KNOWLEDGE IMPACTS OF UNIVERSITIES ON INVESTMENT BEHAVIOR OF INDUSTRY

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Abstract

This paper is concerned with the impacts of academic knowledge production (human capital, research, and consultancy) on investment behavior of the manufacturing industry. Starting from the neoclassical theory of capital accumulation, an interregional investment model for non-residential structures and equipment is developed. Within this model the knowledge impact of universities is represented by a diffusion function, taking into account the possibilities of contagious and hierarchical diffusion of knowledge. Special attention has been given to the identification of spatio-temporal correlation. The latter has been taken into account by means of the use of an EGLS estimator, based on a stationary spatio-temporal Markov scheme for the residual. The main result of the case study relating to The Netherlands is that academic knowledge production does seem to have a significant positive impact on investments in equipment, which is strongest in the neighborhood of central places (i.e. following a hierarchical diffusion pattern).

1. Introduction

In 1577 the local government of the (present) province of South-Holland in The Netherlands granted the University of Leyden freedom from taxes on wine and beer in order to stimulate students and scholars to enter its university. Other provinces, like for example Friesland and Utrecht, likewise exempted members of their university communities from taxes and granted them other privileges in order to promote the development of their regional universities, which were believed to generate important regional benefits (De Vrankrijker, 1938, pp. 137-148). During the 1960's and 70's there was again a competition between various regions in The Netherlands, only now for the establishment of two new universities. It was of course not fought with the same means as four centuries ago, but with arguments such as the suitability of the region, and the need for a positive socio-economic impetus which a university was expected to generate. These events illustrate that the importance (local) governments adhere to universities is large and long-standing.

Although in the US the establishment of new campuses is still being considered (e.g. in California) one may wonder whether in Western Europe there is still a policy interest in the issue of regional economic impacts of universities as, in fact, a reverse process of scale-enlargement and of closing down of departments and institutions is now a dominant policy feature in many European countries. The main reasons for this reverse process are budget cuts and demographic developments, in particular the expected decrease in the number of students. Strategic questions with regard to this closing down process should concern regional impacts on such matters as the participation in higher education, technological and technical development, spatial shifts in expenditure patterns, and the like. So one may conclude that studying regional economic impacts of universities is interesting from a policy point of view, regardless whether the higher education system is in a contracting or booming phase of its development.

The strong policy relevance might lead one to suppose that regional impacts of universities have been thoroughly studied, and that nowadays a profound insight into the importance of a university for regional development exists. As will be argued below, this is only partly the case. The present paper therefore addresses this topic, and will in particular be concerned with the regional impacts of knowledge production at universities on investment decisions of the manufacturing industry (for short denoted as industry in the sequel). Insight into the regional impacts of universities may also provide further evidence on the 'knowledge production function' which describes the role of knowledge in the production process (see Griliches, 1979; Jaffe, 1986).

The organization of this paper is as follows. In section two, the knowledge interaction between universities and industry will be described. It will be argued that an investment model incorporating knowledge production is an appropriate approach to measuring the regional knowledge impacts of universities. Section three is concerned with methodological aspects of various previous studies in which the university's knowledge impact is considered. In section four, an interregional model for investments in non-residential structures and equipment will be derived from the neoclassical theory of capital accumulation. Section five is concerned with econometric aspects, whilst in section six a case study relating to The Netherlands will be presented. Finally, some conclusions are formulated in section seven.

2. Knowledge interaction between universities and industry

With respect to economic impacts of universities a distinction can be made between expenditure and knowledge impacts. The former result from the expenditures by the university, faculty and staff, students and visitors, which generate changes in regional income and employment. Mainly in the 60's and 70's efforts have been made to assess the magnitudes of these impacts. Various familiar methods, like economic base models, Keynesian multiplier models, and input-output analysis, have been applied to estimate these kinds of effects. Due to limited space we will not pay attention to the results and methodological soundness of this type of research (cf. Florax, 1991, for an overview)[1].

Instead we will focus on the university's knowledge effects since they have been studied less thoroughly. The term 'knowledge effects' is used to refer to changes in the quality of production factors induced by the knowledge produced at universities. Knowledge impacts may find expression in technical progress as reflected by production functions (cf. Kennedy and Thirlwall, 1972). They may result not only from university research as such, but also from the accumulation of human capital or from effects related to the university's services to the community. The mechanisms underlying the knowledge impact of universities are the relationship between basic and applied research, and the diffusion of knowledge. Both mechanisms will be briefly described below.

Universities are primarily engaged in basic research which results in original contributions to the advancement of science. They may also perform applied research in which scientific knowledge is generated in order to arrive at product and/or process innovations. However, universities are engaged in applied research mainly in the form of contract research, i.e. research initiated and paid for by external institutions, including the government. The prime performers of applied research (and development) are private companies (cf. Folmer and Hutten, 1989).

The relationship between basic and applied research has been clarified by Evanson and Kislev (1975), and by Binswanger (1974; 1978). In their view, basic research, without direct pay-offs, is complementary to applied research because it may alter the distribution of potential output yields. Applied research is viewed as drawing successive samples from the distribution of potential yields, the parameters of which are determined by basic research, nature and the state of technology. Consequently, the pay-off of applied research equals the difference between the sample point with the highest yield and the current yield. Because of the complementary relationship between both types of research and the concentration of basic research at universities and applied research in private companies intensive interaction between universities and private companies may be expected. The following developments have contributed to an increase in the interaction between universities and private industry (see also Nijkamp et al., 1986).

