary with region i.

commuting time in this time span will hamper the propensity to travel the most (see figure 2.1).

Figure 2.1: Willingness to commute to other municipalities



Source: Johanson et al. (2003)

In order to answer the questions outlined in section 1, the first choice would be to estimate Equation (2.4) with a single regression using export as the dependent variable and accessibility to university R&D, company R&D and human capital on all three geographical levels as exogenous variables. This is, however, not possible because of problems with multicollinearity, especially between the intra-regional variables. Therefore two separate specifications are estimated, one with the R&D variables and the other with human capital as exogenous variables. The following equation is estimated for the R&D variables

$$Exp_i = a + b_1 A_{iL}^{uR\&D} + b_2 A_{iOR}^{uR\&D} + b_3 A_{iL}^{cR\&D} + b_4 A_{iR}^{cR\&D} + b_5 D_1 + b_6 D_2 + u_i \qquad (2.5)$$

where $Exp_i =$ export value and number of export products with a prise above 1000 SEK per kg in municipality *i*, *uR&D* = university R&D in man-years and *cR&D* = company R&D in man-years. The other notations are as before. Any other combination of intra- and inter-regional variables would also accomplish a low degree of multicollinearity (see Gråsjö, 2004, for further details). I have chosen to keep the pair that has the highest correlation with the export variables. To estimate the relationship between exports and accessibility to human capital the following equation is used

$$Exp_i = a + b_1 A_{iL}^{hc} + b_2 A_{iR}^{hc} + b_3 A_{iOR}^{hc} + b_4 D_1 + b_5 D_2 + u_i \qquad (2.6)$$

where *hc* (human capital) is the notation for the number of people in age 16-74 with at least three years of university studies. In order to get a direct comparison of the importance of human capital, company and university R&D on exports and to avoid the multicollinearity problem, one solution is to express the variables of interest with respect to some size variable. When doing that, the intra-regional and inter-regional variables will not make any sense and therefore only local accessibilties are used in the specification

$$\frac{Exph_i}{Exp_i} = \frac{A_{iL}^{hc}}{Pop_i}\beta_1 + \frac{A_{iL}^{cR\&D}}{Pope_i}\beta_2 + \frac{A_{iL}^{uR\&D}}{Pope_i}\beta_3 + u_i \qquad (2.7)$$

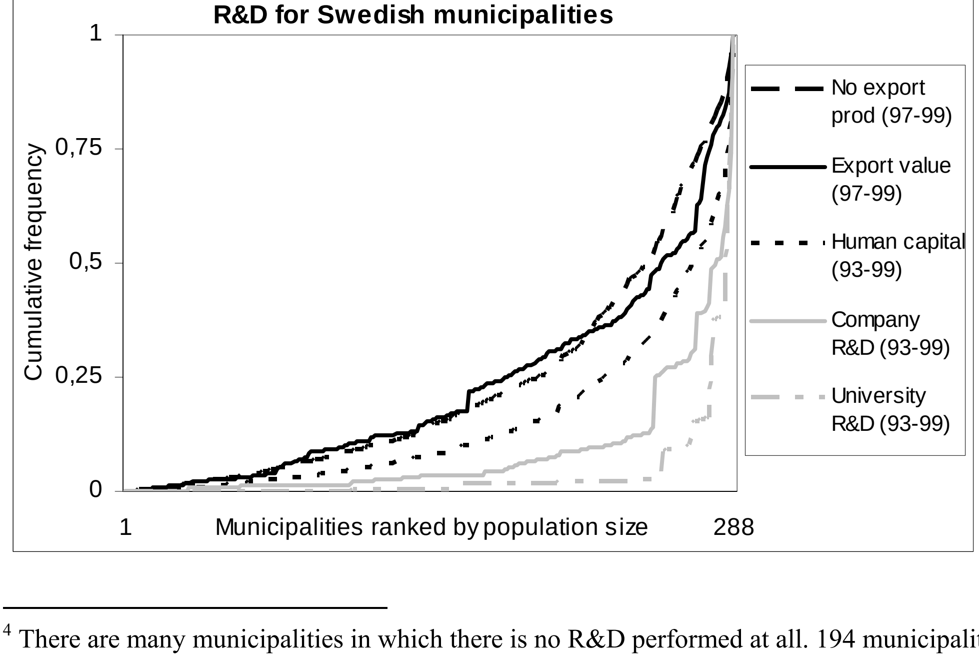
where $Exph_i$ = export value for products with a price > 1000 SEK per kg in municipality *i*, Pop_i = the number of people in age 16-74 in municipality *i* and $Pope_i$ = the number of people in age 16-64 gainfully employed with place of work in municipality *i*. The choice of $Pope_i$ as a scaling factor is motivated by the fact that company and university R&D are registered by workplace. The estimation results of (2.5), (2.6) and (2.7) are presented in section 5.

3. Data and descriptive statistics

Statistics Sweden collects data on companies' exports, performed R&D in universities and companies and the level of education in Swedish municipalities. The export data is registered in the municipality where the company has its main workplace. This means that if a company has its main production in municipality A and the head office situated in municipality B, then the export is registered in municipality A. Furthermore, if a company has production at many workplaces (municipalities), then the export data is only registered at the workplace where the company has its main production. R&D in universities and companies are also registered by workplace.

Figure 3.1 shows the skewed spatial distribution of exports, human capital and R&D in Sweden. In the figure the municipalities are ranked in ascending order according to population size. Numbers of export products and export value have similar distributions as population (not displayed in the figure), but human capital, company R&D and especially university R&D are more concentrated to larger municipalities.[4] An interpretation of Figure 3.1 suggests that if R&D and human capital are important for export performance then there are probably beneficiary knowledge flows from larger municipalities to smaller ones.

Figure 3.1: Cumulative share of exports, human capital and R&D for Swedish municipalities



[4] There are many municipalities in which there is no R&D performed at all. 194 municipalities have no university R&D and 144 municipalities have no company R&D.

The variables used in the coming regressions are

- Export value (in SEK) and number of export products with export price above 1000 SEK per kg are yearly averages during the period 1997-1999 for Swedish municipalities.
- Accessibility to university R&D and company R&D are computed using a yearly average of conducted R&D measured in man years during the period 1993-1999 for Swedish municipalities.
- Accessibility to human capital is computed using a yearly average of the number of people with at least three years of university studies for Swedish municipalities during the period 1993-1999.

National Road Administration in Sweden has data on commuting time between and within Swedish municipalities. Commuting time between and within municipalities in 1990 and 1998 is used in the accessibility calculations. The descriptive statistics of the variables on the aggregated data set are presented in table 3.1. The variable "Large population" equals one if population is greater than 100 000 and "Medium population" equals one if population is between 50 and 100 000.

Table 3.1: Descriptive statistics for the 288 municipalities in Sweden. Aggregated level.

