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Knowledge Spillovers and Economic Growth

an analysis using data of Dutch regions in the period 1987-1995

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Abstract
The importance of knowledge spillovers for achieving innovation and economic growth is widely recognized. It is not straightforward which type of spillovers is most effective: *intra*-sectoral spillovers or *inter*-sectoral spillovers. We investigate this controversy using a model of regional growth. The model also deals with the impact of local competition on innovation and growth. The model is estimated using sectoral data for 40 Dutch regions. We find that local competition is important particularly for economic growth in industry sectors (manufacturing and construction), while diversity, a proxy for *inter*-sectoral spillovers, is important particularly for growth in service sectors. We find no effect for specialization (a proxy for *intra*-sectoral spillovers).

Keywords: knowledge spillovers, innovation, economic growth, industry structure

JEL-classification: O31, R11

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1. Introduction

Spillovers occur if an innovation or improvement implemented by a certain enterprise increases the performance of another enterprise without the latter benefiting enterprise having to pay (full) compensation. In the past decades there has been increasing recognition that spillovers contribute substantially to economic growth. According to the new growth theory (LUCAS, 1988; ROMER, 1986), spillovers are the engine of growth. MACKUN and MACPHERSON, 1997, conclude that the relative importance of firms' in-house R&D compared to external technical activity may be declining. They suggest that external inputs (for example in the form of spillovers) can increase the productivity of in-house initiatives of firms.

There are various types of spillovers (transfers), viz. knowledge spillovers, market spillovers and network spillovers.[1] The new growth theory primarily focuses on knowledge spillovers (AGHION and HOWITT, 1992; AGHION **et al.**, 1997; ROMER, 1986). Knowledge (obtained via, for example, R&D activities) accumulates, and this generates innovations in enterprises. Since enterprises benefit from each other's innovations and ideas, an economy may grow even in the event of maximum input of labour and capital. In other words, spillovers explain part of the phenomenon that economies grow faster than might be expected on the basis of labour and capital input growth.[2] The increasing role of knowledge and small firms in the modern economy (AUDRETSCH and THURIK, 2000 and 2001) motivates the investigation of the effect of knowledge spillovers, as small firms usually are more dependent upon knowledge spillovers than large firms are.

Knowledge spillovers appear to be a local phenomenon (AUDRETSCH and FELDMAN, 1996). Interaction between people and enterprises located in each other's proximity produce the highest likelihood of spillover effects. This seems surprising, considering the current state of information technology, where information can be diffused throughout the world at practically zero cost. AUDRETSCH and THURIK, 1999, refer to a paradox, which they explain by distinguishing between information and (tacit) knowledge. Information consists of facts and may be diffused simply and free of charge, with examples being the gold price in Tokyo, or the weather in New York. Knowledge, contrastingly, may not simply be coded. This is because knowledge is often highly specific in nature (think for instance of technical knowledge), and therefore difficult to transmit through formal means of communication. This makes that face-to-face contacts are important for the diffusion of knowledge. Knowledge diffusion primarily emerges by means of social contacts,

[1] For an extensive elaboration, see JAFFE, 1996. In the present paper, the term spillovers denotes knowledge spillovers, unless stated otherwise.

[2] In the new growth theory, knowledge spillovers are considered an example of *(technological) external economies of scale*. For an individual firm, average costs per unit of output decrease with growing output at the *industry-wide level*. An increase in industry output increases the stock of knowledge through positive information spillovers for each firm, leading to an increase in output at the firm level (VAN OORT, 2002, p. 42).

for example during meetings or sales transactions.[3] It may also emerge in a more structured fashion, as part of public-private initiatives explicitly focusing on knowledge dissemination between clustering firms. We describe a case study of such an initiative in Section 2.

The contribution of knowledge spillovers to economic growth has been demonstrated by several authors (e.g. GRILICHES, 1992; SOETE and TER WEEL, 1999). There are, however, various conflicting theories as regards the exact mechanisms of spillovers, with debates focusing on two questions. *First*, do spillovers primarily emerge within one sector or, alternatively, do spillovers emerge between different sectors? *Second*, how does local competition influence the amount of innovative activity and hence, economic growth?

The present paper focuses on these questions, using a model of regional growth based on GLAESER **et al.**, 1992. The model examines three possible determinants of regional sectoral growth, viz. specialization, diversity and competition. Specialization is hypothesized to facilitate spillovers between firms from the same sector, while diversity is hypothesized to facilitate spillovers between firms from different sectors. The impact of specialization and diversity on growth, therefore, indicates the importance of *intra*-sectoral and *inter*-sectoral spillovers, respectively. The third variable, competition, may have both positive and negative effects on the amount of innovative activity and hence on economic growth. In fact, this involves a trade-off between internalization of innovation externalities (local monopoly) and the necessity to innovate to remain competitive in the market (local competition). By including local competition as a possible determinant of economic growth, this trade-off can be tested.

The model is estimated using data of 40 Dutch regions (spatial NUTS3 aggregation level), that provide information on the number of businesses, employment and real value added for six sectors, viz. mining, manufacturing, construction, the trades, transport&communication and financial services. The 40 regions cover the entire Netherlands. The data cover the period 1987-1995.

We remark that the present study focuses on inter-firm spillovers, i.e., knowledge spilling over between different firms. Our focus is not on knowledge produced by universities or public research institutions spilling over toward private firms. WEVER and STAM, 1999, show that for their sample of Dutch high technology SMEs, “by far the most important external innovation impulses came from other firms ... (instead of knowledge centres such as universities)” (p. 396).

