SERIE RESEARCH MEMORANDA

A MULTIPLE CRITERIA LOCATION MODEL
FOR INNOVATIVE FIRMS
IN A COMMUNICATION NETWORK

H. Dieperink
P. Nijkamp

Researchmemorandum 1987-72 december 1987

VRIJE UNIVERSITEIT
FACULTEIT DER ECONOMISCHE WETENSCHAPPEN
EN ECONOMETRIE
AMSTERDAM

A MULTIPLE CRITERIA LOCATION MODEL FOR INNOVATIVE FIRMS IN A COMMUNICATION NETWORK

Han Dieperink Peter Nijkamp

Department of Economics
Free University Amsterdam

1. Introduction

In recent years, technological innovation as a major instrument for economic revitalisation has received much attention. Technological innovation is however not 'manna from heaven', but is co-determined by various institutional, social, economic and locational conditions (see Freeman et al., 1982).

Innovations are in general not uniformly spread over space, but exhibit sectoral and geographical clusters (see Dieperink and Nijkamp, 1986a, and Malecki, 1985). Spatial innovation patterns are frequently based on a geographical network, in which especially nodal points appear to often suitable locations for innovative activities (Pred, 1977). Such nodal points are not only appropriate concentrations in a physical transportation network, but also points for the exchange of relevant information on market conditions, new technologies, etc. (see also Brotchie et al., 1986, and Giaoutzi and Nijkamp, 1987). Thus the geographical position of a firm in a communication network (incorporating both a physical transportation network and an information network) is of utmost importance. Consequently, in addition to transportation one has to conceive of information as a production factor with a potentially great importance. Especially in an 'urban field' with many complex linkage structures between large, medium-size and small cities such a communication-based view on locational decisions of firms is extremely relevant, and in particular for those firms which for their innovative behaviour are dependent on up-to-date information and rapid adjustments to changing conditions.

Thus both physical infrastructure dealing with transport of goods and/or persons and a communication infrastructure dealing with transfer of information are decisive factors for locational decisions of firms. A reason for traditional locational models to neglect the external information factors of a firm is probably the lack of an operational measurement model for external information and the difficulty to relate information costs to other locational cost factors. This problem is tackled in a multicriteria model for entrepreneurial locational decisions.

The present paper is organized as follows. Section 2 presents some elements of locational decisions of innovative firms. Next, section 3 describes the structure of a multiple criteria (so-called DoubleDutch) locational choice model for an innovative firm, taking into account both the features of a logistic transportation network and an information network. Finally, section 4 presents results from an illustrative application.

2. Locational Decisions of Innovative Firms

Innovations refer in general to the design, construction and succesful introduction of new (or improved) products, services, production processes, or institutional/management procedures (cf. Roberts, 1984). The motives for innovation may originate from either technology-push or demand-pull behaviour (see Kleinknecht, 1986). There are various (mutually non-exclusive and by no means perfectly reliable) measures for innovations, such as patents, number of product/process innovations, amount of R&D expenditures, etc. In general, one may innovation regard as a latent variable, of which the abovementioned observable indicators are measurable units.

Information is a prerequisite for innovation, and most entrepreneurial decisions taken nowadays are based on an 'informatisation' of the industrial system. Specialized information however is not ubiquitous, but concentrated in nodal points of an urban field (cf. Pred, 1977). In this context, multi-locational firms with many branch plants are extremely important, as they create a major linkage pattern between agglomerations. In Pred's view: "Changes in the economic and technological environment have also dictated that these business services become ever more specialized. With specialization, large markets have become necessary for survival. Most new business-service providers have tried to maximize accessibility to potential customers by locating in large metropolitan complexes" (p.194, Pred, 1977).

Empirical research has demonstrated that innovative behaviour has a clearly geographical dimension (see Dieperink en Nijkamp, 1986), so that there is an obvious reason to focus attention on the spatial configuration of innovative behaviour. We will now concentrate our attention on a discrete location model, called DoubleDutch, which takes into consideration locational objectives for both <u>the physical and the information network</u>. We assume that a certain firm has to select a location from a set of candidate points which are nodal points in such a network.