1. The process of increasing knowledge orientation of modern production technology. This applies to all phases of production ranging from product design to after-sales services. It has led to a rise in R&D intensity which in turn is strongly related to basic research (cf. Binswanger, 1978).
2. The growing importance of small production units. Whereas large firms are usually self-supporting with regard to R&D, small firms are mostly (highly) dependent on external research institutes such as universities (cf. Clark, 1985).
3. The aforementioned developments apply in particular to the so-called high tech sector. This sector is rapidly growing and it is dominated by small firms (cf. Markusen et al., 1986; Thwaites and Oaky, 1985).
4. The increasing stimulation and facilitation of knowledge transfer by universities (cf. Lynton and Elman, 1987; Rothwell and Zegveld, 1982, pp. 232-236). This tendency in university policy has been stimulated by the (expected) decrease in university budgets due to diminishing student numbers and retrenchment operations by the central government. Moreover, examples of mutual beneficial university-industry co-operation, like Silicon Valley, Route 128 (cf. Saxenian, 1985), and the Cambridge Phenomenon (cf. Segal Quince & Partners, 1984), have enhanced this policy.[2]

The interaction between universities and private companies may take place via graduates employed by private firms, reported research results and various kinds of consultancy. This interaction process can be modeled by means of the theory of the diffusion of knowledge developed primarily by Hägerstrand (1965; 1967). Hägerstrand postulates that diffusion takes place via two types of diffusion patterns: contagious and hierarchical diffusion. In the contagious case the diffusion of knowledge is concentrated in the vicinity of the originating source and decays strongly with distance. In the hierarchical case knowledge diffuses at first instance among central places. At a later stage it trickles down to places of lower order, successively. The diffusion among places of higher order is faster than among places of lower order because the former have greater access to the knowledge infrastructure due to the presence of research, education and consultancy facilities. Moreover, they are connected to the main transportation and communication networks and they have in general a better educated workforce. The diffusion of knowledge among central places may of course also be subject to spatial friction, although this friction is of quite a different order than in the case of contagious diffusion.

In the analysis of knowledge impacts of universities on investments of industry both diffusion patterns should be taken into account. This can be seen as follows. The transfer of knowledge by graduates is likely to follow both patterns. On the one hand graduates tend to cluster around the originating university (cf. Florax, 1987). On the other hand, the labor market for graduates is truly national of scope, although with a strong concentration in central places (cf. Van Dijk and Folmer, 1986). Also with respect to reported research results both patterns apply, as research results are primarily spread among other universities, research institutes, higher vocational colleges and consultancy firms, which all tend to locate in central places. Central places in which a university is located, however, are likely to have a lead in truly new scientific knowledge. The transfer of knowledge via consultancy obviously requires face-to-face contacts (cf. Törnqvist, 1970). As the intensity of face-to-face contacts depends *inter alia* on distance, contagious diffusion is relevant in this regard. However, hierarchial diffusion of knowledge may be an alternative because of the possibility of indirect access to scientific knowledge, via education, research and consultancy facilities in central places.

From the foregoing it follows that the more the contagious diffusion process dominates, the stronger the tendency to locate in the vicinity of universities, *ceteris paribus*. Consequently, the following hypothesis concerning the impact of universities on industry's investment decisions can be derived.

> The division of labor with regard to universities and private companies requires intensive interaction. This interaction may take place via contagious and/or hierarchical diffusion. If the former dominates, a clustering of private firms around universities may be expected. If hierarchical diffusion dominates, a clustering around central places instead of around universities will show up.

It is, of course, also possible that knowledge transfer occurs via both mechanisms. Moreover, there may be no substantial differences over space in the accessibility to university knowledge, or the accessibility to knowledge produced by universities may be of minor importance in investment decisions.

3. Approaches to knowledge impact assessment

It is not surprising, given the increasing significance of knowledge in the production process and the importance of small (high tech) firms for economic growth, that research on such matters as innovation and the location of small firms has been in the limelight of economic research. Access to knowledge infrastructure is frequently assumed to be one of the main explanatory variables for innovations, location decisions and economic growth. Some methodological aspects of the main approaches in this field will be discussed below so as to justify the methodological approach applied in this paper.

A first kind of approaches focuses on the *location of firms*, in particular high tech firms.[3] The well-known Premus (1982) survey among high technology firms indicated that availability of skilled labor, and nearness to academic institutions are among the significant determinants of both interregional and intraregional location choice. Aydalot (1984) found similar results for France and Nijkamp (1986) for The Netherlands. Markusen et al. (1986), however, found no evidence that research spending was a significant factor in explaining the locational pattern of high tech firms in the US.

A second kind of approach is *innovation research*. Davelaar and Nijkamp (1989) found that access to the knowledge infrastructure is no strong indicator for the innovation potential or actual innovativeness of firms (see also Mouwen and Nijkamp, 1985). Others, however, point to the significance of proximity to universities for internal R&D, which in turn influences innovations (cf. Buswell and Lewis, 1970; Ewers and Wettmann, 1980; Karlsson, 1988; Thwaites and Oakey et al., 1985).

Both approaches mentioned above make use of surveys. Because of the costs involved, relatively few studies are undertaken, both in space and over time. Hence, the empirical evidence is scattered. Moreover, these approaches are subject to the risk of *ex post* rationalization of the decisions involved, which is likely to lead to a gap between the actual and reported motives (cf. Folmer, 1986).

A third kind of approach to be discussed here can be labeled *production function approach*. Examples of this approach are Andersson and Mantsinen (1980) who incorporated the accessibility of knowledge into a regional growth model, and Batten et al. (1989) who derived a production function incorporating the knowledge level of nodal units in terms of the size of their knowledge-handling labor force and the accessibility to knowledge of firms.

A basic problem of the production function approach to measure knowledge impacts of universities is the empirical operationalization of the knowledge variable. For instance, in Andersson et al. (1987) the number of full professors was taken as a proxy for regional R&D capacity. This variable, however, is closely related to the university's payroll which in turn determines the university's contribution to the regional product. Hence, not only the effect of knowledge production but also the university's expenditure impact is measured.

A related approach developed by Jaffe (1989) models spill-over from university R&D in terms of patents. Moreover, university research is modeled as a function of *inter alia* industry R&D and vice versa, in a simultaneous equation system. Although the number of patents may not be an adequate indicator of the importance of knowledge impacts as innovations not always result in patents, and patents only partly reflect the economic importance of innovations (cf. also Griliches, 1979; Griliches et al., 1988), the interesting feature of this approach is the explicit consideration of the interaction between private and university research.[4]

Next to the specific methodological problems of each individual approach, a shortcoming common to all of them is that they restrict the scope to contagious knowledge diffusion and do not take hierarchical diffusion into account.

4. An interregional investment approach

In the present paper the impact of knowledge production at universities on the investment behavior of industry is estimated by means of a regional investment model which allows for spatial spin-offs and spill-overs. The variables to be included in the regional model are derived from the neoclassical theory of capital accumulation. Capital goods are assumed to be heterogeneous. Hence two types of capital goods will be considered, viz. non-residential structures ('buildings' for short) and equipment.