The remainder of this paper is set up as follows. In Section 2 three theories on knowledge spillovers and local competition are discussed. Also, to illustrate how spillovers may come about in practice, we describe a case study on ‘knowledge-intensive industrial clustering’ in the Netherlands. Section 3 outlines the model which the theories are tested with. Also the hypotheses to be tested, the construction of the model variables, and the differences between the present study and the

[3] The distinction between knowledge and information as used in this paragraph is also known in the literature as the distinction between tacit and codified knowledge or that between implicit and explicit knowledge.

study of GLAESER **et al.**, 1992, are dealt with. Section 4 discusses issues concerning spatial aggregation levels to take account of both intra-regional and inter-regional spillovers. Furthermore, Section 4 describes the data employed. In Section 5 we present the estimation results. The final section contains a summary and some conclusions.

2. Theory

The model of GLAESER **et al.**, 1992, departs from the assumption that knowledge spillovers at the regional level are of major significance as regards innovation and economic growth. More precisely formulated, GLAESER **et al.**, 1992, assume that sectors in different regions may have different growth rates because knowledge spillovers work out more effectively in one region than in another. This is because different *types* of knowledge spillovers may emerge in different regions, viz. *intra*-sectoral spillovers versus *inter*-sectoral spillovers. Furthermore, the intensity of local competition may differ between regions. The model examines three theories as to the impact of knowledge spillovers and local competition on regional growth. In this section these theories are discussed. Also, we describe how knowledge spillovers between firms may come about in practice, by means of a case study on 'knowledge-intensive industrial clustering'.

Three theories on knowledge spillovers and local competition

The *first* theory is developed by MARSHALL, 1890; ARROW, 1962, and ROMER, 1986, abbreviated as MAR. They assume that knowledge spillovers are most effective between homogeneous enterprises. So, spillovers primarily emerge within one sector. For a given region, this would imply that specialization in a limited number of activities may contribute to spillovers and growth. An example of this type of within-industry spillovers would be the microchip manufacturing industry in Silicon Valley (GLAESER **et al.**, 1992, p.1130). The MAR economists further assume that the situation of a local monopoly is beneficial for economic growth, since in that case, the vast share of the yields generated by innovation benefits the innovator itself. That is, the externalities associated with innovation are internalized by the innovator. This would produce an additional incentive to innovate. In the MAR theory, regional sectoral growth is maximized if the sector is dominant in the region, and if local competition is not too strong.

The *second* theory is that of PORTER, 1990, who agrees with MAR that knowledge spillovers between firms in specialized sectors (sectors which are concentrated in certain regions) stimulate economic growth. In contrast to MAR, however, Porter assumes that local competition has a positive impact on growth. In his view, competition accelerates imitation and upgrades innovation. Although competition decreases the relative benefits for the innovator (due to larger spillovers flowing to competitors), the amount of innovative activity will increase, because enterprises are "forced" to innovate: enterprises that fail to improve products and production processes in due time will lose ground to their competitors and will ultimately go bankrupt. An example of fierce competition to innovate, resulting in growth, would be the Italian ceramics and gold jewelry industries (GLAESER **et al.**, 1992, p.1128). So, while MAR emphasize the negative effect of competition on the amount of innovative activity, Porter assumes that the positive effect is dominating.

The *third* theory elaborating on the significance of local knowledge spillovers was developed by JACOBS, 1969. Jacobs' theory departs from the assumption that knowledge spillovers work out most effectively among enterprises that practise different activities. Primarily *inter-sectoral* knowledge transfers would thus be of significance. In her view, sectors will grow in regions where, besides the sector itself, various other sectors are important. In this philosophy, regions marked by a high degree of variety (diversity) will thrive.[4] As regards competition, Jacobs agrees with Porter, i.e., Jacobs assumes that local competition accelerates the adoption of new technologies and, consequently, stimulates economic growth.

Knowledge spillovers in practice: the case of Océ [5]

The three theories discussed above all deal with the phenomenon of spillovers flowing between neighbouring firms. But how do these spillovers come about in practice? In the introduction to this paper we already mentioned that face-to-face contacts are important, for example during meetings or sales transactions. However, this is still somewhat vague. As an illustration of how spillovers may work in practice, below we describe a case study on 'knowledge-intensive industrial clustering'.

In modern economies, many high-tech firms operate in highly competitive markets. In these markets it is crucial to constantly improve upon all parts of the production process. This is particularly important with the advent of low-cost but highly skilled competition in Central and Eastern Europe as well as Asia (AUDRETSCH and THURIK, 2001). Therefore, in some regions, innovative clusters of high-tech firms are formed. WINTJES and COBBENHAGEN (2000) describe the case of Océ, a high-tech multinational making specialised copy machines, located in the Eindhoven-Venlo region in the Netherlands. In this region, as a public-private policy initiative, a cluster of (small) local suppliers was formed around Océ with the purpose of benefiting from each other's expertise, by closely working together. Océ, whose core competence is product development (i.e., developing copy machines), outsourced their engineering tasks to the regional suppliers, thereby externalising part of the codification process to the region. The externalities were absorbed, accumulated and cultivated within the regional supplying firms. In this way these firms increased their innovative competences. In particular, the supplying firms, whose innovative capacity traditionally consisted of tacit knowledge built up by years of 'learning by doing', learned how to codify their knowledge. The supplier firms in the cluster used and socialised their tacit knowledge, in order to jointly transform

[4] An example of this type of inter-sectoral spillovers would be the following: "A San Francisco food processor invented equipment leasing when he had trouble finding financing for his own capital; the industry was not invented by the bankers" (GLAESER **et al.**, 1992, p.1132).

[5] The remainder of this section is based on WINTJES and COBBENHAGEN (2000).

a prototype of a new product or module into a manufacturable one. In this way, at his turn, Océ benefited from the supplier firms as these firms were now better equipped to codify their tacit knowledge and communicate their codified knowledge to Océ. Wintjes and Cobbenhagen show that proximity is crucial in these kind of processes as “the restructuring of a codification process requires intensive communicative interaction between heterogeneous knowledge resources”.