For <u>physical infrastructure</u>, geographical distances play a major role, as transport costs are usually proportional to distance. For the physical network we distinguish:

- v_i : a node $(i=1,..,I)$
- e_{mj} : an edge between nodes v_m and v_j $(m,j=1,..,I)$

The nodes are distinguished into:

- v_m : a potential (candidate) location ($m=1,..,M$)
- v_j : an origin or destination point ($j=1,..,J$)

If potential locations are to be selected from the set of nodes in a network, the location choice problem is by definition discrete and finite. Clearly, the union of the set of all v_m's and v_j's gives again the set of all nodes v_i's. Now the following information may be assumed to be available:

(1) Each potential location v_m leads for the firm concerned to a certain total expected annual amount of costs f_m associated with its location in this node.

(2) Each node v_j in the physical network of origin-destination flows is supposed to have a certain importance or weight w_j, which can be measured by means of e.g. the number of times a node is passed through or the number of clients in that node.

(3) For each individual adjacent edge e_{mj}, the distance friction costs c_{mj} can be assessed; these are, although related, not necessarily proportional to distance (see Love and Morris, 1972, 1979).

For the information infrastructure we have a similar approach, except that the information transfer costs are not necessarily related to physical distance. Thus the conventional distance decay pattern does not hold here, which leads to some 'perverse' locational decision problem. In contrast with the physical network, where it is possible to assign monetary values to all cost factors, only some information components can be calculated in this way. Generally, most information components possess many non-monetary characteristics. The construction of the information network depends therefore on the use of proxies of different kinds. The information infrastructure is built up as follows:

- v_m : a potential (candidate) location (m=1,..,M)
- v_p : an information point (p=1,..P).

Such information points (knowledge centres, transfer centres etc.) may be large agglomerations, but also other information centres relevant for the firm such as universities or science parks. It may of course be assumed that between information points mutually or between candidate locations and information points direct information links do exist.

We assume here the availability of the following information on the information network:

(1) Each information point v_p is supposed to have a certain relative weight g_p for the firm at hand, which may depend e.g. on the number of telephone calls made to this centre or on any other meaningful proxy.

(2) For each edge e_{pm} the costs of information transfer are assumed to be equal to b_{pm}.

The locational decision of a firm in this case thus boils down to a tradeoff of physical and information transfer costs. In the next section a locational model for this choice problem will be developed.

3. DoubleDutch: a Locational Choice Model

The DoubleDutch location model aims at finding an optimal location for an individual firm, based on a simultaneous judgement of the two types of network.

The optimal location in the *physical* network can be found by means of the min-sum model, i.e. the *minimum median value* M_1 of all relevant costs of all candidate locations with respect to all relevant origins/destinations, i.e.,

$$M_1 = \min_m M_{1m} = \min_m (\operatorname{sum}_j (w_j . c_{mj}) + f_m) \qquad (3.1)$$

This is a conventional specification from the p-median literature (see among others Hakimi, 1964; Tansel et al., 1983).

The optimal location in the *information* network can be calculated by a similar minimum median value M_2, i.e.,

$$M_2 = \min_m M_{2m} = \min_m (\operatorname{sum}_p g_p . b_{pm}) \qquad (3.2)$$

In the present context it is as an alternative approach also possible to calculate for either the physical network or the information network or both the *min-max location* (i.e., the minimization of the maximum distance from all candidate locations to all points of origin/destination; see Hakimi, 1964).

It is clear that in general the optimal solutions of (3.1) and (3.2) do not coincide. This is a usual situation in case of multiple objective decision models (see Halpern, 1978, 1980; Handler and Mirchandini, 1979; Nijkamp, 1981).