The neoclassical model, as originally put forward by Jorgenson (1963), is based on the following train of thought. A firm's production process is constrained by a production function:

$$F(Q,L,K) = 0 \qquad (1)$$

with Q, L, and K for output, labor, and capital respectively.[5] The production function is assumed to be twice-differentiable and strictly convex. The primary objective of the firm is to maximize its present value, V_t :

$$V_t = \int_t^{\infty} e^{-r(v-t)} R_v \, dv \qquad (2)$$

where r is the interest rate, and R the difference between revenue and outlay on current and capital account:

$$R = pQ - wL - qI \qquad (3)$$

with p the price of output, w wage, q the price of investment goods, and I total investments. Assuming the production function to be of the Cobb-Douglas type and the input of labor to be constant, it follows (cf. Jorgenson and Stephenson, 1967) for the equilibrium level of capital stock (K^+) that:

$$K^+ = \alpha \frac{pQ}{c} \qquad (4\text{-a})$$

where α is the elasticity of output with respect to the input of capital services, and c is the user cost of capital. Although this result is widely used in empirical studies, the assumption of constant labor input is rather restrictive, in particular for investments in equipment. Allowing for substitution, and assuming fixed output rather than fixed labor input, leads to the following equilibrium capital stock:

$$K^+ = \left(\frac{\alpha w}{(1-\alpha) c} \right)^{1-\alpha} Q \qquad (4\text{-b})$$

The user cost of capital c depends on the price of investment goods, the cost of capital, the tax system, and the investment incentive structure (cf. e.g. Millward et al., 1983). If tax allowances and investment subsidies have a negative impact on costs, the user cost of capital can be modeled as follows:

$$c_t = \frac{1 - a_t - s_t - \tau_t d_t}{1 - \tau_t} (\delta + r_t - \dot{q}_t) q_t \text{, with } \dot{q}_t = \frac{q_t - q_{t-1}}{q_t} \qquad (5)$$

where q is the price of investment goods, τ the corporate taxation rate, δ the replacement ratio, and $\dot{q}$ capital gains. The investment incentive structure, comprising tax allowances and investment subsidies, is taken into account by:

- the investment tax credit a_t, given by:

$$a_t = \Sigma_{j=t}^{J} e_{j,t} \left(\frac{1}{1 + r_t}\right)^{j-t} \tag{5-a}$$

  where $e_{j,t}$ is the credit percentage in period j concerning an investment in period t, and J the period over which the allowance is in force,
- the investment subsidy s_t defined as a percentage of q_t, and eventually consisting of an overall subsidy rate plus a regionally differentiated allowance, and
- (accelerated) tax depreciation allowance d_t, given by:

$$d_t = \Sigma_{j=t}^{T} f_{j,t} \left(\frac{1}{1 + r_t}\right)^{j-t} \tag{5-b}$$

  where $f_{j,t}$ is the (accelerated) tax depreciation percentage concerning an investment in period t, and T the economic lifetime.

As gross investment is equal to net investment plus replacement investment, which is assumed proportional to capital stock, the neoclassical theory of investment behavior may be described as:

$$I_t = \mu(S)[K_t^+ - K_{t-1}^+] + \delta K_t \tag{6}$$

where I_t denotes gross investment, and $\mu(S)$ an unspecified lag operator.

Equations (6), (4-a) for buildings and (4-b) for equipment are frequently operationalized by output growth and the level of output (as a proxy for the capital stock). In the regional case the relevant variables are regional output growth and the level of regional output. Moreover, the regional equivalents of the user cost of capital, for both buildings and equipment, can be obtained in a straightforward way.[6]

The following remarks apply. First, as mentioned earlier, two types of capital goods will be considered, because each type may react differently to knowledge production, and is, at least partly, dependent on different exogeneous factors (see Table 1). Moreover, investments in buildings and equipment are complementary.[7] This feature will be handled by applying a simultaneous equation approach which captures these reciprocal impacts. Secondly, because of the time consuming nature of investment projects only a fraction of the projects initiated in a given period will be terminated in the same period. This implies that lags have to be taken into consideration, as already indicated in equation (6). Lags for investments in buildings are usually longer than lags for investments in machines. In the latter case the current period frequently suffices, if the length of the period is one year. In Folmer and Nijkamp (1987) investments in buildings were found to respond to the level of output and changes in output in the previous year and investments in machines to the level of output and changes in output in the current year. In some Dutch macro economic studies applying the Jorgenson type of investment equations, lags of one year were found to be sufficient (see e.g. De Jong and Kiviet, 1979). For these reasons the following variables will tentatively be considered: the one year lagged level of output and the current and one year lagged change in output with respect to buildings, and the current level of output and the current change in output for equipment.

The theory of investment behavior described above, does not take the existence of public goods and externalities into account. It is obvious, however, that next to factor prices and output, exogeneous variables related to the availability of public goods and externalities have to be included in the investment function. In order to model the availability of public goods two variables have been selected, which are assumed to have positive impacts on the (re)location decisions of firms. These variables are: nearness to the center(s) of economic activities[8], and the degree of urbanization. They are indicators of spatial differences in e.g. transportation cost (see e.g. Armstrong and Taylor, 1978) and of a favorable socio-cultural environment and agglomeration economies.

Moreover, two variables related to the availability of externalities originating from the production of knowledge at universities have been included. These variables may not only affect the location behavior of firms, but also the growth rate of investment in equipment. The university's knowledge production may affect the design of a plant, and influence the tailoring of products to the needs of users, marketing, and the physical and socio-economic organization of the production process. All these factors may have an impact on the growth rate of investments in equipment. The operationalization of the knowledge production of universities will be given after a brief description of the knowledge infrastructure in The Netherlands.

The knowledge infrastructure comprises the higher educational system, made up of universities and higher vocational colleges, and private and public research institutes. The universities are engaged in education and (primarily) basic research, whereas the vocational colleges are mainly engaged in education. In addition to universities there are some public research institutes engaged in basic research, which might have an impact on investment. Due to data scarcity only universities and public research institutes linked to universities will be considered. This implies that, although the great majority of knowledge production centers is included, the set of centers is not entirely complete.