3. Model, hypotheses, operationalization of variables, and earlier work

In this section the model to be estimated is described. Also the hypotheses to be tested, and the operationalizations of the variables specialization, competition and diversity, which are crucial in the model, are discussed. Finally, at the end of this section, we discuss the surplus value of the present paper with regard to the study of GLAESER **et al.**, 1992.

Model

We use a simple model to test the three theories described above. The model assumes that each individual firm in a certain sector and region has a production function of output which depends on labour input and the overall level of technology. Each firm takes technology, prices and wages as given and sets labour input such that profits are maximized. Furthermore, the overall level of technology is assumed to have both national components and local components. Growth of *local* technology captures technological externalities present in the sector in the region. These externalities can be measured by variables such as specialization, local competion and diversity. Using these assumptions one can derive that employment growth in a sector in a region depends on wage growth, growth of *national* technology, and these measures of (local) technological externalities. For a formal derivation we refer to GLAESER **et al.**, 1992, pp. 1132-1134.

The above framework leads us to an equation that we can test empirically by means of regression analysis. The dependent variable is employment growth in a sector in a region. The explanatory variables are specialization, local competion and diversity and a constant term. The constant term captures both growth of *national* technology and wage growth (note that we thus assume a national labour market instead of a local one). By including these variables in the regression equation, the empirical validity of the various theories from Section 2 can be tested.

In our empirical application, regional sectoral economic growth is measured between 1987 and 1995. Growth is analysed at the mid-term (we use an eight-year period), since it is assumed that the effects of knowledge spillovers are not immediately observable. Newly obtained knowledge has to be implemented in existing structures, etcetera. Obviously, economic growth cannot entirely be explained by the three variables specialization (S), competition (C) and diversity (D). Therefore, we employ a number of control variables, the most important being national sector-growth. This variable corrects for demand shifts. If the demand for products of a given sector changes (at the national level), then for a given region, the demand for the products of that sector is also likely to change. As a result, growth of that sector in that region will be affected. This has nothing to do with the spillover effects that we want to investigate, so we include *national* sector-growth as a control variable. By including this variable, merely *regional* sector-growth is left to be explained. Indeed, regional sector-growth is exactly what we want to explain (given the assumption that knowledge spillovers are a local phenomenon). So, national sector-growth is a useful control variable. Besides, we also investigate whether there are region-specific effects not covered by the model. For this purpose, we include region-dummies. As the regional dummies *might* be interpreted as an indicator of *inter-regional* spillovers, we use dummies at various spatial aggregation levels to investigate the relevant range of these inter-regional spillovers. This will be explained in Section 4. The model reads as follows:

(1) $$\Delta y_{i,r} = b_0 + b_1 S_{i,r} + b_2 C_{i,r} + b_3 D_{i,r} + g_1 \Delta y_{i,NL} + \sum_{k=2}^{K} g_k R_k + e_{i,r} ,$$

where:

Δy : average annual relative growth of real value added in the period 1987-1995

S: specialization in 1987

C: competition in 1987

D: diversity in 1987

R: region-dummy

i: sectoral index (i=1,..,6)

r: regional index (r=1,..,K; K dependent upon spatial aggregation level used)

b : vector with parameters of main explanatory variables

g : vector with parameters of control variables

e : disturbance term

NL: indicator for The Netherlands

Hypotheses

The outlined theories of MAR, Porter and Jacobs as regards the effects of S, C and D may now be expressed in model hypotheses in terms of expected signs of the parameters b_1 to b_3. In MAR's theory, specialization has a positive effect on growth, and local competition a negative effect. According to Porter, both specialization and local competition positively affect growth. According to Jacobs, diversity as well as local competition generate positive effects on growth. In formulas (2a) to (4b), the various hypotheses are formally expressed in terms of null hypotheses H_0 and alternative hypotheses H_a:

(2a) $H_0: \ b_1 = 0,$ $H_a: \ b_1 > 0$ (specialization; MAR)

(2b) $H_0: \ b_2 = 0,$ $H_a: \ b_2 < 0$ (competition; MAR)

(3a) $H_0: \ b_1 = 0,$ $H_a: \ b_1 > 0$ (specialization; Porter)

(3b) $H_0: \ b_2 = 0,$ $H_a: \ b_2 > 0$ (competition; Porter)

(4a) $H_0: \quad b_2 = 0, \qquad H_a: \quad b_2 > 0$ (competition; Jacobs)

(4b) $H_0: \quad b_3 = 0, \qquad H_a: \quad b_3 > 0$ (diversity; Jacobs).

Note that the alternative hypotheses always assume a specific sign for the parameter value (positive or negative), hence the hypotheses have to be tested by means of one-tailed test procedures.

Operationalization of variables

It is important how the variables specialization, competition and diversity are defined, as the estimation results of equation (1) may be different for different variable operationalizations. The operationalizations employed in the present paper are discussed below. The three variables are defined at the spatial NUTS3 aggregation level (i.e., 40 regions for the Netherlands).

Specialization is defined as the employment share of the sector in the region, relative to the share of that sector in the whole country (in our case The Netherlands). If a sector is overrepresented in a region (relative to the national employment share of that sector), then there are larger-than-average opportunities for within-sector spillovers to emerge, and according to MAR and Porter, this would stimulate growth of that sector in that region. The expression of specialization (S) reads as follows:

(5) $$S_{i,r} = \frac{Empl_{i,r} / Empl_{tot,r}}{Empl_{i,NL} / Empl_{tot,NL}},$$

where "Empl" stands for employment and "tot" for total. The value of the variable is expressed as a quote in deviation from one, which figure corresponds to the national average employment share of the sector. Note that the value of S for a given sector is independent of the shares of the other sectors in the same region. That is, for a given region, small sectors may have larger values of S than large sectors. This is because we are only concerned with the relative extent of regional concentration for the sector under consideration. According to formula (5), there are many possibilities as regards within-sector spillovers if relatively many employees work in the same sector. This may be the case if in a sector a few relatively large enterprises operate, or, alternatively, if relatively many small enterprises operate.[6]

Competition is defined as the number of businesses in a sector in a region relative to the number of businesses in that sector in the whole country, adjusted for the size of the region. The (economic) size of a region is measured as total employment in that region. The variable assesses whether local (regional) competition is higher or lower than national competition. According to MAR, intensive local competition in a sector impedes economic growth in that sector. In case of intensive competition, MAR assume that enterprises limit their amount of innovative activities

[6] Of course, inter-firm spillovers can not occur if one very large enterprise were to operate alone. In that case, the specialization variable would have to be fixed at zero, considering that the variable is used as an indicator of the facilitation for intra-sectoral spillovers. Our dataset does not comprise such a case.