In multi-objective programming theory a wide variety of approaches have been developed in order to tackle the problem of conflicting objectives, like e.g. the ideal-point approach, the game-theoretic approach, etc. (see Rietveld, 1980).

For our locational problem, various alternative methods do exist, e.g., the minimization of a convex (linear e.g.) combination of (3.1) and (3.2), or the minimization of one dominant criterion subject to constraints on other objective functions (the so-called constrained median problem). However, the objective function of the information network violates a distance decay pattern and is not necessarily convex.

In the context of the present paper, we will develop a new algorithm based on a step-wise analysis of dominant (or efficient) solutions for the various potential locations.

The first step is the calculation of the shortest routes (or minimum distance costs) from each potential location to the origin/destination points and the information points. This can be done inter alia by means of the Floyd-Warshall algorithm (see Papadimitriou and Steiglitz, 1982).

The second step implies the calculation of all values M_{1m} and M_{2m} $(m=1,..,I)$, or respectively the total logistic costs and the total information transfer costs.

The third step consists of a sequential procedure, in which first the minimum value of M_{1m}, i.e. M_1, is calculated. Next, all locations m with a value for M_{2m} that is higher than or equal to the corresponding value at the location corresponding to M_1 are left out (including the median location itself). Then for the remaining points the median is again calculated, and so forth, until at the end the optimal location in the information network is kept.

This algorithm produces a selection of candidate locations that are efficient in the sense that for each selected location it is impossible to find another location that is better situated in both networks.

The final step is to choose an 'optimal' location from this selection. If this selection consists of a single location then this location is of course optimal, but if the selection contains more locations, this step requires definitely a multi-objective approach since no selected location dominates another.

One way to solve this problem is to presuppose that there exists a fixed financial tradeoff between the total of the logistic costs and the information costs. Without having to know the exact amount of this tradeoff price this presupposition causes a further selection, since any location m that satisfies conditions (3.3) and (3.4) can then be left out.

$$M_{1m} > s.M_{1i} + (1-s).M_{1j} \quad \text{for some } s \text{ in } [0,1] \tag{3.3}$$

$$M_{2m} > s.M_{2i} + (1-s).M_{2j} \tag{3.4}$$

with s a variable on [0,1] and v_i and v_j part of the set of selected locations.

When the tradeoff price t is known, the determination of the optimal location m^* follows directly from minimization of the total costs for each selected location, i.e.,

$$\min_m (M_{1m} + t.M_{2m}) \quad \text{for } m \text{ in } (1,..,I).$$

However, if the tradeoff price t is not known with certainty then it is still possible to determine for each selected location a range for t in which that location is optimal. It can be shown that such a range exists for each selected location at this stage (see Dieperink, 1986). By defining the ranges to the corresponding locations it is no longer necessary to know the tradeoff price. An estimation in which range the price falls determines uniquely the optimal location. This will be shown in the next section by means of an illustrative example.

4. An Illustrative Application for an Innovative Firm

By way of empirical illustration we will present in this section the results of a study on the locational choice of an innovative firm, called (fictitiously) Infomanagement Inc. This is a consultancy firm specialized in automation processes for communication and information systems in firms. This rapidly growing firm considers a re-location in the urban field of the Netherlands (the so-called Rimcity or Randstad). Most of its clients are located in this large conurbation. Now the aim is to find a new location, which takes into account both the physical and the information network. The firm has identified 20 candidate locations (see Fig. 1) as well as the most relevant information centres (5 in total) and origin/destination points (8 in total). For each location the cost components f_m, the transfer costs c_{mj} and b_{pm} for all edges concerned, and the weights w_j and g_p for all nodes concerned have been assessed.