FIGURE 1: The spatial division of The Netherlands in nodal COROP-regions and the location of universities.

The location of the Dutch universities (along with the adopted level of spatial desaggregation) is presented in Figure 1. The traditional universities (in Leyden, Groningen, Nijmegen, Utrecht, and two in Amsterdam) are full universities in the sense that education and research in science, social sciences and arts and humanities are covered. The technical universities (in Delft, Eindhoven and Twente) and the agricultural university (in Wageningen) focus on the technical and agricultural sciences, although research and education in the social sciences is also delivered, albeit to a lesser extent. Finally, at the universities in Rotterdam, Maastricht and Tilburg there is no science department with the exception of a medical faculty at the former two. It should be observed that, due to central government regulation, there is hardly any quality hierarchy in the Dutch system of higher education, so that in this respect the Dutch system markedly differs from e.g. the US system.

These features of the Dutch system of knowledge production imply that the externalities of Dutch universities are likely to be relevant for all kinds of industries (although probably in different degrees), and hence for industry as an aggregate. In the empirical analysis the manufacturing sector of industry will therefore be investigated as a whole.

The knowledge production of universities has been operationalized by total university expenditures. This proxy is preferable to dummies representing the presence or absence of a university in a region because it accounts for the scale of a university. Various indicators of knowledge production (number of graduates and staff, number of reported research results, intensity of consultancy) are highly correlated with the expenses. In the context of modeling the transfer of knowledge the openness of regions, leading to inter-regional linkages, should be taken into account. This implies that investments in a given region may be influenced by the knowledge produced by universities located in other regions in the country. The transfer of knowledge is subject to spatial friction, which is most adequately modeled by means of a logistic function. As the longest roundtrip by car in The Netherlands is approximately eight hours, the upper flat part of the logistic function does not fully apply in the present study. For that reason the inverted distance has been chosen as a proxy for the spatial friction. For contagious diffusion, these considerations lead to:

$$DKC_r = \Sigma_{r'} \frac{UE_{r'}}{d_{rr'}}, \forall r, r' \text{ and } d_{rr'} = 1 \text{ for } r = r' \qquad (7\text{-a})$$

where DKC represents contagious diffusion of knowledge, $UE_{r'}$ denotes the expenditures of the university located in region r', and $d_{rr'}$ is the distance between the largest urban centers of region r and r'. Hierarchical diffusion is modeled as:

$$DKH_r = UE_r + UH_r \Sigma_{r' \atop r \neq r'} \frac{UE_{r'}}{d_{rr'}}, \forall r, r' \qquad (7\text{-b})$$

where *UH* is the ranking in the urban hierarchy, operationalized as the number of inhabitants of the largest city in each region.[9]

A feasible interregional form of the model elucidated above is presented in Table 1, together with a variable legend. It should be observed that the equilibrium level of capital stock, in equations (4-a) and (4-b), is a composite variable. As argued by Lund (1971, p. 141), the significance and explanatory strength of a composite variable cannot be attributed to its seperate components. Therefore, the components of the composite variable enter the regression model seperately.[10]

An investment approach as outlined above, has some advantages as compared to the approaches mentioned in the previous section. First, using investments as an indicator that might be influenced by knowledge transfer at least partly overcomes the problem that indicators used in location and innovation research (e.g. number of patents, innovations, etcetera) do not reveal the economic significance that might be attached to the transfer of knowledge. If the hypothesis that universities have a positive impact on investments is not rejected, a next step could be to obtain information on induced effects on e.g. regional income and employment by means of conventional approaches such as input-output analysis.

Secondly, an important difference between the investment and the production function approach concerns the appropriateness of the dependent variable, viz. investments vs output, as sensors of knowledge impacts of universities. In a neoclassical framework, investments respond to both demand and costs. The latter are *inter alia* dependent upon the presence of externalities, such as the stock of academic knowledge. This implies that if both demand and accessibility to knowledge are included in the specification (which is the case in the present empirical analysis), the impact of the latter can be estimated seperately. Consequently there is no mix-up between the expenditure and the knowledge impact in the estimation procedure. It should also be noted that the contribution of knowledge production by universities to economic growth is an indirect relationship which goes *inter alia* via investments. In order to prevent unnecessary complications, such as lengthened lag structures caused by the transformation of knowledge into investments and subsequently of investments into output, it is preferable to estimate the impact on the directly affected variable, i.e. investments (cf. Folmer, 1981).

Finally, an interregional investment approach is close to an analysis of location decisions of firms. It differs from the usual survey approach in the sense that it is based on *ex post* observations of behavior. It does not make use of information provided by firms on questions concerning the relevance of location variables, and hence there is less

TABLE 1: The specification of a neoclassical interregional investment model.

$$IB_{rt} = \alpha_0 + \alpha_1 IM_{rt} + \alpha_2 Q_{rt-1} + \alpha_3 \Delta Q_{rt} + \alpha_4 \Delta Q_{rt-1} - \alpha_5 c_{irt-1} + \alpha_6 DU_{rt} - \alpha_7 DR_r + \alpha_8 DKC_{rt} + \alpha_9 DKH_{rt} + \varepsilon_{rt}$$

$$IM_{rt} = \beta_0 + \beta_1 IB_{rt} + \beta_2 Q_{rt} + \beta_3 \Delta Q_{rt} - \beta_4 c_{irt} + \beta_5 w_{rt} + \beta_6 DKC_{rt} + \beta_7 DKH_{rt} + \mu_{rt}$$

where

$$c_{irt} = \frac{1 - a_t - s_{irt} - \tau_t d_{irt}}{1 - \tau_t} (\delta_i + r_t - \dot{q}_{it}) q_{it}$$

$$\text{with } \dot{q}_{it} = \frac{q_{it} - q_{it-1}}{q_{it}}, \; a_t = \Sigma_{j=t}^{J} e_{j,t} \left(\frac{1}{1 + r_t}\right)^{j-t} \text{ and } d_t = \Sigma_{j=t}^{T} f_{j,i,t} \left(\frac{1}{1 + r_t}\right)^{j-t}$$

$$DKC_{rt} = \Sigma_{r'} \frac{UE_{r't}}{d_{rr'}}, \; \forall r, r' \text{ and } d_{rr'} = 1 \text{ for } r = r'$$

$$DKH_{rt} = UE_{rt} + UH_{rt} \Sigma_{r' \, (r \neq r')} \frac{UE_{r't}}{d_{rr'}}, \; \forall r, r'$$

with:

IB	investment in buildings of the manufacturing industry, in 1977 prices	δ	replacement ratio
IM	investment in equipment of the manufacturing industry, in 1977 prices	*r*	interest rate
Q	output of the manufacturing industry, in 1977 prices	*w*	real wage
ΔQ	first-order difference in output	*DU*	degree of urbanization
c	real user cost of capital	*DR*	distance to the core region (*Randstad*)
q	price index for capital goods	*DKC*	contagious knowledge diffusion
$\dot{q}$	capital gains	*DKH*	hierarchical knowledge diffusion
τ	corporate tax rate	*UE*	university expenditures, in 1977 prices
a	tax investment credit	*UH*	ranking in the urban hierarchy
s	investment subsidy rate	$d_{rr'}$	distance between regions *r* and *r'*
d	tax depreciation allowance	*i*	subscript indicating type of capital good (buildings or equipment)
e	credit percentage for the investment tax credits	*r*	subscript indicating spatial units
f	(accelerated) tax depreciation percentage	*t*	subscript indicating time

risk of *ex post* rationalization.[11]

Before presenting the estimation results of the interregional investment model for The Netherlands, we will first pay attention to some econometric aspects.

5. Econometric aspects

As mentioned in the foregoing the data set to be analyzed consists of a time-series of cross-sectional (i.e. regional) observations. This implies that spatio-temporal autocorrelation in the residuals should be considered. Moreover, because of the spatial heterogeneity among the regions the assumption of a constant variance for the disturbance term, i.e. the homoscedasticity assumption, may be unrealistic.

Spatial autocorrelation can be detected by applying the Moran statistic I_g to the regression residuals, and reads for a pooled data as:

$$I_g = \frac{R}{S_g} \frac{e' (\mathbf{I} \otimes \mathbf{W}_g)\, e}{e'\, e} \tag{8}$$

where R refers to the number of regions in the spatial system, T to the number of time periods, e is the vector of estimated residuals, $\mathbf{I}$ is the $(T \times T)$ identity matrix, $\mathbf{W}_g$ the $(R \times R)$ weighting matrix with elements $w_{g,rr'}$ (defined below) corresponding to the spatial lags of order g[12], and $S_g = \Sigma_r \Sigma_{r'} w_{g,rr'}$ for $r \neq r'$. I_g has been shown to be asymptotically normally distributed (cf. Cliff and Ord, 1981, pp. 200-206).[13] Temporal autocorrelation will be tested by means of the Durbin-Watson test for pooled data.

Spatial and temporal correlation will be remedied by applying an EGLS estimator based on an additive stationary spatio-temporal Markov scheme for the disturbance term (cf. Hordijk and Nijkamp, 1978):

$$\varepsilon_{r,t} = \lambda\, \varepsilon_{r,t-1} + \Sigma_g\, \rho_g\, w_{g,r}'\, \varepsilon_{r,t} + \mu_{r,t} \tag{9-a}$$

or in matrix notation:

$$\varepsilon_t = \lambda\, \varepsilon_{t-1} + \Sigma_g\, \rho_g\, \mathbf{W}_g\, \varepsilon_t + \mu_t \tag{9-b}$$

where $w_{g,r}'$ is a vector with $\forall\, r$ and r':

$$\begin{cases} w_{g,rr'} = 1 & \text{if region } r \text{ and } r' \text{ are } g\text{-th order contiguous; and} \\ w_{g,rr'} = 0 & \text{otherwise,} \end{cases}$$

A region is non-contiguous with itself, i.e. $w_{g,rr'} = 0$, $r = r'$.

It should be observed that a first-order scheme usually adequately captures temporal residual correlation, whereas spatial residual correlation frequently requires higher order schemes.

From Hordijk and Nijkamp (1978) it follows that if $\lambda + \Sigma_g \rho_g < 1$, the variance of ε_t is equal to:[14]

$$E(\varepsilon_t \varepsilon_t') = \sigma_\varepsilon^2 \mathbf{A} (\mathbf{I} - \lambda^2 \mathbf{A}\mathbf{A}')^{-1} \mathbf{A}' = \sigma_\varepsilon^2 \mathbf{V} \tag{10-a}$$

where $\mathbf{A} = (\mathbf{I} - \Sigma_g \rho_g \mathbf{W}_g)^{-1}$. The remaining elements of the variance-covariance matrix are:

$$E(\varepsilon_t \varepsilon_{t-i}') = \sigma_\varepsilon^2 \lambda^i \mathbf{A}^i \mathbf{V}\text{, and } E(\varepsilon_t \varepsilon_{t+i}') = \sigma_\varepsilon^2 \lambda^i \mathbf{V} (\mathbf{A}')^i \tag{10-b}$$

Hence, EGLS estimates can be obtained by applying OLS to the data matrix which has been transformed with the following $(R\times(T\text{-}1))\times(R\times(T\text{-}1))$ transformation matrix $\mathbf{T}$:

$$\mathbf{T} = \begin{bmatrix} -\lambda\mathbf{I} & \mathbf{A}^{-1} & \cdot & \cdot & \cdot & \cdot & 0 & 0 \\ 0 & -\lambda\mathbf{I} & \mathbf{A}^{-1} & & & & \cdot & \cdot \\ \cdot & & & \cdot & & & \cdot & \cdot \\ \cdot & & & & \cdot & & \cdot & \cdot \\ \cdot & & & & & \cdot & \cdot & \cdot \\ 0 & \cdot & \cdot & \cdot & \cdot & \cdot & \mathbf{A}^{-1} & 0 \\ 0 & \cdot & \cdot & \cdot & \cdot & \cdot & -\lambda\mathbf{I} & \mathbf{A}^{-1} \end{bmatrix} \tag{11}$$

with $\mathbf{A}$ as defined earlier.[15] The matrix T is obtained by means of (10-a) and (10-b) and by estimating model (9-a) for the estimated residuals.