(e.g. by cutting down R&D expenses) because too much new knowledge spills over to competitors (i.e., externalities are considered too large). According to Jacobs and Porter, to the contrary, intensive local competition benefits economic growth, because enterprises are "forced" to innovate (the alternative being demise). The expression of local competition (C) reads as follows:

$$C_{i,r} = \frac{B_{i,r} / Empl_{tot,r}}{B_{i,NL} / Empl_{tot,NL}}, \tag{6}$$

where B stands for the number of businesses. Local competition of sector i in region r is thus defined as the region-size-adjusted number of businesses in the sector relative to the nation-wide number of businesses in that sector. The value of the variable is expressed as a quote in deviation from one, which figure corresponds to the nation-wide (adjusted) number of businesses in the sector.

In our approach, specialization and competition are different concepts in that specialization deals with the clustering of workers while competition deals with the clustering of businesses (see formulas 5 and 6). Since the number of workers and the number of businesses may be positively correlated, the variables specialization and competition may also be correlated. In our dataset, the correlation between specialization and competition is 0.37. This value is low enough to ensure that our model outcomes do not suffer from multicollinearity.

For a given sector in a given region, *diversity* is defined as the employment share of the three smallest sectors in the *remaining* five sectors in the region, adjusted for the employment share in the region of those five sectors.[7] The first factor measures diversity of the region (excluding the sector of analysis). A larger share of the smallest sectors implies a more diverse sector structure. Adjustment for the employment share of the remaining five sectors is required, since large sectors can benefit relatively less from spillovers from the remaining sectors, plainly because these remaining sectors are relatively small compared to the (large) sector of analysis. In other words, assuming an identical structure of the remaining sectors, the potential to benefit from inter-sectoral spillovers is relatively higher for a small sector of analysis than for a large sector of analysis. According to Jacobs, higher degrees of diversity generate higher growth rates. The expression of diversity (D) reads as follows:

$$D_{i,r} = 100 \times \frac{\sum_{k=1}^{3} Empl_{-i[k],r}}{\sum_{-i} Empl_{i,r}} \times \frac{\sum_{-i} Empl_{i,r}}{Empl_{tot,r}} = 100 \times \frac{\sum_{k=1}^{3} Empl_{-i[k],r}}{Empl_{tot,r}}, \tag{7}$$

with:

$Empl_{-i[k],r}$ Employment of kth smallest sector in region r, sector i excluded,

$\sum_{-i} Empl_{i,r}$ Total employment in region r, sector i excluded.

Formula (7) shows that the two factors may be rewritten as one expression: the share of the three smallest sectors (*excluding* the sector of analysis) in total re-

[7] In this paper, the (nonagricultural) economy is disaggregated into six sectors.

gional employment (*including* the sector of analysis). The variable is expressed in percentages.

Diversity is not to be interpreted as the counterpart of specialization. High levels of specialization may coincide with high levels of diversity. A sector may be relatively dominant in a region, while at the same time the remainder of that region may be characterized by a high degree of diversity. However, because employment of the sector of analysis is part of the denominator in (7), there will be some negative correlation between the variables specialization and diversity. In fact, in our dataset, the correlation is -0.26. Again, this does not lead to multicollinearity problems.

Differences between present study and study GLAESER **et al.**, 1992

There are several ways to specify the concepts of specialization (S), competition (C) and diversity (D) in model variables. GLAESER **et al.**, 1992, choose an alternative operationalization of local competition. They use the number of businesses per worker for a sector-region combination relative to the number of businesses per worker in the entire sector (whole country). This variable measures the inverse average business size but this may not be appropriate as a measure of local competition.[8] Furthermore, if a positive effect of the business size measure on growth is found, one may have found merely the effect that small firms grow faster than large firms. See for example KLEIJWEG and NIEUWENHUIJSEN, 1996. Also for specialization and diversity there are alternative operationalizations. Some measures are discussed in NIEUWENHUIJSEN and VAN STEL, 2000, pp.29-37. Besides the operationalizations of the variables S, C and D, there are also other differences between the present study and that of GLAESER **et al.**, 1992. While they investigate employment growth in the United States in the period 1956-1987, the present study investigates value added growth in the Netherlands in a more recent, hence more knowledge-intensive period (1987-1995). Furthermore, while GLAESER **et al.**, 1992, consider only large two-digit sectors, we consider firms from all sectoral sizes, albeit at a higher level of aggregation. Consequently, we also include small sectors, which -on average- have a relatively high small firm presence. This is important for the purpose of the present study, because small firms usually are more dependent upon knowledge spillovers than large firms are.

4. Intra-regional spillovers, inter-regional spillovers, and data

In this section we describe the spatial aggregation level at which we use data, and we describe a new method to take account of inter-regional spillovers. This involves the use of regional dummies at various spatial aggregation levels. The method also corrects for spatial autocorrelation. We end this section with a description of the data that are used in this paper.

[8] For example, for a given sector in equally large regions, the inverse business size measure cannot distinguish between regions with 100 businesses with on average 5 workers, and regions with 20 businesses, also with on average 5 workers. Clearly, competition is more intense in regions with 100 businesses. The operationalization (6) employed in the present paper takes account of that.

