Free University
Amsterdam
Dept. of Economics
P.O. Box 7161

LONG WAVES OR CATASTROPES IN REGIONAL DEVELOPMENT

Peter Nijkamp

Researchmemorandum 1982-1 jan.

Paper presented at the North-American meetings of the Regional Science Association, Montreal, November, 1981.

Contents

page

1. Structural Economic Changes 1
2. Innovations and Economic Growth 3
3. Spatial Dimensions of Innovation and Economic Development 5
4. Spatial Development Patterns in the Netherlands 7
5. Explanatory Models for Spatio-temporal Dynamics 9
6. A Catastrophe Model for Spatio-temporal Systems 11

References 23

Summary

This paper addresses itself to long-term economic developments in a spatial context. Particular attention is paid to the recent discussion on long-term cycles and the impacts of innovations. The spatial diffusion and impacts of long waves, especially in a regional setting with threshold levels and bottlenecks, are also discussed, while also some empirical evidence regarding long-term developments in the Netherlands is given.
After a brief survey of some long-run spatio-temporal models, a dynamic model based on elements of catastrophe theory is developed. This model includes <u>inter alia</u> productive capital, social overhead capital (infrastructure) and R & D capital as main driving forces. Various stability aspects of this dynamic control model are finally examined.

1. Structural Economic Changes

Already for many decades economists have been fascinated by long cycles (cf. Adelman, 1965). There are various reasons why since a couple of years long-term economic developments have increasingly received explicit attention in economic planning:

- the persistent and deeply-rooted economic recession in almost all areas of the world;
- the deep-going long-term impacts exerted by often unpredictable actions of countries in conflict situations (the Middle-East, e.g.);
- the unequal distributive implications of long-run economic changes for less prosperous areas;
- the inability of government policies to restore or to assure a stable or harmonious economic and technological development.

The eighties appear to become a decade of structural uncertainty. Consequently, future developments may demonstrate drastic changes which might even take the form of crisis-like phenomena. Since the era of an ever-increasing economic prosperity is drawing to a close, relatively more attention is being paid to long-term waves in economic development patterns. Questions such as future shocks, (un)balanced or (un)stable equilibria and regional discrepancies receive increasing attention (see also Buhr and Friedrich, 1981a, 1981b).

In light of the structural economic changes during the last decade, Kondratieff's theory on long cycles shows a revival among economists (see Delbeke, 1981, Van Duijn, 1979, Mandel, 1980, and Rostow, 1978). The cyclical pattern of long waves in a free-enterprise economy normally includes 5 stages: take-off, rapid growth, maturation, saturation and decline.

Apart from Schumpeter (1939), many economists have regarded the Kondratieff cycle mainly as an economic curiosity reflected in price changes (cf. Mass, 1980). The cyclical pattern of a capitalist economy, however, cannot easily be demonstrated due to lack of reliable historical data. In general, the long-wave hypothesis has been tested in terms of long-run price cycles, while next (partial) data on actual economic development processes (inter alia in terms of volumes of commodities and foreign trade) have been confronted with this series of data on prices, so as to infer an explanatory analysis for a long-term cyclical pattern as an endogenous pattern in industrialized countries. This implies that a theory had to be designed which explained the emergence of each new phase of a wave (prosperity, recession, depression and recovery) from economic and technological developments during a previous phase. For instance a prerequisite for a period of economic recovery is the fact that during the preceding 'downswing' technological progress and innovation should pave the road for a renewed economic growth.

It should be noted that in the literature several distinctions of cyclical wave patterns have been made. In addition to the long-term Kondratieff cycles (up to approx. 50 years), also Kuznets cycles (approx. 20 years), Juglar cycles (approx. 10 years) and business cycles (up to approx. 4 years) may be mentioned. The actual pattern of waves is evidently formed by a superposition of all these cycles (in a way analogous to the superimposed Löschian spatial pattern).