Variable	Mean	Median	Std. dev.	Min	Max
Export value (10^9 SEK)	2.236	0.720	5.507	0.00086	48.43
Number of products, export price > 1000 SEK per kg	60.09	28.67	88.37	0.667	727.7
(Value of products with export price > 1000 SEK per kg) / (Export value) in %	9.54	1.48	17.4	0.005	96.4
Accessibility to university R&D, local	52.53	0	320.8	0	3012
Accessibility to university R&D, intra-regional	114.9	1.726	301.0	0	1990
Accessibility to university R&D, inter-regional	96.49	22.64	164.1	0.00049	1023
Accessibility to company R&D, local	8.339	0.001	46.34	0	643.8
Accessibility to company R&D, intra-regional	19.47	0.641	50.91	0	383.3
Accessibility to company, inter-regional	13.89	7.390	19.34	0.00010	168.2
Accessibility to human capital, local	1755	477.3	5699	1.562	82442
Accessibility to human capital, intra-reg	3280	399.1	8172	0	56610
Accessibility to human capital, inter-reg	2948	2166	2954	0.031	20611
Access. to hum. cap., local, per 1000 inhabitants	53.42	44.26	35.81	0.080	312.8
Access. to univ. R&D, local, per 1000 employed	0.892	0	4.325	0	39.35
Access. to comp. R&D, local, per 1000 employed	0.251	0.00018	0.816	0	9.625
Large population (>100 000)	0.038	0	0.192	0	1
Medium population (50 to 100 000)	0.125	0	0.331	0	1

Note the large differences between the mean and the median for all variables. This is especially troublesome for the variables that are treated as endogenous in the regressions. If the distribution of the dependent variable is skewed with a few very influential variables an OLS regression gives biased results.

4. Model and estimation considerations

4.1 Modelling spatial dependence

When modeling spatial inter-dependencies it is important to check whether there are any remaining effects in the error terms, i.e. if the chosen specifications in Section 2 models feasible spatial effects. Anselin (2003) distinguishes between

1) unmodelled effects (with spatially lagged error terms)
2) modelled effects (with spatially lagged explanatory variables)
3) unmodelled and modelled effects (with spatially lagged dependent variables)

The model specifications (2.5 and 2.6) derived in Section 2 are examples of the second category. To test that spatially lagged explanatory variables are the right choice, i.e. that it is not the error terms or the dependent variables that should be spatially lagged, three different test statistics for spatial dependence have been calculated. Moran's *I* is probably the most used test statistic, but it does not leave any suggestions about how to proceed (which alternative spatial model to use) if it signals presence of spatial autocorrelation.[5] Therefore, two Lagrange Multiplier tests, *LM-err* and *LM-lag*, are also performed.[6] How to calculate Moran's *I*, *LM-err* and *LM-lag* can be found in Appendix 1.

The three test statistics have been calculated using three different weight matrices *W1*, *W2* and *W3*. *W1* is a row standardized binary weight matrix and *W2* and *W3* are inversed time distance matrices with the following weights:

- *W1*, with weights $w_{ij} \neq 0$ if municipality *i* and *j* are in the same region
- *W2*, with $w_{ij} = 1/t_{ij} \neq 0$ if $t_{ij} < 30$ minutes, zero otherwise
- *W3*, with $w_{ij} = 1/t_{ij} \neq 0$ if $t_{ij} < 60$ minutes, zero otherwise

In Table 4.1 the results of the tests are presented. The tests are performed with different dependent variables on Equation (2.5) – (2.7).

Table 4.1: Pre-estimation tests for spatial dependence

Equation, Dependent variable	*Moran's I*			*LM-err*			*LM-lag*		
	W1	*W2*	*W3*	*W1*	*W2*	*W3*	*W1*	*W2*	*W3*
Eq. 2.5, Export value	-0.019 (0.44)	-0.044 (0.34)	-0.015 (0.46)	0.144 (0.70)	0.646 (0.42)	0.253 (0.62)	0.005 (0.95)	0.033 (0.86)	0.027 (0.87)
Eq. 2.5, No. of export products	-0.014 (0.47)	0.035 (0.32)	0.022 (0.37)	0.073 (0.79)	0.404 (0.53)	0.532 (0.47)	8.1E-8 (1.00)	0.0004 (0.99)	0.0001 (0.99)
Eq. 2.6, Export value,	-0.013 (0.48)	-0.021 (0.45)	-0.002 (0.48)	0.064 (0.80)	0.141 (0.71)	0.006 (0.94)	0.0005 (0.98)	0.002 (0.97)	0.0003 (0.99)
Eq. 2.6, No. of export products	-0.002 (0.42)	0.006 (0.44)	-0.0002 (0.47)	0.248 (0.62)	0.012 (0.91)	6.4E-5 (0.99)	0.0002 (0.99)	6.1E-7 (1.00)	1.8E-8 (1.00)
Eq.2.7, Value share of high valued export prod.	0.003 (0.46)	0.027 (0.36)	0.039 (0.30)	0.003 (0.96)	0.243 (0.62)	1.64 (0.20)	0.001 (0.97)	0.004 (0.95)	0.020 (0.89)

Note: p-values in parenthesis

[5] Moran's *I* was originally adopted only on single variables, but Cliff and Ord (1972) and Hordijk (1974) applied the principle for spatial autocorrelation to the residuals of regression models for cross-sectional data.

[6] See e.g. Burridge, 1980; Anselin, 1988; Anselin & Florax, 1995

Equation (2.7) is without spatially lagged explanatory variables, i.e. without intra- and inter-regional accessibilities. Hence, this specification might experience a higher risk of having spatially auto-correlated errors. As can be seen from Table 4.1 neither Moran's *I*, *LM-err* nor LM-lag indicate spatially auto-correlated errors for any model specification at the 5% significance level. The lowest p-value can, not surprisingly, be found for Equation (2.7) (*LM-err* with weight matrix *W3*). There are two explanations for the results in Table 4.1: 1) the chosen specifications model the spatial effects or 2) there are no spatial effects to model. In Section 5 the regression results are presented and the statistical significance of the intra- and/or inter-regional accessibilities will tell us if 1) or 2) holds.

4.2 Choice of estimation method

In Appendix 2 the distributions of the dependent variables are analyzed graphically. It is easy to see that the distributions are skewed and have outliers. One way of dealing with highly influential outliers is to use quantile regression as an alternative to OLS.[7] The quantile regression method has the important property that it is robust to distributional assumptions. The quantile regression estimator gives less weight to outliers of the dependent variable than OLS, which weakens the impact outliers might have on the results.

There are also theoretical advantages with quantile regressions. The municipalities are most likely heterogenous in their abilities to export products. Thus the effects of the variables explaining the abilities do not have to be and probably are not the same for all municipalities. It could be the case that the municipalities where the export values are low do not experience the same effect from an accessibility increase of highly skilled labour as the municipalities where the export values are high. OLS cannot account for heterogeneity of this kind. OLS assumes that the conditional distribution of the export values, given the set of municipality characteristics, is homogenous. This implies that no matter what point on the conditional distribution is analyzed, the OLS estimates of the relationship between the dependent variable and the regressors are the same. OLS regression estimates the conditional mean of the dependent variable as a function of the explanatory variables. In contrast, quantile regression enables the estimation of any conditional quantile of the dependent variable as a function of the explanatory variables. By estimating the marginal effects of the explanatory variables for different quantiles, a more complete description of the relationship between dependent and explanatory variables is achieved.

Koenker and Basset (1978) originally recommended quantile regressions as a robust alternative to OLS to solve the problem with errors that are not normally distributed. The quantile regression model expresses the conditional quantile as a linear function of explanatory variables.[8] For an arbitrary quantile, θ, the model specification is[9]

[7] Another alternative is to run OLS on the logarithmic values of the variables with skewed distributions. This is an option if the variables never take the value zero. In this paper estimations are conducted both on aggregated level and for three industrial sectors and several municipalities do not have any high valued export on sector level.

[8] This is analogous to the OLS regression where the conditional mean of a random variable is expressed as a linear function of explanatory variables.