As mentioned above, in addition to autocorrelation heteroscedasticity should be taken into consideration. For this purpose the Breusch-Pagan test has been used. This test is based on OLS residuals and covers a wide range of heteroscedastic situations. In particular, it allows the variance to depend on several explanatory variables which need not move in the same direction. Moreover, Breusch and Pagan (1979) found that in finite samples the test rejects the null hypothesis when it is true less frequently than indicated by the chosen Type I error, and that it is quite powerful in the case of heteroscedasticity. If the hypothesis of homoscedasticity is rejected a Glejser type of analysis (cf. Judge et al., 1985, pp. 431-434) will be applied to identify the appropriate transformation. The variable which is likely to cause heteroscedasticity is the level of regional output.

In summary, the estimation procedure is as follows.

1. Estimate the model in Table 1 by means of 2SLS and calculate the estimated residuals.
2. Test the estimated residuals for heteroscedasticity and, if necessary, transform the data and re-estimate the model by means of 2SLS.
3. Test the estimated residuals of step 2 for spatio-temporal correlation and, if necessary, transform the data (of step 2) by the transformation matrix given in (11).
4. Apply 2SLS to the transformed data of step 3.
5. Test the estimated residuals of step 4 for spatio-temporal autocorrelation and, if necessary, transform the data of step 4, apply 2SLS, and so on, until the hypothesis of spatio-temporal correlation is rejected.[16]

The application of the 2SLS procedure leads, however, to an inconsistent estimator for σ^2. Therefore a consistent estimator due to Theil (1971, p. 451) has been used, which reads as $s^2 = u_i' u_i / (N - k)$ with $u_i = y_i - \mathbf{Y}_i \hat{\beta}_i - \mathbf{X}_i \hat{\gamma}_i$, where i refers to the i-th equation.

6. Empirical results for The Netherlands

The investment model has been estimated for the Dutch manufacturing industry on the basis of a time-series of cross-sectional observations on 40 spatial units, for the period 1977-1984. The estimation results for investments in buildings and equipment are presented in Table 2.

The first two columns of Table 2 give the 2SLS results without corrections whatsoever. It may be inferred from the statistical tests that the model contains non-linearities[17], and that the null-hypotheses of a constant variance and no temporal autocorrelation for the estimated residuals must be rejected for both models. Moreover, some of the Moran coefficients for spatial autocorrelation are significantly different from zero. The second step in the estimation procedure was to eliminate the heteroscedasticity by using weighted 2SLS, and the non-linearity by using a semi-log function for the investments in equipment equation. By means of the Glejser procedure the appropriate weight structure was identified as $Q^{-½}$ for *IB* and $Q^{½}$ for *ln(IM)*. The model was re-estimated and the statistical tests indicate that heteroscedasticity and non-linearity are severely reduced. As heteroscedasticity may be partly due to the presence of spatiotemporally correlated errors no further transformations to remove heteroscedasticity were applied at this stage. The Durbin-Watson statistic still indicated temporal autocorrelation. Hence, the EGLS estimator was used in order to take this kind of autocorrelation into account. The results are given in the columns labeled 'EGLS, temporal', and show that the Moran coefficients for several orders of contiguity are significantly different from zero. In detail, for *IB* the spatial autocorrelation is positive for low orders of contiguity, and negative for most higher orders of contiguity, which indicates that there is a trickle-down mechanism among regions which are geographically close in the spatial system, and competition between the metropolitan and peripheral areas. Concerning *IM* spatial autocorrelation is positive for almost all orders of contiguity and relatively strong. Subsequently, spatial and temporal autocorrelation were taken into account simultaneously as indicated in section five, and the model was re-estimated. The results are shown in the last two columns of Table 2.

The estimation results may be summarized as follows. Investments in buildings depend solely on 'economic' variables: i.e. the one-year lagged regional output, the current growth in output, and the user cost of capital. 'Non-economic' variables, such as location factors and knowledge diffusion are not significantly different from zero. Concerning investments in equipment it should first of all be observed that strong multicollinearity exists between the level of regional output and estimated investments in buildings. This probably explains the wrong sign and insignificance of the level of regional output. Anyway, there is empirical support for dependence of investments in equipment on investments in buildings. The growth in output is not significantly different from zero, whereas the user cost of capital and to a lesser extent the wage level are significant explanatory variables. This shows that investments in machines are primarily supply-driven. Finally, hierarchical diffusion of knowledge is significant at approximately the 8% level, so that one may conclude that universities seem to have a significant hierarchical knowledge impact as far as technical change embodied in equipment is concerned.

The differences in hierarchical knowledge impact for buildings and equipment might be due to the aggregate nature of the analysis. It is well-known that certain types of industries, e.g. the high tech sector, are much more knowledge dependent than industries which are more mature. Knowledge dependent industries tend to locate in the vicinity of metropolitan areas and are dominated by small firms. As small firms tend to operate via the rent or lease market the location of a new firm in the vicinity of metropolitan areas does not show up in an increase of investment in buildings of the manufacturing industry, whereas it will still lead to an increase in investments in equipment.

Table 2: Two-stage least square estimates for investments in buildings and machines of the manufacturing industry, in COROP regions during the period 1977-1984.[a]