Investigating intra-regional spillovers: which spatial aggregation level to use?

In the present paper we use a new database with sector-information at the spatial level of the 40 Dutch *Corop* regions, covering the period 1987-1995. The 40 regions cover the entire Netherlands. In terms of the international NUTS classification of regions, the *Corop* level corresponds to NUTS3 level.[9] This level is appropriate to assess intra-regional knowledge spillovers, because the *Corop* regions are constructed so that most regions are characterized by some degree of clustering. Furthermore, the scale of *Corop* regions is such that personal contacts *between* regions are likely to occur less frequently than personal contacts *within* regions. Therefore it is plausible to assume that the vast share of spillovers emerges within these regions. Some support for this assumption is provided by OOSTERHAVEN **et al.**, 2001. Using bi-regional input-output data they are able to identify both *intra*-regional and *inter*-regional clusters of interrelated economic activity. They focus on three regions, of which two are defined at the NUTS3 level (Greater Amsterdam and Greater Rotterdam) and one is defined at NUTS1 level (Northern Netherlands). Even for the smaller NUTS3 regions, they find a substantial number of *intra*-regional clusters, including the important sea and air transport sector in Greater Rotterdam.

Correcting for inter-regional spillovers

Although we argued above that the NUTS3 level is the appropriate level for investigating *intra*-regional spillovers, we acknowledge that there are also *inter*-regional knowledge spillovers. For instance, the above-mentioned study of OOSTERHAVEN **et al.**, 2001, also finds a number of inter-regional clusters, including linkages between Amsterdam business services and trade sectors on the one hand, and several other sectors in the rest of the Netherlands.

In the present paper we use a regional dummy approach to take account of inter-regional spillovers. We compute regressions using regional dummies at the NUTS1 (4 regions), NUTS2 (12 regions) and NUTS3 (40 regions) levels, and using no regional dummies at all. Next, making use of a standard model selection procedure (Schwarz information criterion), we establish the most adequate spatial aggregation level at which the regional dummies must be defined.[10] By and large, the selected aggregation level may be interpreted as the *range* of the inter-regional spillovers. This can be seen as follows. Formally, a significant parameter estimate of a regional dummy explains part of the variation in the endogenous variable that can not be explained by the other model variables. Now, when the regional dummy is defined at higher aggregation level than the level at which the 'regular' model variables are defined, a significant parameter estimate indicates that the underlying regions have 'something in common' that explains the regional variation in the endogenous variable.

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[9] For the Netherlands, the NUTS1 classification distinguishes 4 regions (Northern, Eastern, Western and Southern Netherlands), while the NUTS2 classification distinguishes 12 regions (the 12 provinces of the Netherlands). The *Corop* or NUTS3 regions are still smaller.

[10] The Schwarz information criterion weighs the statistical fit against the number of parameters. The lower the Schwarz information criterion, the more 'efficient' the model specification.

For example, if the selection procedure chooses the specification with NUTS2 level dummies, then apparently real value added growth 1987-1995 at NUTS3 level is partly explained by a factor that is common for all NUTS3 regions within a NUTS2 region. As *intra*-regional spillovers are captured already by the variables specialization, competition and diversity, it is not implausible to assume that the NUTS2 dummies reflect, among other things, *inter*-regional spillovers flowing between firms from different NUTS3 regions within the same NUTS2 region.

In this line of reasoning, the spatial aggregation level selected by the Schwarz information criterion gives us an indication about the range of the inter-regional spillovers. For example, when a specification with NUTS2 dummies is selected, then apparently the NUTS3 regions are so uniform that the regional variations in economic growth not captured by the 'regular' model variables, can be explained by a common variable (i.e., a NUTS2 dummy). On the other hand the NUTS2 regions apparently are too different from each other to make a NUTS1 dummy specification appropriate. In terms of the range of spillovers, this example would be consistent with spillovers flowing between firms within *the same* NUTS2 region, but not with spillovers flowing between firms from *different* NUTS2 regions.

So, by investigating the four possible specifications (NUTS1, 2 or 3 level dummies, or no dummies at all), we take account of inter-regional spillovers. Furthermore, this method corrects for spatial autocorrelation, as the unexplained variation in the endogenous variable that is common for adjacent NUTS3 regions is captured by a higher level regional dummy. This pragmatic method to correct for spatial autocorrelation follows KEEBLE **et al.**, 1993, p. 34.

A study which takes account of inter-regional spillovers in a more sophisticated way is done by BROUWER **et al.**, 1999. They use the same Dutch *Corop* regions and an index of agglomeration advantages, which is based both on physical distances between the central towns of the different *Corop* regions, and on population density of the regions (Manshanden-index). They provide mixed empirical evidence on the so-called innovation breeding place hypothesis: R&D intensities of manufacturing and service firms do not depend on the value of the Manshanden-index, whereas the amount of innovation output of firms, given a certain level of R&D intensity, *does* depend on the value of the Manshanden-index. The latter result implies that the advantages associated with location in an agglomerated region (such as the physical proximity of business partners) result in a more efficient use of R&D inputs.

Data

The regional information is disaggregated into six sectors (excluding agriculture): mining, manufacturing, construction, the trades, transport&communication and financial services. The data are obtained from Statistics Netherlands (CBS) and the Netherlands Association of Chambers of Commerce (VVK). Table 1 illustrates the database variables adopted, as well as the respective source and the use in model (1).

[TABLE 1 ABOUT HERE]

Nominal value added is deflated with help of a value added price index that is sector-specific, not region-specific. The deflator is derived from CBS National Accounts. For more information on the data employed, see NIEUWENHUIJSEN **et al.**, 1999.