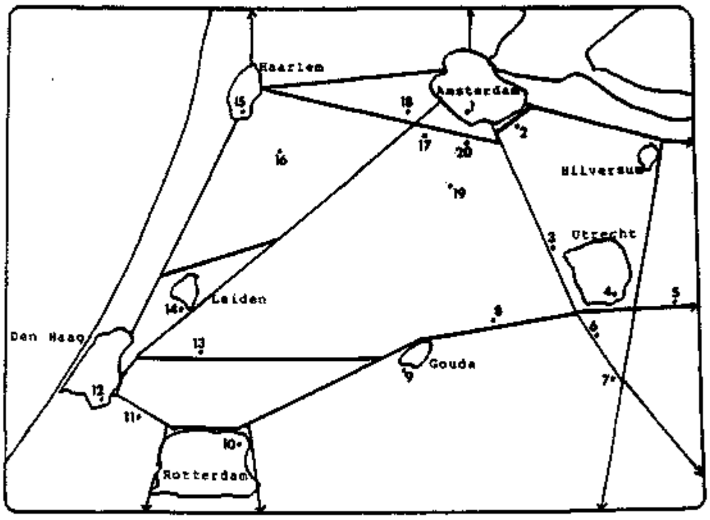

Fig. 1 Candidate locations for Infomanagement.

The relevant data for this locational choice problem are included in Tables 1 to 4. In Table 1 the location costs f_m are

Table 1
Location costs f(m) (in Dfl.)

	Location	
1	Amsterdam Zuid	254.000
2	Amsterdam Z.O.	239.000
3	Maarssenbroek	186.000
4	Utrecht	227.000
5	Bunnik	194.000
6	Nieuwegein	197.000
7	Vianen	187.000
8	Woerden	204.000
9	Gouda	195.000
10	Rotterdam	223.000
11	Delft	214.000
12	Den Haag	260.000
13	Zoetermeer	205.000
14	Leiden	206.000
15	Haarlem	216.000
16	Hoofddorp	198.000
17	Schiphol	241.000
18	Badhoevedorp	218.000
19	Uithoorn	200.000
20	Amstelveen	252.000

(Source R.B.O.G. Consultants)

Table 2
Transport costs c(m,j) (in Dfl.)

Location	Origin / destination							
	A	B	C	D	E	F	G	H
1	--	--	90	40	10	60	76	--
2	--	--	--	--	20	40	66	--
3	--	--	--	--	60	40	15	--
4	--	--	96	--	76	36	5	62
5	--	--	--	--	--	--	18	--
6	--	--	--	--	--	--	20	--
7	--	--	--	--	--	--	35	--
8	--	--	60	--	--	--	36	36
9	38	48	58	86	88	--	68	5
10	10	40	--	--	--	--	--	38
11	32	16	--	--	--	--	--	--
12	48	10	30	--	--	--	--	48
13	32	20	45	--	--	--	--	34
14	--	30	5	70	90	--	115	56
15	--	--	70	5	46	--	--	--
16	--	--	50	30	36	90	100	100
17	--	--	50	40	28	90	100	100
18	--	--	65	28	22	80	80	120
19	--	--	70	56	45	--	75	--
20	--	--	76	40	20	70	70	--
A: Rotterdam	x	46	--	--	--	--	--	38
B: Den Haag		x	32	--	--	--	--	54
C: Leiden			x	70	90	--	115	58
D: Haarlem				x	46	--	--	--
E: Amsterdam					x	60	78	--
F: Hilversum						x	36	--
G: Utrecht							x	68
H: Gouda								x

-- : no direct connection

Table 3
Information 'costs' b(p,m)

Location	Information centre				
	A	B	C	D	E
1	80	80	70	10	70
2	85	90	80	10	50
3	90	90	90	70	15
4	80	80	70	60	10
5	90	90	90	90	15
6	90	90	90	85	10
7	90	90	90	85	30
8	70	90	70	85	30
9	40	60	50	80	60
10	10	30	40	80	70
11	20	5	15	80	90
12	40	15	10	60	70
13	60	60	15	90	90
14	60	60	20	60	90
15	85	90	70	40	90
16	85	90	80	60	80
17	80	90	70	30	50
18	90	90	90	20	90
19	40	90	90	40	80
20	85	90	80	15	[illegible]
A: Rotterdam	x	15	10	30	90
B: Delft		x	15	40	90
C: Den Haag			x	20	25
D: Amsterdam				x	20
E: Utrecht					x