	2SLS		EGLS, temporal		EGLS, spatio-temporal	
	$IB_{r,t}$	$IM_{r,t}$	$IB_{r,t}$	$ln(IM_{r,t})$	$IB_{r,t}$	$ln(IM_{r,t})$
intercept	16.9296***	-209.5870***	14.1232	3.8012***	16.9373	3.7133***
	(3.150)	(-3.389)	(0.608)	(7.772)	(0.630)	(5.671)
$Q_{r,t}$		0.1171***		-0.0001		-7.59E-6
		(7.120)		(-1.064)		(-0.055)
$Q_{r,t-1}$	0.0308***		0.0162***		0.0131***	
	(4.893)		(3.557)		(2.730)	
$\Delta Q_{r,t}$	0.0119***	-0.0751***	0.0118***	0.0001	0.0091***	6.29E-6
	(2.684)	(-3.674)	(3.276)	(1.440)	(2.858)	(0.061)
$\Delta Q_{r,t-1}$	-0.0115**		0.0019		0.0049*	
	(-2.375)		(0.627)		(1.635)	
$c_{i,r,t}$		-15.2987		-0.3592***		-0.4289***
		(-1.053)		(-3.889)		(-2.918)
$c_{i,r,t-1}$	-8.0504***		-7.0335***		-8.2063***	
	(-5.426)		(-4.294)		(-6.377)	
$w_{r,t}$		0.0056***		1.59E-5		1.97E-5
		(3.572)		(1.102)		(1.200)
DR_r	-0.0662**		-0.0589		0.0129	
	(-2.059)		(-1.039)		(0.148)	
$DU_{r,t}$	0.0891		-0.1196		-0.2451	
	(0.445)		(-0.295)		(-0.563)	
$\widehat{IB}_{r,t}$		-0.6114		0.0265***		0.0170*
		(-0.824)		(4.079)		(1.897)
$\widehat{IM}_{r,t}$	-0.0813		1.7261		0.1602	
	(-1.406)		(0.290)		(0.025)	
$DKC_{r,t}$	-0.0229*	-0.1859***	-0.0037	-0.0001	0.0239	0.0001
	(-1.747)	(-4.927)	(-0.163)	(-0.295)	(1.038)	(0.261)
$DKH_{r,t}$	-0.0062***	0.0110	0.0029	0.0002*	0.0041	0.0002*
	(-2.580)	(1.273)	(0.418)	(1.915)	(0.589)	(1.787)
R^2	0.63	0.70	0.36	0.95	0.58	0.89
R^2-adjusted	0.62	0.69	0.34	0.95	0.57	0.89
Overall F-value	59.28**	102.47**	15.49**	661.24**	32.31**	246.54**
$z_{I(g)}$, $g = 1$[b]	2.26*	0.74	1.44	3.15**	0.51	0.83
$g = 2$	0.50	-0.25	2.76**	2.21*	1.03	-0.64
$g = 3$	0.85	0.80	0.58	1.42	0.25	-0.09
$g = 4$	0.44	2.62**	-2.03*	1.62	1.51	0.59
$g = 5$	-2.26*	-0.76	-0.31	1.71	-0.25	-1.31
$g = 6$	-0.64	-0.35	-2.86**	-0.00	-0.46	-0.71
$g = 7$	-1.02	-0.27	0.41	0.53	0.35	-0.22
DW[c]	0.83†	0.61†	2.24	1.73†	2.12	1.52†
BP[d]	101.07**	397.39**	29.38**	69.33**	16.74**	38.76**
$NONLIN$[e]	12.94**	38.73**	0.31	2.20	0.32	0.46

[a] The regression coefficients are presented with two-sided t-values in parentheses. ***, ** and * indicate significance at the 0.01, 0.05 and 0.10-level respectively.

[b] $z_{I(g)}$ is the standardized residual Moran coefficient for different orders of contiguity g. The critical two-sided p-levels used for the standard normal deviate of the Moran coefficient are 0.01 and 0.05 percent. Significance is indicated by ** and * respectively.

[c] The (first-order) Durbin-Watson test is used to identify temporal correlation. † and ‡ indicate a value lower than the upper bound at the 0.01 and 0.05-level respectively, given in conventional Durbin-Watson tables for $N = 200$.

[d] The Breusch-Pagan statistic is given in order to identify heteroscedasticity. The critical χ^2-values used, are the 0.99 and 0.95 levels, and significance is indicated by ** and * respectively.

[e] A non-linearity test was carried out, by adding the square and the cube of the predicted values of each regression as additional explanatory variables, to test the functional form of the models. F-values are reported for the joint significance (indicated by ** and * at the 0.01 and 0.05-level respectively) of the additional regressors.

The statistical tests indicate that the regular assumptions of the least-square regression model are met. With regard to the R^2's it should be noted that they are not restricted to the (0,1) interval either because of the use of the 2SLS estimator (cf. Basmann, 1962), or because of the lacking constant term due to the transformations for heteroscedasticity and spatio-temporal correlation. In particular, small R^2's are thus not necessarily indications for a poor fit.

Spatial and temporal autocorrelation in the disturbance term have been adequately removed through the use of the EGLS estimator: the Moran coefficients, and the Durbin-Watson statistic for the *IB*-model are no longer significantly different from zero. The non-linearities have also been sufficiently taken into account by the semi-log specification for investments in equipment. Finally it should be noted that the *t*-values may be overestimated to an unknown extent as it was not possible to fully exclude heteroscedasticity. Moreover, the Durbin-Watson statistic for the *IM*-model is still significantly different from zero.

7. Summary and conclusions

The present paper addresses the problem of regional economic impacts of universities, in particular, the impacts related to the production of knowledge as distinct from university-related expenditure impacts. It has been argued that universities and private firms are likely to co-operate closely because the former are engaged in basic research and the latter in applied research. The outcome of applied research is to a large extent determined by basic research. Regarding the transfer of academic knowledge a distinction is made between contagious and hierarchical diffusion. The diffusion pattern is expected to influence the investment behavior of private firms. In this regard a distinction is made between investments in buildings and in equipment. If contagious diffusion dominates, a clustering of investments around universities is likely to occur *ceteris paribus*. In that case the location of a university has considerable impacts on investments in the region of its location or its immediate surroundings. If hierarchical diffusion dominates, a clustering of investments around central places will show up. In that case knowledge intensive (footlose) industries need not locate in the vicinity of a university, as they can get indirect access to the knowledge produced at universities by locating in central places of the spatial system.

It should be observed that a general shortcoming of studies in the present field is the neglect to account for the (hierarchical) diffusion of knowledge. The present paper also differs from many other studies because of the use of investments as sensors of knowledge impacts.

The overall conclusion to be drawn from the empirical analyses is that for investments in buildings nearness to universities is not an important location factor. There is some evidence, however, that investments in equipment are influenced by hierarchical knowledge diffusion.

The status of the above-mentioned conclusions does of course depend on the adequacy of the analysis. With regard to the latter some remarks are in order. First, it should be observed that the use of the Cochrane-Orcutt estimator increases the multicollinearity of the explanatory variables, in particular if there is strong spatial correlation. Secondly, the proxy used for the knowledge production of universities might not be entirely adequate. It could be argued that in addition to expenses, other indicators such as the number of publications, graduates, and consultancy activities, should also be included in the analysis. Thirdly, the results might be typical for a small country like The Netherlands with a spatially equilibrated distribution of thirteen universities (see Figure 1), where regular face-to-face contacts are possible independently of the location. Fourthly, the present analysis is in terms of the sector of the manufacturing industry as an aggregate. As argued above, desaggregation by maturity might show quite different results. Finally, the impact variable is inadequate when the location of a new firm does not lead to an increase in investments in the manufacturing industry. This will be the case when a new firm operates via the rent or lease market or when universities provide facilities. In order to explore such effects in more detail a different impact variable, e.g. employment or production growth, would be needed, although in such a framework it will be difficult to distinguish between the expenditure and the knowledge impact of universities (see section four).