As we see from Table 1, enterprises are measured in terms of establishments. This may be a disadvantage, since one enterprise may consist of several establishments, and our study covers inter-firm spillovers and inter-firm competition.[11] The problem is limited though, since the number of establishments and the number of enterprises are highly correlated. Furthermore, we consider *local* competition in the model. Establishments of one firm operating in different regions is not contradictory with the concept of local competition. Since most enterprises operating several establishments probably have their establishments dispersed throughout several regions, the competition variable (6) is hardly affected by the use of establishments instead of businesses.

Basically, there are 240 observations available (viz. 6 sectors times 40 regions). However, a number of observations is not used in the determination of the parameter estimates. The sector mining is not used since in many regions there are no mining activities at all. For those regions with some form of mining activities, employment in this sector is considered too small. Of the remainder 200 observations, 3 extreme observations (outliers) are removed, leaving 197 observations in the data set. The model is estimated on the basis of these 197 observations. Table 2 presents some characteristics of the data set employed.

[TABLE 2 ABOUT HERE]

5. Estimation results

In this section the estimation results are discussed. In the first instance, the model is estimated with data for all sectors included in the estimation sample. We call this the macro-estimation. However, we suspect that the spillover mechanisms may work out differently for different sectors of economy. Therefore, we also present estimation results for the sectors "Industry" and "Services" separately.

Macro estimates

Model (1) is estimated with ordinary least squares (OLS) and the results are in Table 3. We have a sample of 197 observations (see Section 4). We estimated the four model variants described earlier, i.e., including regional dummies at NUTS1, NUTS2 and NUTS3 level (model variants (1b) until (1d) in Table 3) and no regional dummies at all (model variant (1a)). From the Schwarz information criterion we see that NUTS3 level dummies are not appropriate; model variant (1d) has the highest value. So, apparently, variations in value added growth not captured by the 'regular' model variables can be explained satisfactorily by higher level regional dum-

[11] In this paper, we use the terms enterprises, firms and businesses interchangeably.

mies. This indicates that adjacent NUTS3 regions have ‘something in common’ explaining growth, and, among other things, this may reflect inter-regional spillovers between firms from these adjacent regions.

On the other extreme, the specification which includes no dummies at all is also not appropriate, as model variant (1a) has the second highest value for the Schwarz information criterion. So, at least some regional variation in value added growth is explained by regional dummies, possibly indicating that inter-regional spillovers do not occur at a country-wide level, but rather are restricted to smaller areas.

Model variants (1b) and (1c) have the lowest Schwarz information criterion values, indicating that specifications which include regional dummies at NUTS2 or NUTS3 level are statistically most efficient. Recall that the regional dummies also correct for spatial autocorrelation. Having described the various implications of the four model variants for inter-regional spillovers, we are now ready to move on to the main interest of our study: the results for the intra-regional spillover variables specialization, competition and diversity.[12] We will concentrate on the statistically most efficient model variants (1b) and (1c).

[TABLE 3 ABOUT HERE]

Specialization

From Table 3, we see that the estimate of the specialization parameter has a negative sign in both the model variants (1b) and (1c). This finding is in contrast to the theories of MAR and Porter who predict a positive sign (see hypotheses 2a and 3a). However, absolute t-values are well below unity. We may conclude that the effect of specialization on (regional) economic growth is small or absent. That is, spillovers between homogeneous enterprises do not contribute significantly to economic growth. By and large, this finding is in line with WEVER and STAM, 1999, who find that regional clusters of high technology small and medium sized enterprises (SMEs) hardly exist in the Netherlands.[13] They find that, even in regions where high technology SMEs are overrepresented, most of the customers and suppliers that the interviewed high technology SMEs consider relevant for their innovative development are located outside their own region.

The finding that specialization has practically no impact on regional growth seems to contradict the experience that many regions are characterized by high levels of concentration of homogeneous enterprises. But many reasons other than growth opportunities may account for these high concentration levels. MARSHALL, 1890, mentions the possibility to jointly utilize production factors (e.g. highly skilled staff). HENDERSON, 1986, explains a high level of business concentration of a certain

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[12] Again, we notice that the regional dummies do not necessarily reflect inter-regional spillovers alone. However, the inclusion of these dummies enables straightforward interpretation of the estimation results for the intra-regional spillover variables.

[13] Wever and Stam define a regional cluster as “a geographical concentration of firms which exhibit a significant degree of intraregional linkages” (WEVER and STAM, 1999, p. 393). Like the present study, they apply the spatial level of the Dutch *Corop* regions (i.e., NUTS3 regions).

sector in a certain region by a relatively high demand for the products of that sector in that region, favouring business startups in such regions because of low transport costs. By and large, the above explanations state that specialization emerges because of the *static* efficiency thus achieved. The present study, however, investigates *dynamic* efficiency (i.e., growth). See also GLAESER **et al.**, 1992, p.1129.

Competition

The estimate of the competition parameter b_2 is positive in both model variants (1b) and (1c). We may conclude that MAR's theory on competition is rejected, see (2b). Enterprises do not limit innovative activity out of fear that their efforts employed will spill over to competitors. Instead, the results seem to confirm the theories of Porter and Jacobs, i.e., enterprises innovate to a higher extent so as not to incur a backlog compared to competitors. The higher levels of innovation, in turn, lead to higher growth rates. The t-value of the estimate of b_2 is not high though. The parameter estimate is significant at 5% level (one-tailed test) in model variant (1b), but only at 10% level in model variant (1c). So, we must be cautious when claiming a positive relation between local competition and growth.

As regards the size of the effect, we compute the effect on average annual growth in percent points if competition were to increase by one standard deviation. We do this because the measurement unit adopted for the competition variable is not trivially interpretable (competition is expressed as a quote in deviation from one), and standard deviations can be interpreted independently of the measurement unit employed. From Table 2, we see that the standard deviation of competition in our data set equals 0.29. The estimate of the competion parameter equals 0.70 (variant 1b estimate). So, a ceteris paribus increase of one standard deviation has an effect on average annual growth of $0.29 \times 0.70 = 0.20\%$-point.