Frequently, the long-term cyclical pattern of economic growth is assumed to be caused by fluctuations in the demand for productive capital (cf. Heertje, 1981). Especially, the use of long-run production capacity shows a fairly unstable temporal pattern : a rapid expansion during a period of economic growth leading to high capital costs, followed by a decline in the production of capital goods leading to low capital costs etc. (cf. Graham and Senge, 1980). Until recently, in empirical research, the attention was mainly focussed on the related cyclical price movements caused by inflexible capital stocks rather than on cyclical patterns in technological growth. (including innovation and diffusion).
The current economic stagnation has stimulated research in the area of cyclical waves. Especially in the industrialized world, (lack of) of innovation and diffusion is mentioned rather frequently as a basic cause for cyclical economic patterns (see, among others, Clark et al., 1981 , Kleinknecht, 1981, and Mensch, 1979). For instance, Mensch has emphasized the relevance of basic or radical innovations for long-run economic developments : after a period of rapid economic and technological growth, a certain retardation and saturation will occur leading to an economic recession; this situation may stimulate new innovations (the 'depression-trigger' hypothesis). Clark et al., however, question Mensch's theoretical explanation of innovation during an economic 'downswing', as innovations might then be too risky. Kleinknecht demonstrates that only relative risks are important, which may also explain technological progress during a period of economic recession.

On the other hand, other authors (for instance, Forrester, 1977) argue that the transformation of demand impulses into new productive investments and/or the long gestation period of productive capacities cause the emergence of long waves in economic life. This cyclical economic pattern which is essentially caused by over- and underinvestments is essentially due to rigidity and inertia in economic behaviour. In this respect, overcapacity accompanied by corresponding price movements form the major constituents of an explanatory analysis for long cycles. This is also reflected in so-called vintage and puttyclay models (cf. Clark, 1980). An alternative interpretation of the over- and under-investments hypothesis is given by Mandel (1980), who argues (from a Marxist point of view) that a successive acceleration and deceleration of capital accumulation may lead to crises in a capitalist economy.

Finally, from a global viewpoint Rostow (1978) explains long-term international fluctuations by means of economic distortions caused by the supply of food stuff and raw materials and by its related and subsequent price pattern.

Before the abovementioned notions will be incorporated in a regional development theory, more explicit attention will be given to the relevance of innovations for economic growth.

2. Innovations and Economic Growth

It is clear that innovations are concentrated in certain sectors of industry, so that the process of economic and technological growth is not spread uniformly over all sectors of a national economy (cf. Kleinknecht, 1982, and Mahdavi, 1972). The development process of individual economic sectors is characterized by a cyclical pattern as well. In this respect, the economic development is usually determined by **key** sectors (the chemical industry or the electronic industry, e.g.) that give rise to basic or radical innovations and transmit growth impulses to other sectors. This growth process constitutes also the basis of the growth pole theory developed by Perroux. This theory - originally formulated in a purely economic space - claimed that polarisation phenomena (scale advantages, intersectoral linkages and technological innovation) created the conditions for a rapid economic development which might lead to a diffusion of growth impulses from propulsive industries to other sectors.

Normally, an 'upswing' of a certain economic sector will be based on (1) a rise in demand for its products, (2) an associated technological innovation favouring this change in demand, (3) a sufficient implementation of required productive investments and (4) a satisfactory supply of public capital supporting this growth process. A reverse development takes place during a 'downswing' (cf. also Graham and Senge, 1980).

It is clear that basic innovations may be regarded as the propulsive factors behind the process of structural economic growth. This implies much more emphasis on 'supply-side' economics than in traditional Keynesian models (cf. Giersch, 1979). The current revival of growth pole theory (or of variants thereof) is thus due to the observed lack of fundamental innovations at the supply-side during the current economic recession.

It should be noted, however, that in the Schumpeterian view innovation is not an exogenous determinant of economic growth, but an endogenous instrument in a profit-maximizing economy. Thus, the profit motive is the main driving force of innovation and hence of cyclical economic patterns. Clearly, the discontinuities associated with the adoption and diffusion of innovations may lead to perturbations and catastrophes in an economic system, while rigidities, inertia, bottlenecks and indivisibilities at the supply side preclude the attainment of smooth and continuous growth processes.