Table 4
Nodal weights w(j) and g(p)

w(a) = 600	g(a) = 8
w(b) = 500	g(b) = 4
w(c) = 100	g(c) = 5
w(d) = 200	g(d) = 8
w(e) = 800	g(e) = 5
w(f) = 200	
w(g) = 500	
w(h) = 100	

presented on the basis of the annual rent, adjusted for deviances in quality and accessibility standards. The transport costs in Table 2 include mileage and wage costs for a single journey. Information 'costs' are a compound non-monetary aggregate of a diversity of indices for city size, agglomeration economies, public utility level, etc. (see Dieperink and Nijkamp, 1986b). The weights in Table 4 represent the relative importance of the origin/destination points and the information centres respectively; the first ones are measured by the expected annual number of journeys to the nodes, the latter by assessing weights to the different components of the external information flows (see Dieperink, 1986).

With the use of these data as input, the above mentioned algorithm was able to produce a selection of seven efficient locations, none of them dominating another one in both networks. Table 5 shows this result by presenting the efficient locations with their logistic costs and information costs. It is essential to note that both types of costs are measured in different dimensions, so that comparison of, or even worse, summation of logistic and information costs is meaningless.

Table 5
Output DoubleDutch Model for Infomanagement Inc.

Location	Transport costs(Dfl)	Information 'costs'
9 : Gouda	390.300	1650
3 : Maarssenbroek	427.500	1135
14: Leiden	431.200	1025
13: Zoetermeer	440.400	875
10: Rotterdam	470.300	800
11: Delft	476.300	735
12: Den Haag	494.700	685

It is however assumed, in line with section 3, that there exists a fixed, but otherwise unknown, tradeoff price t between transport and information costs. The analytical consequences are described in section 3. Here the graphical representation of this approach is presented. Fig. 2 shows a plot of the efficient locations of Table 5. If the tradeoff price t were known, then the optimal location could be found by drawing a line through all efficient points, with a slope of -t. The line, that is closest to the origin, would then determine the optimal location.

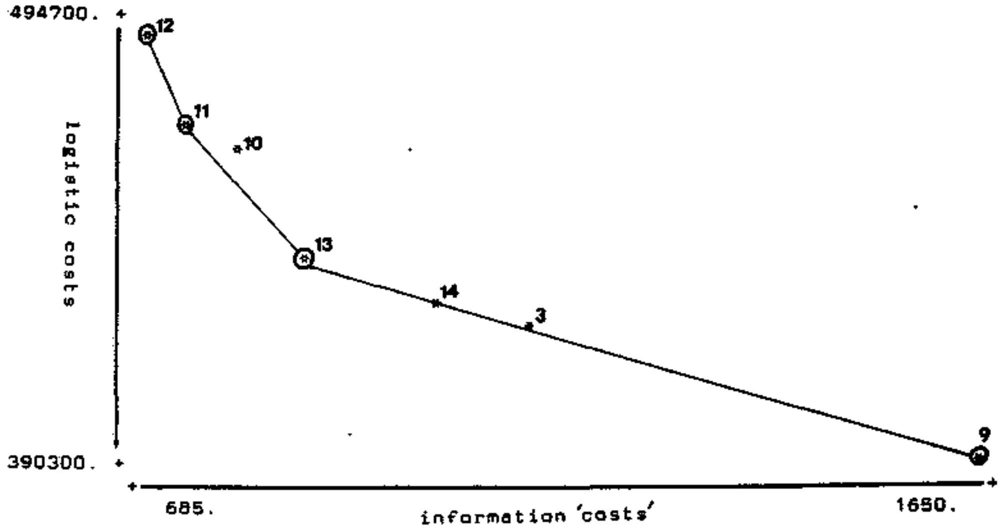

Fig.2 Tradeoff curve for efficient locations for Infomanagement Inc.