[9] See e.g. Buchinsky (1998)

$$y_i = x_i'\beta_\theta + \varepsilon_{\theta i}, \tag{4.1}$$

where β_θ is a vector of regression parameters associated with quantile θ, x_i is a vector of independent variables, y_i is the dependent variable and $\varepsilon_{\theta i}$ is the error term. The conditional quantile, θ, of y_i given x_i is $Q_\theta(y_i|x_i) = x_i'\beta_\theta$. The only necessary assumption concerning $\varepsilon_{\theta i}$ is $Q_\theta(\varepsilon_{\theta i}|x_i) = 0$. The quantile regression estimate for β_θ is that value of β_θ that solves the following minimization problem

$$\min_\beta \frac{1}{n}\left(\sum_{i:y_i \geq x_i'\beta} |y_i - x_i'\beta|\theta + \sum_{i:y < x_i'\beta} |y_i - x_i'\beta|(1-\theta) \right) \tag{4.2}$$

The weights of the residuals in Equation (4.2) are different for different quantiles. For the median regression, 50 percent of the residuals are negative and 50 percent are positive and then all residuals get equal weights.[10] However, when estimating the 75th percentile, 75 percent of the residuals are negative and 25 percent are positive. The negative residuals are weighted by 0.25 and the positive residuals by 0.75. Solving the minimization problem (4.2) is not straightforward since it is not differentiable at the origin. But Buchinsky (1998) showed how (4.2) can be solved with linear programming.

Quantile regression is especially useful in the presence of heteroscedasticity, because the marginal effects of the covariates, given by β_θ, may differ for different quntiles, θ. In the special case where the errors are homoscedastic, the marginal effects will be the same across quantiles, though the intercept will differ. Koenker and Bassett (1982) proposed a method to estimate the variance-covariance matrix. But Rogers (1992) and Gould (1992) argued that this method underestimates the standard errors if the residuals are heteroscedastic. Gould (1992) suggested a bootstrap re-sampling procedure to overcome this problem. The procedure is standardized in Stata statistical package.[11]

Although quantile regression has been widely used in the past decade in many areas of applied econometrics, applications concerning knowledge production are not that easily found. One exception is Audretsch, Lehmann & Warning (2004) in their examination of locational choice as a firm strategy to access knowledge spillovers from universities, using a data set of young high-technology start-ups in Germany.[12]

Needless to say, quantile regression is not the same as dividing the complete data set into different quantiles of the dependent variable and then run OLS on these subsets. This action would truncate the dependent variable, introduce a sample selection bias and will result in a procedure where not all observations are being used for each estimate. In the next section quantile regression results are presented. OLS results are presented for comparison reasons.

[10] Koenker & Bassett (1978) state that the conditional median in a regression is more efficient than the least squares estimator for any distribution for which the median is more efficient than the mean.

[11] The procedure is called the design matrix bootstrap (see Gould, 1992, for further details)

[12] See also Gråsjö (2004)

5. Regression results

Regressions are conducted for every fifth quantile (Q5, Q10, Q15 etc.). The results together with the results from OLS regressions are presented graphically.[13] If the parameter estimates of the accessibility variables are not statistically significant for any conditional quantile then no graph is presented. The parameter estimates of the population dummy variables can be found in Appendix 3. In order to solve the heteroscedsticity problem for the quanitle regressions, bootstrap with 3000 replications are conducted. The analyses are carried out both on aggregated level and for the sector "Manufacture of office machinery, electrical machinery and communication equipment". This sector has the highest total export value and also the largest number of high valued export products. The multicollinerarity problem is less severe on sector level, but when two variables are collinear I have chosen to keep the variable measuring the accessibility to company R&D. The export value or the number of high valued export products in sector *j* is regressed against the accessibility measures for university R&D on aggregated level and the three accessibility measures for company R&D in sector *j*. All the industrial sectors with some registered export are presented in Appendix 4.

5.1 How to interpret the marginal effects of the accessibility variables

The marginal effect of the accessibility variables answers the question "What is the effect on the dependent variable if the accessibility to an opportunity (R&D, human capital) increases by 1?" The natural follow question is then "How can an accessibility increase by 1 be accomplished?". It has already been stated in this paper that the accessibility is affected by the size of the opportunity and commuting time within a municipality or between municipalities. The following exercise focuses on the size of the opportunity and has the intention to help the reader with the result interpretations in section 5.

Suppose that commuting time between and within municipalities is according to Table 5.1.

Table 5.1: Time sensitivity values and assumed time distances

Accessibility	ω	*t (min)*
Local	0.02	15
Intra-regional	0.1	30
Inter-regional	0.05	90

With values from Table 5.1, a local accessibility increase by 1 is accomplished if the opportunity increases by 1.35. The computation is straightforward and looks like this

$$\Delta A_{iL}^{X} = \exp(-\omega_L t_L)\Delta x_i = \exp(-0.02 \cdot 15) \cdot \Delta x_i = 1$$

and then solving for Δx_i,

$$\Delta x_i = \frac{1}{\exp(-0.02 \cdot 15)} = 1.35$$

[13] OLS with White's robust standard errors

The intra-regional accessibility increase equals 1 if the sum of all opportunity changes, $\sum_{r\in R,r\neq i}\Delta x_r$, is 20 according to

$$\Delta A_{iR}^{X} = \exp(-\omega_R t_R)\sum_{r\in R,r\neq i}\Delta x_r = \exp(-0.1\cdot 30)\cdot\sum_{r\in R,r\neq i}\Delta x_r = 1$$

$$\sum_{r\in R,r\neq i}\Delta x_r = \frac{1}{\exp(-0.1\cdot 30)} = 20$$

The corresponding calculation for the inter-regional accessibility is as follows

$$\Delta A_{iOR}^{X} = \exp(-\omega_{OR} t_{OR})\sum_{k\notin R}\Delta x_k = \exp(-0.05\cdot 90)\cdot\sum_{k\notin R}\Delta x_k = 1$$

$$\sum_{k\notin R}\Delta x_k = \frac{1}{\exp(-0.05\cdot 90)} = 90$$

Thus, if commuting time between municipality i in region R and all municipalities outside R is 90 minutes, then the aggregated opportunities in municipalities outside region R has to increase by 90 in order to achieve an inter-regional accessibility increase by 1.

5.2 Export and accessibility to R&D

In order to examine to what extent variations in accessibility to R&D explain variations in export value and number of high valued export products Equation (2.5) is estimated

$$Exp_i = a + b_1 A_{iL}^{uR\&D} + b_2 A_{iOR}^{uR\&D} + b_3 A_{iL}^{cR\&D} + b_4 A_{iR}^{cR\&D} + b_5 D_1 + b_6 D_2 + u_i \qquad (2.5)$$

Figure 5.1 shows the marginal effects of accessibility to university and company R&D on export values for aggregated data. The 95% confidence bands from bootstrapped estimation errors (quantile regression) and White's robust standard errors (OLS) are shown as dotted lines. As can be seen it is only local accessibility to company R&D that can explain the variations in export value for Swedish municipalities. The parameter estimates are positive and significant for municipalities with total export values corresponding to the upper part of the conditional distribution (except for Q95). An accessibility increase raises the export value the most for municipalities corresponding to Q80. The quantile value for Q80 is 2.64 billion SEK and hence a municipality with this export value will increase its export value by approximately 0.15 billion SEK if the accessibility increases with one. Note also the large differences between the marginal effects for the different quantiles (although most of them are statistically insignificant). The OLS parameter estimate of local accessibility to company R&D is significant (and constant) and corresponds to the mean export value.