Diversity

A diverse economic environment of a sector appears to have a positive effect on growth. The estimate of the parameter of diversity is significantly positive at 5% level in model variant (1b) and at 1% level in variant (1c). This result is consistent with Jacobs' theory on diversity. Higher degrees of regional diversity generate higher spillovers and, therefore, higher growth rates. As many different enterprise types as possible should locate in each other's proximity to enable enterprises to capitalize on ideas they do not develop themselves since they exercise very different business activities. According to the estimation results, a ceteris paribus increase of one standard deviation of the diversity variable has a positive impact of $6.12 \times 0.041 = 0.25\%$-point.

Sector estimates

It is possible that the spillover mechanisms work differently in different sectors of economy. For example, knowledge spillovers may be more important in manufacturing industries than in service industries, given the –on average- higher levels of R&D in manufacturing. Therefore we want to analyze the different sectors of economy separately. However, it is not possible to obtain separate reliable results for each of the five sectors in our data set, because of too few observations. Therefore, we subdivide our data set in two larger sectors, viz. “Industry” and “Services”. The industry-sector contains the observations of manufacturing and construction, while the services-sector contains the trades, transport&communication and financial services. Again, for both samples we computed the four model variants (1a) until (1d) described earlier. The estimation results are given in Table 4. To save space, for each sector we report only the two model specifications with the lowest value for the Schwarz information criterion. This involves variants (1a) and (1b) for Industry and variants (1b) and (1c) for Services.

[TABLE 4 ABOUT HERE]

Table 4 illustrates that the results are indeed quite different for different sectors of economy. For the industry-sectors, competition appears to be of particular importance as regards realizing regional economic growth. For the service sectors, on the other hand, diversity appears to have a positive impact on growth.

These results may be interpreted as follows. In industry sectors, R&D expenses are relatively high in comparison with service sectors. Therefore, in industry sectors, growth mainly originates from the amount of firms’ own innovative activities, rather than from inter-firm spillovers. Indeed, the estimates of the parameters of both spillover facilitating variables specialization and diversity have t-values below unity, while the estimate of the competition parameter is significantly positive (1% level, one-tailed test). So, in the industry sectors, if local competition is intensive, innovation and rapid adoption of new technologies is required for firms in order to not lose ground to competitors. That is, intensive competition encourages a process that could be characterized as an “innovation race”.

In contrast to the industry sectors, knowledge spillovers seem to be important in the service sectors. It concerns spillovers between heterogeneous enterprises rather than spillovers between homogeneous enterprises. Diversity appears to have a positive effect on growth (parameter estimate is significant at 1% level; model variant (1c)), while specialization again has a very low t-value. Note that, given the construction of the diversity variable (see formula 7), the positive effect of diversity does not necessarily imply that service sectors benefit from spillovers from industry sectors. It is also possible that, for instance, the financial service sector capitalizes on ideas originating from the transport&communication sector. However, given the higher amounts of R&D in the industry sectors, it seems plausible that service sectors benefit from spillovers from industry sectors rather than from other subsectors within the service industries. The non-significant estimate of the competition parameter suggests that it is not crucial for enterprises in these sectors to generate many innovations by themselves. If they were to lag behind in that field, they will not directly incur a critical backlog compared to their competitors. The combination of non-significant parameter estimates for specialization and competition and a significantly positive estimate for diversity suggests that innovation processes in service industries are more or less accidental in nature: there appears to be little competition in innovation and few spillovers originating from within the own sector. Instead, innovations or improvements at firms in the service sectors seem to be dependent on innovation-generating firms (which apparently are in the industry sectors) located nearby. So, for service industries, a high degree of diversity is especially important.

6. Summary and conclusions

In recent decades, the importance of knowledge spillovers for the processes of innovation and economic growth has been widely recognized. Firms can improve their performance by implementing innovative ideas that were not originally developed by themselves. In this way economies may grow without having to use additional labour and capital inputs.

Although the importance of knowledge spillovers is undisputable, little is known about the size of spillover effects and what type of spillovers is more important for achieving growth: spillovers emerging *within* sectors or spillovers emerging *between* sectors. Furthermore, the impact of local competition on innovation and growth is not straightforward. All these issues are investigated in the present paper, using a regional growth model that is based on GLAESER **et al.**, 1992. In the model mid-term growth at sectoral and regional level is explained by specialization, competition, diversity and some controls. By including these variables in the model, the empirical validity of three theories about knowledge spillovers and innovation can be tested.

The *first* theory is that of Marshall, Arrow and Romer (MAR). According to these economists, important spillovers primarily emerge among homogeneous enterprises, implying a positive impact of specialization on economic growth. As regards the role of competition, they assume a negative impact, due to the limited possibilities to internalize the externalities associated with innovation in case of fierce competition. The *second* theory is that of Porter. He assumes, like MAR do, a positive effect of specialization. As regards competition, however, Porter assumes a positive impact on growth, resulting from the sheer necessity for firms to innovate, as the alternative to innovation is demise. The *third* theory is developed by Jacobs. Like Porter, she assumes a positive effect of local competition. As regards knowledge spillovers, however, she emphasizes the importance of spillovers emerging among heterogeneous enterprises, implying a positive effect of diversity on economic growth.

We use a new data set with information at six-sector level and at the spatial level of 40 Dutch (so called *Corop*) regions, covering the entire Netherlands. Regional data are used because geographical proximity is considered important, as face-to-face contacts are assumed a necessary condition for knowledge spillovers to occur.

We find no empirical evidence for a positive relationship between specialization and value added growth, suggesting that specialization contributes to static efficiency rather than to dynamic efficiency (i.e., growth). We find evidence for positive relationships between competition and value added growth and between diversity and value added growth. The empirical evidence supports the theory of Jacobs. It does not support the theories of Marshall, Arrow and Romer, whereas it is inconclusive regarding Porter's theory. The estimation results further imply that local competition is particularly important for achieving growth in the industry sectors while diversity is particularly important for achieving growth in the service sectors. By and large, this can be interpreted as intensive competition in the industry sectors encouraging an "innovation race", and high extents of diversity encouraging spillovers from industry sectors towards service sectors.