By varying t from 0 upward, in total four locations appear to arise as optimal candidates in a certain range for t. For $t < 65$, the transport network median, Gouda (9), is optimal. Next, for $256 > t \geq 65$, Zoetermeer (13) is optimal. Furthermore, for $368 > t \geq 256$, Delft (11) is optimal, and finally if $t \geq 368$ location

(12), the information network median Den Haag, optimizes the multi-criteria function. Clearly without further information on t, no unique result can be obtained. It would be plausible to regard location (13), Zoetermeer as the most appropiate place for Infomanagement Inc., because of the large range of t, for which this location is optimal. This can be seen as a measure of robustness. In a real-life situation it would of course be necessary to produce a sensivity analysis by iterating the algorithm for other data values, especially those related to the information network. The main feature of our algorithm is however that the original decision problem containing 20 possible solutions is reduced to a surveyable and more manageable four-location problem.

References

Brotchie, J., P. Newton and P. Hall (eds.) (1986), The Spatial Impact of Technological Change, Croom Helm, London.

Dieperink, J.P.H. and P. Nijkamp (1986a), Spatial Dispersion of Industrial Innovation, Researchmemorandum 1986-9, Free University, Amsterdam.

Dieperink, J.P.H. and P. Nijkamp (1986b), De Agglomeratie-Index, Planning, 1986, 27, 1-8.

Dieperink, J.P.H. (1986), Een Lokatiemodel voor Innovatieve Ondernemingen, Department of Operations Research, Free University, Amsterdam.

Freeman, C., J. Clark and L. Soete(1982), Unemployment and Technical Innovation, Frances Pinter Ltd., London.

Giaoutzi, M. and P. Nijkamp (eds.) (1987), Informatics, High Tech and Regional Development, Gaven, Aldershot.

Hakimi, S.L. (1964), Optimum locations of switching centers and medians of a graph, Operations Research 12, 406-409.

Halpern, J. (1978), Finding minimal center-median convex combination (cent-dian) of a graph, Management Science 24, 535-544.

Halpern, J. (1980), Duality in the cent-dian of a graph, Operations Research 28, 722-735.

Handler, G.Y. and P.B. Mirchandini (1979), Locations on Networks, The M.I.T. Press, Cambridge, Massachusetts.

Kleinknecht, A. (1986), Crisis and Prosperity in Long Term Development, Oxford University Press, Oxford.

Love, R.F. and J.G. Morris (1979), Mathematical models of road travel distances, Management Science 25, 130-139.

Love, R.F. and J.G. Morris (1972), Modelling inter-city road distances by mathematical functions, Operations Research Quarterly 23, 61-71.

Malecki, E.J. (1985), Industrial Location and Corporate Organization in High Technology Industries, Economic Geography 61, 345-369.

Nijkamp, P. (1981), Multidimensional Spatial Data and Decision Analysis, Wiley, New York.

Papadimitriou, C.H. and K. Steiglitz (1982), Combinatorial Optimization Algorithms and Complexity, Prentice-Hall, Englewood Cliffs.

Pred, A.R. (1977), *City-Systems in Advanced Economies*, Wiley, New York.

Rietveld, P. (1980), *Multiple Objective Decision-Making for Regional Planning*, North-Holland Publ. Co., Amsterdam.

Roberts, E.B.(1984), Generating Effective Corporate Innovation, *Technology Review* 1984, special issue on innovation.

Jansel, B.C., R.L. Francis and T.J. Lowe (1983), Location on networks: a survey, *Management Science* 29, 482-511.