In Figure 5.2 export value on sector level is regressed against accessibility to R&D. As on aggregated level it is only local accessibility to company R&D that has an effect on export value. Although the marginal effects of the quantile regressions and the OLS regression are very similar (approximately 50 million SEK), the statistical significance differ a lot. The OLS estimate is positive and very much significant (a narrow confidence band), but the quantile regression estimates are only significant for municipalities in the middle part of the conditional distribution.

In Figure 5.3 the output measure is changed to number of export products with price above 1000 SEK per kg. As expected this is a more proper output measure, with more variables being statistically significant resulting also in higher R^2 values. The intra-regional effect is positive and statistically significant over the whole conditional distribution, with the largest marginal effects in the upper tail of the distribution (from 0.2 to 0.7). As an example, a municipality corresponding to the median i.e. with approximately 28.7 high valued export products will increase this number by 0.5 if the intra-regional accessibility to company R&D is raised by 1. There are also productive knowledge flows from municipalities outside the functional region. Inter-regional accessibility to university R&D affects the number of high valued export products positively for municipalities corresponding to quantiles above the median of the conditional distribution.

In Figure 5.3 it can also be seen that increasing local accessibility to company R&D has a proved effect for municipalities with a number of export products below the median. OLS shows a misleading significance for local accessibility to university R&D. This is an illuminating example on the weakness of OLS since a deletion of the nine highest observations of the dependent variable eliminates the significance. The parameter estimate shrinks to 0.0005 and the t-value to 0.04 (see Appendix 5 for further details). In Gråsjö (2004) it was evident that local university R&D was of no importance on patent production in Swedish municipalities. The pattern is repeated in this paper when the output is export value or high valued exports. Thus the positive effects from university R&D found in US (Acs et al 2002) cannot be repeated.

According to Figure 5.4, intra-regional accessibility to company R&D is the variable that best explains the variations of the dependent variable in the industrial sector “Manufacture of office machinery, electrical machinery and communication equipment”. Once again the largest marginal effects can be found in the upper part of the distribution. The values are in a range from 0.4 for Q5 to 1.3 for Q90. This is a more comprehensive way to describe the relationship between the dependent variable and an independent variable, instead of only report the effect at a single point, the conditional mean, as in OLS. There are also some statistically significant positive effects (Q85 and Q90) of inter-regional accessibility to university R&D.

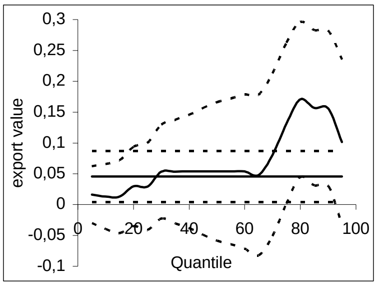
Regression results. Export and accessibilty to R&D

Dependent variable: **Export values** (10^9 SEK) for Swedish municipalities, n = 288, aggregated level

	Q5	Q10	Q15	Q20	Q25	Q30	Q35	Q40	Q45	Q50	Q55	Q60	Q65	Q70	Q75	Q80	Q85	Q90	Q95	OLS
Q, mean	0.05	0.08	0.13	0.17	0.26	0.31	0.36	0.44	0.53	0.72	0.87	1.05	1.23	1.50	2.04	2.64	3.67	4.76	7.57	2.24
Pse R^2, R^2	0.15	0.16	0.18	0.19	0.20	0.21	0.23	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.34	0.37	0.41	0.45	0.53	0.44

Figure 5.1: Marginal effects of accessibilty to R&D, with 95% confidence limits

Local, company



	QR	OLS
Intra-regional, company	ns	ns
Local, university	ns	ns
Inter-regional, university	ns	ns

(95% confidence level)

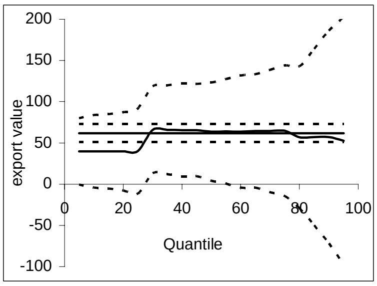
Dependent variable: **Export values** (10^6 SEK) for Swedish municipalities, n = 288, sector level

Manufacture of office machinery, electrical machinery and communication equipment

	Q5	Q10	Q15	Q20	Q25	Q30	Q35	Q40	Q45	Q50	Q55	Q60	Q65	Q70	Q75	Q80	Q85	Q90	Q95	OLS
Q, mean	0.03	0.14	0.26	0.47	1.00	1.34	2.41	3.71	5.61	7.83	10.9	17.0	28.2	45.2	78.9	128	239	375	1180	442
Pse R^2, R^2	0.12	0.12	0.12	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.24	0.25	0.25	0.10

Figure 5.2: Marginal effects of accessibilty to R&D, with 95% confidence limits

Local, company



	QR	OLS
Intra-regional, company	ns	ns
Inter-regional, company	ns	ns
Local, university	ns	ns
Inter-regional, university	ns	ns

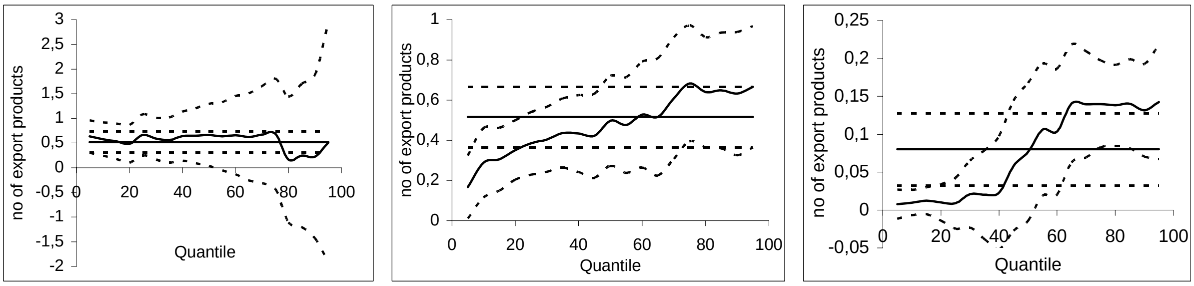
(95% confidence level)

Dependent variable: **Number of high valued export products** for Swedish municipalities, n = 288, aggregated level

	Q5	Q10	Q15	Q20	Q25	Q30	Q35	Q40	Q45	Q50	Q55	Q60	Q65	Q70	Q75	Q80	Q85	Q90	Q95	OLS
Q, mean	3.3	5.3	7.7	9.3	11.7	13.9	17.4	19.9	23.7	28.7	32.3	39,0	44.3	53.6	66.8	84.1	108	167	224	60.1
Pse R^2, R^2	0.32	0.33	0.35	0.37	0.39	0.41	0.43	0.44	0.46	0.47	0.50	0.52	0.54	0.56	0.59	0.62	0.66	0.69	0.73	0.82

Figure 5.3: Marginal effects of accessibilty to R&D, with 95% confidence limits

Local, company | Intra-regional, company | Inter-regional, university



Note: Local, university - never statistically significant (95% confidence level) with QR, but + significant with OLS

Regression results. Export and accessibilty to R&D (cont.)