There are a number of limitations to our approach which makes that the results presented in this paper should be interpreted with some caution. *First*, the present study investigates only one type of spillovers, viz. knowledge spillovers. As mentioned earlier, there exist other types of spillovers such as network spillovers and market spillovers. The latter type emerges through mutual supplies between firms (for example if a firm purchases a computer). But it is safe to assume that these other types of spillovers do not have a specific regional character, as face-to-face contacts are not crucial for these types of spillovers. If we assume that the network and market spillovers are distributed randomly across regions, we may claim that the model picks up the effects of knowledge spillovers adequately, accounting for growth differences between regions.

Second, the sectoral aggregation level strongly determines the meaning of the variables specialization, competition and diversity. Interpretations of results are conditional upon the aggregation level applied. For example, as regards the competition variable, the question arises whether the six-sector classification adopted in the present paper is appropriate. By defining the entire manufacturing industry as one sector, one implicitly assumes that businesses in, for instance, the metal industry compete with businesses in the food industry. This is implausible. Note, however, that the actual aggregation level is lower than six sectors, because not all subsectors are represented in all regions.

Despite these limitations, we argue that the present study provides some important insights concerning the mechanisms of knowledge spillovers and innovation at the regional level. Future research should concentrate on performing comparable exercises for more countries as the results of the present study need to be confirmed for other countries as well. Policy makers may want to base policy measures concerning regional firm clustering on the empirical findings of more countries. Furthermore, as the sectoral aggregation level applied is crucial in this type of research, it may be worthwhile to perform the regressions while defining the variables specialization, competition and diversity at lower aggregation levels.

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Table 1: Variables; source and use

Database variable	Years covered	Source	Use in model (1)
Number of establishments	1987	VVK	Competition
Labour volume[1]	1987	CBS: Annual Regional Economic Data	Specialization, competition, diversity
Value added[2]	1987, 1995	CBS: Annual Regional Economic Data	Growth value added
Deflator value added	1987, 1995	CBS: National Accounts	Growth value added

[1] Number of full-time jobs
[2] Gross value added at factor costs (current prices)

Table 2: Characteristics of model variables (based on 197 observations)

Variable	Minimum	Maximum	Average	Median	Standard deviation
Average annual growth real value added (%)	-3.22	9.93	2.84	2.84	2.14
Specialization (national average = 1)	0.43	1.90	0.98	0.95	0.27
Competition (national average = 1)	0.50	2.15	1.07	1.04	0.29
Diversity (%)	10.94	38.00	21.44	20.23	6.12

Table 3: Estimation results model (1), all sectors, dependent variable average annual growth real value added; 1987-1995 [1]

Explanatory variable (parameter)	Model (1a)	Model (1b)	Model (1c)	Model (1d)
Constant (b_0)	-1.17	-1.17	-1.90 **	-0.97
	(-1.39)	(-1.45)	(-2.45)	(-0.92)
Specialization (b_1)	-0.34	-0.25	-0.11	-0.056
	(-0.70)	(-0.56)	(-0.26)	(-0.13)
Competition (b_2)	0.71 *	0.70 *	0.59	-0.15
	(1.65)	(1.75)	(1.50)	(-0.27)
Diversity (b_3)	0.034 *	0.041 *	0.050 **	0.041 *
	(1.76)	(2.28)	(3.01)	(2.25)
Macro growth sector (g_1)	1.09 **	1.08 **	1.08 **	1.05 **
	(12.0)	(12.9)	(14.0)	(13.5)
Number of observations	197	197	197	197
Regional aggregation level:[2]				
NUTS1 (4 regions)		X		
NUTS2 (12 regions)			X	
NUTS3 (40 regions)				X
R^2	0.469	0.547	0.640	0.713
Schwarz info criterion	379.3	371.7	370.2	422.0

[1] T-values between parentheses.
[2] The model specifications (1a) until (1d) use 0, 3, 11, and 39 regional dummies, respectively. Dummy coefficients are not reported due to space limitations.
* Significant at 5% level (one-tailed test).
** Significant at 1% level (one-tailed test).

Table 4: Estimation results model (1), industry and services, dependent variable average annual growth real value added; 1987-1995 [1]

Explanatory variable (parameter)	Industry: model (1a)	Industry: model (1b)	Services: model (1b)	Services: model (1c)
Constant (b_0)	-1.05	-0.43	-0.49	-0.35
	(-0.52)	(-0.23)	(-0.43)	(-0.33)
Specialization (b_1)	-0.076	-0.61	0.13	-0.30
	(-0.11)	(-0.94)	(0.18)	(-0.48)
Competition (b_2)	1.91 **	1.69 **	-0.44	-0.21
	(2.86)	(2.81)	(-0.81)	(-0.41)
Diversity (b_3)	-0.027	0.011	0.075 *	0.092 **
	(-0.44)	(0.20)	(1.92)	(2.48)
Macro growth sector (g_1)	0.74 *	0.92 **	0.79 *	0.60 *
	(2.10)	(2.88)	(2.22)	(1.80)
Number of observations	80	80	117	117
Regional aggregation level: [2]				
NUTS1 (4 regions)		X	X	
NUTS2 (12 regions)				X
NUTS3 (40 regions)				
R^2	0.253	0.424	0.421	0.587
Schwarz info criterion	165.1	161.2	216.4	215.7

[1] T-values between parentheses.

[2] The model specifications (1a) until (1d) use 0, 3, 11, and 39 regional dummies, respectively. Dummy coefficients are not reported due to space limitations.

* Significant at 5% level (one-tailed test).

** Significant at 1% level (one-tailed test).