The final conclusion to be drawn here is that (for the manufacturing industry as an aggregate and for a country with the scale of The Netherlands) the recent trend in regional economic policy and science and technology policy to stress the importance of the proximity to academic knowledge infrastructure in order to stimulate regional development, is expedient.

Notes

[1] In the US a simple, though remarkably insufficient, model developed for the American Council on Education (Caffrey and Isaacs, 1971) has frequently been used.

[2] Examples of typical policy measures in this respect are the installation of liaison offices, the development of science parks (mostly in close contact with local industry and/or government), and the stimulation of spin-offs (cf. STRIDE, 1987). With regard to the latter some Dutch universities have created temporary entrepreneurial facilities, so that

graduates or former faculty are employed full-time by the university, but are allowed to spend half their time on their own company.

[3] A special case among the location studies are those concerned with spin-offs from universities. For The Netherlands Van der Meer and Van Tilburg (1984) and Buck and Roelofs (1987) found that spin-offs tended to cluster around the universities where they originated from. This does not necessarily imply that nearness to the university is a significant location factor, as the concentration may primarily be the result of other location factors such as geographical location, acquaintance with local conditions, etcetera.

[4] Regarding the investment model, for which a theoretical basis and empirical results are given in the sequel, the production of private R&D has not been included explicitly as neither for private R&D expenditure, nor for the number of employed engaged in R&D or the number of patents, reliable (aggregate) data are available for The Netherlands.

[5] The subscript t is suppressed whenever there is no risk for confusion.

[6] Detailed information on data sources, variable construction, and intermediate estimation results, is given in an appendix, which is available from the authors upon request.

[7] Investments in new buildings require investments in equipment and vice versa. However, universities frequently provide location facilities for small, newly established firms. Moreover, there is often a relatively large rent market in the vicinity of universities. This implies that the location of a new firm does not necessarily lead to an increase in investments in buildings. The location of a new firm can even occur without any increase in investments in the manufacturing industry if the equipment can also be leased.

[8] In the case of The Netherlands this is the Western metropolitan area (the so-called *Randstad*). As this variable has been operationalized as distance from the urban center of the nodal regions to the geographical center of the *Randstad*, its sign is expected to be negative.

[9] In addition to the accessibility to the knowledge infrastructure, the availability of labor with appropriate skills might be a determinant of the spatio-temporal investment pattern. However, the availability of higher educated labor, is an essential part of the knowledge produced at universities. As its diffusion has already explicitly been modeled by means of contagious and hierarchical knowledge diffusion, the inclusion of a variable representing the availability of higher educated labor is redundant. Moreover, the scarcity of other kinds of labor is reflected by the regional wage level.

[10] This implies that the neoclassical model reduces to a simple accelerator model, if the user cost of capital turns out to be not significantly different from zero.

[11] Moreover, data can usually be derived from official surveys underlying the national accounts. This is likely to increase the response rate and the reliability because of the legal duty of firms to co-operate. As there is a high degree of international similarity in

these surveys, and they are repeated periodically, comparison over space and time is possible.

[12] With regard to spatial autocorrelation the order of contiguity should be taken into account. It is defined as follows (cf. Hordijk, 1974). Assume an area, A, to have been partitioned into regions A_r $(r = 1, 2, ..., R)$ such that:

$$\cup A_r = A \ , A_r \cap A_{r'} = \emptyset \ , \forall r \ , r \neq r'$$

Then any two regions of A are first-order contiguous if they have a common border of non-zero length. A region r of A is contiguous of the k-th order $(k > 1)$ to a region r' of A $(r \neq r')$ if region r is first-order contiguous to one of the regions of A, which is contiguous of order k - 1 to r' and is not already contiguous of an order less than k. A region is non-contiguous with itself. The test for spatially autocorrelated residuals should be applied for all possible orders of contiguity.

[13] The Moran coefficient can be transformed into a standard normal deviate in the usual manner, that is $z_I = \{I - E(I)\} \ / \ \sigma(I)$, where the mean and the variance of I can be computed as follows (Cliff and Ord, 1981, pp. 200-203):

$$E(I) = \frac{R}{S} \frac{\mathrm{tr}(\mathbf{MW})}{(R \times T - K)} \text{, and}$$

$$V(I) = \left(\frac{R}{S} \right)^2 \frac{\mathrm{tr}(\mathbf{MWMW}') + \mathrm{tr}(\mathbf{MW})^2 + [\mathrm{tr}(\mathbf{MW})]^2}{(R \times T - K)\ (R \times T - K + 2)} - [E(I)]^2$$

where all variable definitions are as in the main text, K is the number of explanatory variables, and **M** is the projection matrix $\mathbf{I} - \mathbf{X}(\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'$.

[14] If the matrices $\mathbf{W}_g$ are symmetric **V** may be written as $(\mathbf{A}^{-2} - \lambda^2\ \mathbf{I})^{-1}$.

[15] In particular when the sample size is small, the Prais-Winsten method may be used, as it increases the efficiency of the estimation. In that case the $(R \times T) \times (R \times T)$ matrix $\mathbf{T}^*$ should be used, which is equal to the transformation matrix **T** enlarged by the partitioned $(R \times (R \times T))$ matrix $[\ \mathbf{V}^{-1/2} \mid \mathbf{0} \mid \ ... \mid \mathbf{0}\ ]$ as the first R rows. Given the relatively large sample size in the present study (N = 320), the matrix **T** has been used.

[16] This procedure is similar to the iterative Cochrane-Orcutt estimator (cf. Judge et al., 1985, p. 286).

[17] Non-linearity for investments in equipment frequently shows up in empirical studies (cf. Bruyne and Rompuy, 1982; Luger, 1984). Logarithmic transformations usually suffice to take these features into account.

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