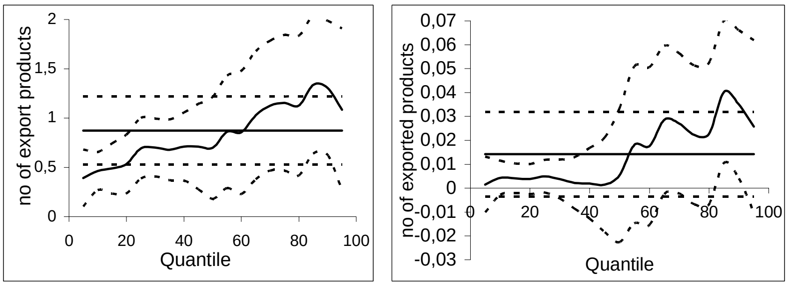
Dependent variable: **Number of high valued export products** for Swedish municipalities, n = 288, sector level

Manufacture of office machinery, electrical machinery and communication equipment

	Q5	Q10	Q15	Q20	Q25	Q30	Q35	Q40	Q45	Q50	Q55	Q60	Q65	Q70	Q75	Q80	Q85	Q90	Q95	OLS
Q, mean	0.3	0.7	1.3	1.7	2.3	3.3	4,0	4.7	5.7	7.3	9.3	10.8	12.3	15.1	20.2	27.4	37.7	56.7	77.7	18.5
Pse R^2, R^2	0.22	0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40	0.42	0.43	0.45	0.47	0.50	0.52	0.54	0.56	0.58	0.59	0.72

Figure 5.4: Marginal effects of accessibilty to R&D, with 95 % confidence limits

Intra-regional, company — Inter-regional, university



	QR	OLS
Local, company	ns	+
Inter-reg, company	ns	+
Local, university	ns	ns

(95% confidence level)

Before exploring the importance of human capital on exports, a short sum up of the main results might be in order.

- The total value of exported products is affected by local accessibility to company R&D. The effects are positive and significant for municipalities where the values of the aggregated export are high. Knowledge flows between and within functional regions are of no importance.
- The intra- and inter-regional accessibilities play a more important roll for the number of high valued products in Swedish municipalities. This is the case both on aggregated level and on sector level.

5.3 Export and accessibility to human capital

To establish to what extent accessibility to human capital affects exports in Swedish municipalities Equation (2.6) is estimated

$$Exp_i = a + b_1 A_{iL}^{hc} + b_2 A_{iR}^{hc} + b_3 A_{iOR}^{hc} + b_4 D_1 + b_5 D_2 + u_i \quad (2.6)$$

Estimation results of Equation (2.6) presented in Figure 5.5 indicate positive effects of increased local accessibility to human capital. Opposed to R&D (see Figure 5.1) well educated people appear to have significant positive effects also for municipalities with export values in the lower part of the distribution. A local accessibility increase of 1 raises the export value by approximately 0.5 million SEK (Q10 to Q50). Furthermore, there are negative impacts of intra-regional accessibility to human capital. This is some what surprising, and the interpretation is that an increased number of well educated people in a municipality have a positive effect on the export value of the municipality but a negative effect on the other municipalities' export values in the region. Another way to put it, municipalities endowed with a lot of human capital are more likely to dominate the region when it comes to exporting capacity measured my total export value. From Figure 5.5 it is also evident that there are no beneficial knowledge flows from municipalities outside the own region.

On sector level (see Figure 5.6), the only statistically significant effects can be found from local accessibility. This is the case for quantiles in the upper part of the distribution (except Q95).

When the number of high valued export products is used as an output, the results are quit different (see Figure 5.7). The local accessibility to human capital seems to matter only for the municipalities that have few high valued export products (Q5 and Q10). Figure 5.7 also shows that it is not necessary to have well educated people living in the municipality where the number of high valued export products is registered. Hence, both intra-regional and inter-regional accessibility to human capital have positive and statistically significant parameter estimates over the whole conditional distribution.

Figure 5.8 shows the marginal effects of accessibility to human capital in the industrial sector "Manufacture of office machinery, electrical machinery and communication equipment". The number of exported products in a municipality is above all affected by the accessibility to well educated people within the region but outside the own municipality. The largest effects can be found for the municipalities with an export performance corresponding to the largest quantiles.

When examining the figures displaying the marginal effects of R&D and human capital it might strike the reader the much smaller magnitude of the marginal effects of human capital. The explanation is that the magnitudes of the accessibilities to human capital are much higher (see Table 3.1).[14]

[14] As a clarification, elasticity calculations evaluated at the median reveal the following result:

Aggregated level, intra-regional accessibilty to company R&D on no. of high valued export products:	0.011
Aggregated level, intra-regional accessibilty to human capital on no. of high valued export products:	0.014

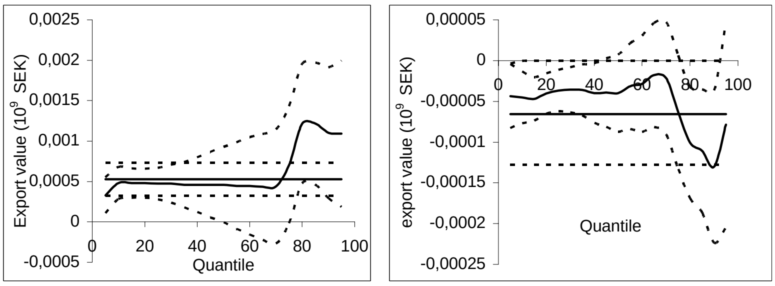
Regression results. Export and accessibilty to human capital

Dependent variable: **Export values** (10^9 SEK) for Swedish municipalities, n = 288, aggregated level

	Q5	Q10	Q15	Q20	Q25	Q30	Q35	Q40	Q45	Q50	Q55	Q60	Q65	Q70	Q75	Q80	Q85	Q90	Q95	OLS
Q, mean	0.05	0.08	0.13	0.17	0.26	0.31	0.36	0.44	0.53	0.72	0.87	1.05	1.23	1.50	2.04	2.64	3.67	4.76	7.57	2.24
Pse R^2, R^2	0.15	0.18	0.21	0.23	0.24	0.24	0.25	0.26	0.27	0.28	0.29	0.29	0.30	0.31	0.32	0.34	0.36	0.39	0.48	0.44

Figure 5.5: Marginal effects of accessibilty to human capital, with 95% confidence limits

Local | Intra-regional | Inter-regional



Never significant with QR or OLS
(95% confidence level)

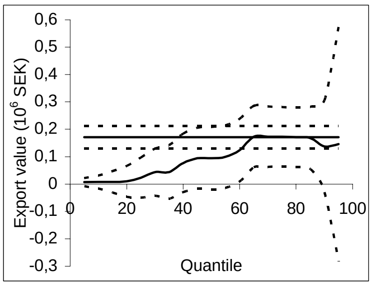
Dependent variable: **Export values** (10^6 SEK) for Swedish municipalities, n = 288, sector level

Manufacture of office machinery, electrical machinery and communication equipment

	Q5	Q10	Q15	Q20	Q25	Q30	Q35	Q40	Q45	Q50	Q55	Q60	Q65	Q70	Q75	Q80	Q85	Q90	Q95	OLS
Q, mean	0.03	0.14	0.26	0.47	1.00	1.34	2.41	3.71	5.61	7.83	10.9	17.0	28.2	45.2	78.9	128	239	375	1180	442
Pse R^2, R^2	0.009	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.08	0.10	0.11	0.13	0.15	0.17	0.18	0.20	0.21	0.22	0.24	0.10

Figure 5.6: Marginal effects of accessibilty to human capital, with 95% confidence limits

Local | Intra-regional | Inter-regional



Never significant with QR or OLS
(95% confidence level)