1983-13	J.H.A. van Maanen	De rationele verwachtingshypothese
1983-14	P. Nijkamp, M. van Pelt	Spatial Impact Analysis for Developing Countries: A Framework and a Case Study
1983-15	P. Nijkamp P. Rietveld A. Rima	Sensitivity of Information for the Aggregation Level of Spatial Data
1983-16	H. Blommestein en P. Nijkamp	Testing the spatial scale and the dynamic structure in regional models
1983-17	F. Brouwer/ P. Nijkamp/ H. Scholten	Hybrid Log-Linear Models for Spatial Interaction and Stability Analysis
1983-18	G. Morello	The 'Made In' Issue: A Comparative Research on the Image of Domestic and Foreign Products.
1983-19	S.C.W. Eijffinger	Het monitaire beleid van De Nederlandsche Bank
1983-20	G.M. van Westrienen	De rol van de agrariese sektor in het transitie-proces van de Nicaraguaanse ekonomie. Exportgewassen versus basis-voedselgewassen
1983-21	H. Jansen	Het gedrag van de Nederlandse monetaire beleidsmakers: 'Maximizing' of 'Satisficing'?

1984-1	A.J. Vermaat	Vraagrevelatie-Methoden voor Kollektieve Goederen
1984-2	P. Nijkamp	Long-Term Economic Fluctuations: A Spatial View
1984-3	W. Hafkamp P. Nijkamp	An Operational Multi-Component Multie-Actor Policiy Model for Economic-Environmental Scenarios
1984-4	P. Nijkamp N. Wrigley	Facts and Figures in Regional Science
1984-5	P. Nijkamp	Information Systems for Regional Development Planning: A State-of-the-Art Survey
1984-6	W. Keizer	De Economie van de Utopie
1984-7	J.P.M. Sijm maart 1984	Over het schuldenvraagstuk en de derde wereld - dilemma tussen aanpassing en financiering
1984-8	H. Linnemann	World Food Prospects till 2000
1984-9	H.M.I. van der Putten mei 1984	Beheersbaarheid en controleerbaarheid van geautomatiseerde informatieverzorging in kleinschalige organisaties
1984-10	H. Visser	New Classical Macroeconomics as seen by an impressed Non-believer or, Keynes and the Classics all over again
1984-11	W. van Ditmars	Mantelprojekt 'Management & Politiek' Managers en Ekonomische Politiek, een onderzoek naar de voorstellingen van topmanagers bij de zaak van ekonomische politiek
1984-12	F.C. Palm/ Th.E. Nijman	Consistent Estimation using Proxy-Variables in Models with Unobserved Variables
1984-13	F.C. Palm/ Th.E. Nijman	Missing observations in a quarter model for the aggregate labor market in the Netherlands
1984-14	J.G. Leibbrandt, F.T. J. Keijzer, H. Schreuder	Tijdreeksvoorspellingen van omzetten, bedrijfsresultaten en winsten: replicatie en uitbreiding
1984-15	H.P. Smit/ H. Clemens	Market Developments for Jute Fibre and Jute Goods - a preliminary investigation -
1984-16	W. Keijzer	Further contributions by L. von Mises to the Central European debate on socialist calculation
1984-17	A. Nieman	Investeringsselectie in de praktijk

1985-1	Ron Janssen Peter Nijkamp	A Multiple Criteria Evaluation Typology of Environmental Management Problems
1985-2	Peter Nijkamp Adriaan Perrels	Impacts of Electricity Rates on Industrial Location
1985-3	Peter Nijkamp	Mobolity as a Societal Value: Problems and Paradoxes
1985-4	Peter Nijkamp	Equity and Efficiency in Environmental Policy Analysis: Separability versus Inseparability
1985-5	Floor Brouwer Peter Nijkamp	A Satllite Design for Integrated Regional Environmental Modelling
1985-6	Manfred M. Fischer Peter Nijkamp	Explanatory Discrete Spatial Data and Choice Analysis: A State-of-Art Review
1985-7	Arnoud Mouwen Peter Nijkamp	Measurement and Tests of Long-term Urban-spatial Evolution