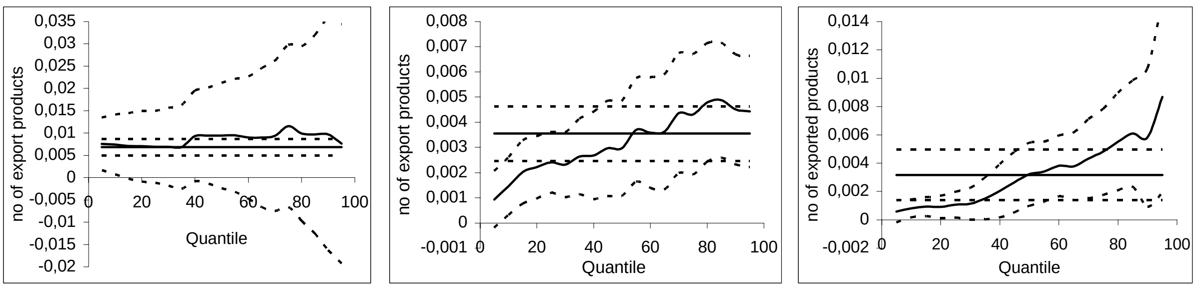
Never significant with QR or OLS
(95% confidence level)

Dependent variable: **Number of high valued export products** for Swedish municipalities, n = 288, aggregated level

	Q5	Q10	Q15	Q20	Q25	Q30	Q35	Q40	Q45	Q50	Q55	Q60	Q65	Q70	Q75	Q80	Q85	Q90	Q95	OLS
Q, mean	3.3	5.3	7.7	9.3	11.7	13.9	17.4	19.9	23.7	28.7	32.3	39,0	44.3	53.6	66.8	84.1	108	167	224	60.1
Pse R^2, R^2	0.33	0.36	0.38	0.4	0.42	0.44	0.45	0.47	0.49	0.51	0.53	0.55	0.57	0.59	0.62	0.64	0.68	0.7	0.74	0.83

Figure 5.7: Marginal effects of accessibilty to human capital, with 95% confidence limits

Local | Intra-regional | Inter-regional

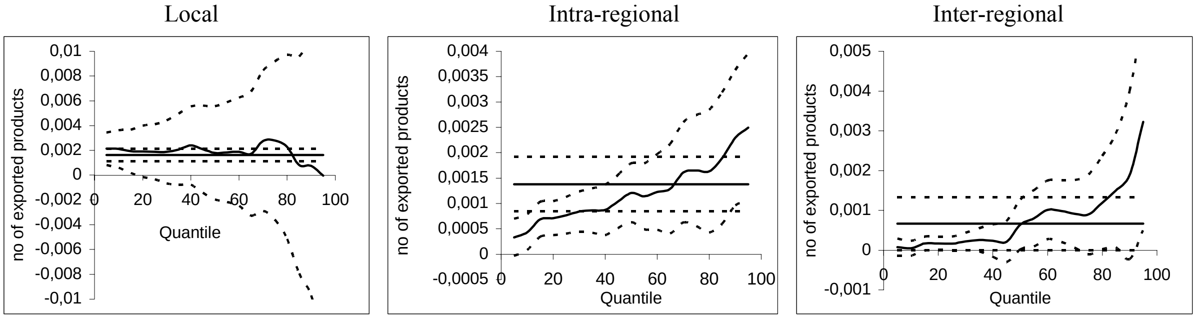


Regression results. Export and accessibilty to human capital (cont.)

Dependent variable: **Number of high valued export products** for Swedish municipalities, n = 288, sector level
Manufacture of office machinery, electrical machinery and communication equipment

	Q5	Q10	Q15	Q20	Q25	Q30	Q35	Q40	Q45	Q50	Q55	Q60	Q65	Q70	Q75	Q80	Q85	Q90	Q95	OLS
Q, mean	0.3	0.7	1.3	1.7	2.3	3.3	4,0	4.7	5.7	7.3	9.3	10.8	12.3	15.1	20.2	27.4	37.7	56.7	77.7	18.5
Pse R^2, R^2	0.26	0.29	0.32	0.35	0.36	0.39	0.4	0.42	0.44	0.46	0.47	0.49	0.5	0.53	0.55	0.56	0.58	0.59	0.59	0.73

Figure 5.8: Marginal effects of accessibilty to human capital, with 95 % confidence limits



5.4 Human capital or R&D, what is most important?

In order to answer the question if it is accessibility to R&D or accessibility to human capital (well educated people) that best explains the variations in municipalities' exports, Equation (2.7) is estimated.

$$\frac{Exph_i}{Exp_i} = \frac{A_{iL}^{hc}}{Pop_i}\beta_1 + \frac{A_{iL}^{cR\&D}}{Pope_i}\beta_2 + \frac{A_{iL}^{uR\&D}}{Pope_i}\beta_3 + u_i \qquad (2.7)$$

The regression results on aggregated level and sector level are presented in Figures 5.9-5.10. The results indicate a clear dominance for accessibility to human capital both on aggregated data and sector level. Thus, having a large share of high valued exported products is primarily determined by accessibility to human capital. Accessibility to company R&D and university R&D are obviously to a large extent crowded out by accessibility to human capital.

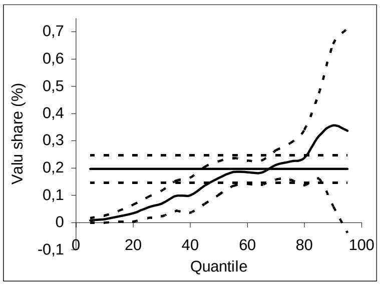
Regression results. Human capital vs. R&D

Dependent variable: **Value share of high valued export products** (%) for Swedish municipalities, n = 288, aggregated level

	Q5	Q10	Q15	Q20	Q25	Q30	Q35	Q40	Q45	Q50	Q55	Q60	Q65	Q70	Q75	Q80	Q85	Q90	Q95	OLS
Q, mean	0.04	0.09	0.13	0.19	0.32	0.43	0.61	0.81	1.13	1.48	2.18	2.83	4.49	6.62	10.3	14.2	22.1	29.7	53.8	9.54
Pse R^2, R^2	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.10	0.11	0.13	0.14	0.16	0.17	0.18	0.18	0.17	0.14	0.08	0.16

Figure 5.9: Marginal effects of local accessibilties with 95% confidence limits

Human capital per 1000 inhabitants



	QR	OLS
Company R&D per 1000 employed	ns	ns
University R&D per 1000 employed	ns	ns

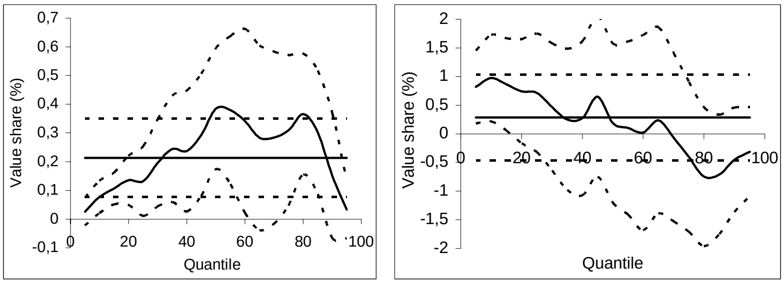
Dependent variable: **Value share of high valued export products** (%) for Swedish municipalities, n = 288, sector level

Manufacture of office machinery, electrical machinery and communication equipment

	Q5	Q10	Q15	Q20	Q25	Q30	Q35	Q40	Q45	Q50	Q55	Q60	Q65	Q70	Q75	Q80	Q85	Q90	Q95	OLS
Q, mean	0.08	0.37	1.19	2.77	4.65	7.50	11.1	14.9	18.1	24.0	31.3	38.0	43.2	54.1	60.0	68.1	79.5	87.7	96.2	34.5
Pse R^2, R^2	0.03	0.04	0.05	0.05	0.06	0.06	0.06	0.05	0.05	0.06	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.01	0.01	0.06

Figure 5.10: Marginal effects of local accessibilties with 95% confidence limits

Human capital per 1000 inhabitants | University R&D per 1000 employed



Company R&D per 1000 employed

Never significant with QR or OLS (95% confidence level)

6. Conclusions

The purpose in this paper has been to investigate the importance of accessibility to university R&D, company R&D and human capital on exports in Swedish municipalities. Two different output measures have been used, export value and number of export products with a price above 1000 SEK per kg. Although it is hard to separate the effects of the explanatory variables, due to multicolllinearity problems, the empirical findings indicate that accessibility to human capital is the factor that drives the export performance the most. Both accessibility to company R&D and accessibility to human capital affects exports separately so it could be worth while investigating this aspect further. Perhaps the problem could be solved by structural equation modeling (SEM), factor analysis (which is incorporated in SEM) or ridge regression, but this is left for future research. Accessibility to university R&D seems to have very little impact on exports.

How about the importance of geographical proximity? The effects are very local when total export value in municipalities is the dependent variable in the knowledge production function.

Local (within the municipality) accessibility to human capital or company R&D is the only variable that has a positive statistically significant effect on aggregated data. Especially the intra-regional, but also to some extent the inter-regional knowledge flows appear to be more influential when the output measure is the number of high valued export products.

All estimations are conducted with quantile regression. The paper emphasizes the appropriateness of this regression technique, especially when the dependent variable has influential outliers and the distribution is skewed. But also in general, when the research unit is heterogeneous with respect to the explanatory variables and an investigation performed over the whole conditional distribution is needed.

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Appendix 1

Moran's *I* :

$$I = \frac{N}{S}\left(\frac{e'We}{e'e}\right)$$

where
N = number observations
S = sum of all elements in W
W = spatial weight matrix
e = vector of residuals (OLS)

Resultant values of Moran's I are in the range from -1 to 1.
The test on the null hypothesis that there is no spatial autocorrelation between observed values over the N observations can be conducted based on the standardised statistic:

$$Z(I) = \frac{I - E(I)}{V(I)^{0,5}}$$

where

$$E(I) = \frac{N}{S} \cdot \frac{tr(MW)}{N-K}$$

$$V(I) = \left(\frac{N}{S}\right)^2 \cdot \left(\frac{tr(MWMW') + tr(MW)^2 + (trMW))^2}{(N-K)(N-K+2)}\right) - (E(I))^2$$

where
tr = trace operator (sum of the diagonal elements)
$M = I - x(x'x)^{-1}x'$ (Projection matrix)
K = number of explanatory variables

LM-err:

$$LM - err = \frac{N^2}{tr(W'W + W^2)}\left(\frac{e'We}{e'e}\right)^2$$

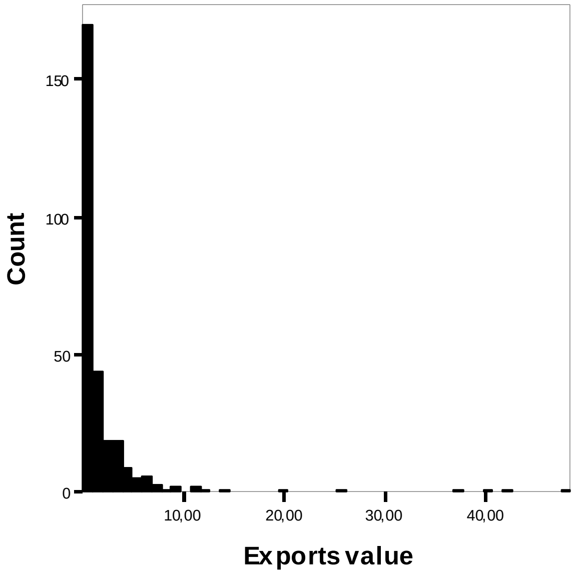
LM-lag:

$$LM - lag = \frac{N}{\frac{(Wx\beta)'M(Wx\beta)}{e'e} + tr(W'W + W^2)}\left(\frac{e'Wy}{é'e}\right)^2$$

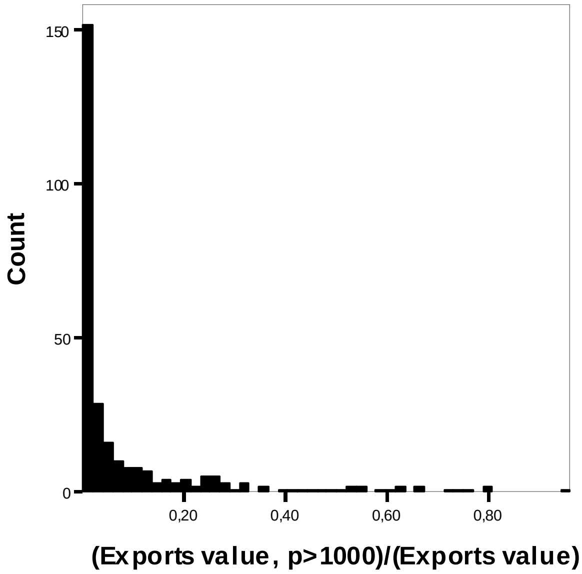
β = vector of coefficient estimates
y = dependent variable

Both the LM-err and the LM lag statistic are distributed as χ^2 with one degree of freedom.

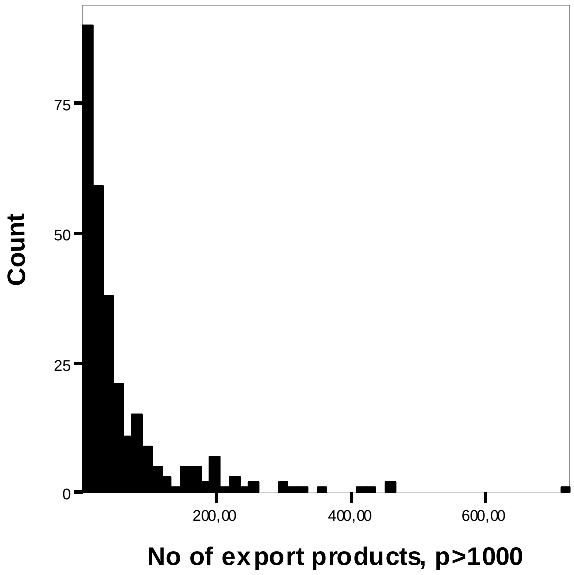
Appendix 2



Count
150
100
50
0
10,00
20,00
30,00
40,00
Exports value



Count
150
100
50
0
0,20
0,40
0,60
0,80
(Exports value, p>1000)/(Exports value)



Count
75
50
25
0
200,00
400,00
600,00
No of export products, p>1000

Appendix 3

Parameter Estimates for population dummy variables. Exports and Accessibility to human capital, Eq. 2.5
D1 = 1 if population > 100 000, D2 = 1 if population between 50 000 and 100 000.

	Export value (10^9 SEK), aggregated level				Export value (10^6 SEK), sector level				No. of export products, aggregated level				No. of export products, sector level			
	d1	t	d2	t	d1	t	d2	t	d1	t	d2	t	d1	t	d2	t
q5	3.05	2.10	ns		ns		ns		ns		36.2	6.90	ns		10.0	4.00
q10	ns		ns		ns		ns		123	3.36	35.0	3.96	ns		11.4	3.56
q15	3.42	2.03	0.75	3.20	ns		ns		126	3.76	43.3	3.72	ns		14.6	3.41
q20	ns		0.90	3.71	ns		ns		132	4.33	50.4	3.89	ns		16.6	3.06
q25	ns		0.89	3.07	ns		ns		140	4.93	55.7	4.03	ns		22.4	3.83
q30	ns		0.87	2.50	ns		ns		136	5.13	70.4	5.10	36.3	2.01	25.1	4.42
q35	4.14	2.23	1.20	3.11	ns		ns		136	4.73	73.5	5.52	34.2	1.97	28.0	5.54
q40	4.20	2.13	1.30	3.06	ns		ns		133	4.11	71.6	5.46	38.0	2.18	30.0	6.62
q45	4.17	2.02	1.31	2.64	ns		ns		138	3.28	72.1	5.83	37.5	2.26	29.7	6.84
q50	5.08	2.30	1.60	2.46	ns		ns		136	3.28	80.0	5.83	47.5	2.67	ns	
q55	5.01	2.04	1.59	1.97	ns		ns		133	2.49	83.0	5.63	ns		ns	
q60	ns		2.15	2.21	ns		ns		132	2.07	81.3	4.98	49.2	2.28	33.1	5.54
q65	ns		2.98	2.69	ns		257	2.23	ns		91.9	5.33	51.0	1.98	31.4	4.77
q70	ns		2.97	2.37	ns		ns		ns		101	5.63	ns		33.4	4.23
q75	ns		3.80	2.82	ns		ns		ns		101	5.62	ns		32.0	3.45
q80	ns		3.55	2.14	ns		ns		334	3.14	107	5.83	ns		33.4	3.12
q85	ns		ns	1.88	ns		ns		327	3.16	121	6.62	98.8	2.50	50.1	4.65
q90	ns		ns	0.69	ns		ns		326	3.44	117	6.57	96.4	2.31	49.4	4.73
q95	ns		ns	0.93	ns		ns		323	3.39	112	5.93	113	2.59	51.6	4.89
ols	5.34	3.63	3.82	2.31	ns		ns		162	4.75	80.8	8.14	49.4	3.81	30.9	7.45

ns = not statistically significant at 95% confidence level

Parameter Estimates for population dummy variables. Exports and Accessibility to human capital, Eq. 2.6
D1 = 1 if population > 100 000, D2 = 1 if population between 50 000 and 100 000.

	Export value (10^9 SEK), aggregated level				Export value (10^6 SEK), sector level				No. of export products, aggregated level				No. of export products, sector level			
	d1	t	d2	t	d1	t	d2	t	d1	t	d2	t	d1		d2	
q5	ns		ns		ns		ns		82.9	2.55	19.1	2.11	ns		ns	
q10	ns		ns		ns		ns		83.8	2.26	ns		ns		ns	
q15	ns		ns		ns		ns		100	2.49	34.6	2.24	27.7	2.36	10.56	2.24
q20	ns		ns		ns		ns		99.3	2.42	ns		27.3	2.23	ns	
q25	ns		ns		ns		ns		105	2.67	56.7	3.09	28.1	2.07	20.43	3.08
q30	ns		ns		ns		ns		104	2.48	60.7	3.30	ns		21.0	3.26
q35	ns		ns		ns		ns		101	2.42	64.1	3.44	ns		24.21	3.90
q40	ns		ns		ns		ns		94.4	2.18	60.4	3.09	ns		23.61	3.74
q45	ns		ns		ns		ns		ns		64.5	3.14	ns		26.26	3.81
q50	ns		ns		ns		ns		ns		73.6	3.39	43.0	2.51	26.58	3.68
q55	ns		ns		ns		ns		ns		75.0	3.30	41.1	2.30	29.44	3.89
q60	ns		ns		ns		ns		ns		82.9	3.51	38.8	1.98	29.1	3.63
q65	ns		ns		ns		ns		ns		84.6	3.31	ns		28.35	3.27
q70	ns		ns		ns		ns		ns		75.7	2.89	ns		25.36	2.63
q75	ns		3.74	2.09	ns		ns		ns		69.6	2.58	ns		23.93	2.17
q80	ns		ns		ns		ns		ns		86.5	3.07	ns		29.31	2.13
q85	ns		ns		ns		ns		ns		81.7	2.67	ns		47.87	2.88
q90	ns		ns		ns		ns		ns		98.0	2.87	ns		46.24	2.43
q95	ns		30.6	2.21	ns		ns		ns		93.6	2.62	ns		ns	
OLS	3.42	2.10	3.76	2.14	-111	-2.22	ns		142	4.21	75.4	7.68	47.3	3.55	28.11	6.94

Appendix 4

Description and statistics of the industrial sectors

Group	Export value per year, bSEK (1997-1999)	No. of export products with price > 1000 SEK/kg (1997-1999)	Description	SNI codes
G1	3.60	54	Agriculture, forestry and fishing	1, 2, 5
G2	5.95	14	Mining	10, 11, 12, 13, 14
G3	14.45	55.67	Manufacture of food and tobacco products	15, 16
G4	11.36	1045.33	Manufacture of textiles, clothing an leather products	17, 18, 19
G5	24.59	33.67	Manufacture of wood and wood products, except furniture	20
G6	68.49	432.67	Manufacture of paper, paper products, publishing and printing	21, 22
G7	70.30	783.33	Manufacture of coke, refined petroleum products and nuclear fuel, chemicals and chemical products	23, 24
G8	16.45	389.33	Manufacture of rubber and plastics products	25
G9	6.16	255	Manufacture of other non-metallic mineral products	26
G10	44.41	296	Manufacture of basic metals	27
G11	20.85	1010.67	Manufacture of fabricated metal products, except machinery and equipment	28
G12	88.60	2961	Manufacture of machines and equipment	29
G13	127.29	5315.33	Manufacture of office machinery, electrical machinery and communication equipment	30, 31, 32
G14	18.82	3550.33	Manufacture of medical, precision and optical instruments, watches and clocks	33
G15	106.49	417	Manufacture of motor vehicles and other transport equipment	34, 35
G16	13.69	563.67	Manufacture of furniture	36
G18	2.20	3	Distribution of water and electricity	40
G27	0.06	71.33	Other business activities	74
G30	0.24	58.33	Other community, social and personal service activities	90, 91, 92, 93
Tot	643.99	17309.67		

Appendix 5

In the table below the sensitiveness of OLS from outliers is demonstrated. The first column shows the estimation of the full sample. If the eight largest observations of the dependent variable are deleted the parameter estimate of local accessibility to university R&D is still significant. But when the nine largest observations are deleted, the estimate becomes insignificant. Note also the drop in R^2.

OLS results on number of high valued export products			
	N=288	N=280	N=279
(Constant)	19.27 (8.48)	20.46 (9.74)	26.61 (9.80)
Access to univ R&D, local	**0.046 (2.48)**	**0.047 (2.90)**	**0.0005 (0.04)**
Access to univ R&D, inter-reg	0.080 (3.31)	0.080 (3.29)	0.078 (3.22)
Access to comp R&D, local	0.520 (4.80)	0.440 (4.48)	0.394 (5.02)
Access to comp R&D, intra-reg	0.517 (6.75)	0.439 (7.05)	0.449 (7.04)
Large population (>100 000)	161.7 (4.75)	115.1 (10.0)	126.9 (12.2)
Medium population (50 to 100 000)	80.76 (8.14)	75.07 (7.45)	76.59 (7.53)
Adj R^2	0.815	0.701	0.684