It is conceivable that - recently - a growth of R & D sectors is being regarded as a remedy against the current economic stagnation, especially as in the past these sectors have also displayed an extremely high growth rate. It should be added, however, that economic growth also requires both a supply of sufficient infrastructure and a transmission of initital growth impulses toward other sectors of the economy. Evidently, such an integrated innovation process is very hard to establish. This also questions the reliability of straightforward causal links from innovation to economic growth (reflected inter alia by the discussion on the validity of either 'depression-trigger' innovation or 'demand-pull' innovation ; cf. also Kleinknecht, 1981, and Mowery and Rosenberg, 1981). Innovation can essentially be regarded as one of the necessary conditions (and thus instruments) for economic growth ; it may be induced in both an 'upswing' or a 'downswing' of the economy pending on specific market circumstances and on specific features of the commodities concerned. It should also be added that even a dual sectoral structure may exist; this implies that an 'upswing' in the one sector may be accompanied at the same time by a 'downswing' in the other one, while both sectors may either display new innovations or just lack of new innovations.

It should also be mentioned that the definition and measurement of innovation is a far from easy task, as innovation may relate to structural sectoral changes, technological progress in production processes, or adoption of new products or of new marketing techniques. According to Haustein et al. (1981) the innovation process may display several stages varying from research, invention, development, application and exploitation, so that dynamic evolutionary models may be used to describe innovation and diffusion processes (cf. Nelson and Winter, 1977).

Therefore, the direct and indirect impacts of such innovations are hard to quantify, especially because innovations may take place in interrelated clusters of industry such as electronics, petrochemical and plastics industry, etc. (cf. Mensch, 1979). Of course, it may be possible to measure the direct and indirect success of innovations by means of changes in industrial growth and profit rates . For instance, Brinner and Alexander (1977) have found a strong correlation between sectoral R & D spending and sectoral growth rates. Also at the individual level of the industry or firm the innovation intensity may be measured by means of the expenditures for R & D activities or the number of requests for patents on industrial products (appropriability of innovations is a necessary condition ; cf. Thomas, 1981). But it is clear that in general the data on innovations are characterized by much uncertainty (cf. Terleckyj, 1980). Also the identification of long-term innovation cycles through sectors or regions is fraught with difficulties due to lack of appropriate statistical techniques (though cross-spectral analysis may be a helpful tool).

There is in several countries,, however, a certain evidence that only a limited number of industrial sectors account for the major share of expenditures in innovation-oriented activities (for instance, electronics, petrochemics and aircraft). It has to be added, however, that also small firms may be a source of major innovations, for instance, in the area of micro-processors (cf. Rothwell, 1979 and Thomas, 1981).

A major concern in adopting innovative behaviour is uncertainty. Marginal innovations (usually called 'improvements') generally imply only little uncertainty, but radical innovations are usually accompanied by high uncertainty (cf. Freeman, 1974). It is clear that the uncertainty will be lower, as the innovation investment at hand is supported by a sufficient availability of (public) infrastructure capital. Furthermore, a risk-minimizing industrial behaviour may stimulate the adaption of innovations by 'followers', but will not stimulate new and basic inventions by 'leaders' and 'trend-setters'. Such a 'leader-follower' situation may also be responsible for the S-shaped (logistic) innovation curve for product life cycles.

3. Spatial Dimensions of Innovation and Economic Development

Innovation and growth processes are also reflected in spatial patterns. Depending on locational conditions, infrastructure and sectoral composition, regions and cities will also display growth patterns related to structural economic and technological changes (cf. Chatterji, 1971 and Czamanski, 1966).

The spatial economic aspects of these changes are exposed in several theories, such as (see also Nijkamp, 1982) :

- economic base-multiplier type models
- regional and interregional input-output models
- gravity and income potential models
- growth pole models
- centre-periphery models
- unbalanced growth models
- development potential models.

Especially growth pole models have offered a framework for studying the spatial impacts of structural economic and technological changes. It should be noted, however, that a growth pole is a purely economic concept, while a growth centre is the geographical and locational representation of a set of propulsive activities. Thus, a growth centre is a geographical concentration of economic activities which can - beyond a given initial threshold level - achieve self-sustaining growth, so that growth is diffused to other (normally less developed) areas. If the reverse process takes place, i.e., if a centre is developing in detriment of surrounding areas, it is usually mentioned an attraction centre (see Nijkamp and Paelinck, 1976). As the temporal evolution of innovation is normally exhibiting an S-shaped curve, one may also expect a similar shape for the impacts on other areas (though with a certain time lag), as is also reflected by the literature on innovation-diffusion processes.

Clearly, after an expansion stage a contraction stage may arise due to external diseconomies (congestion effects, e.g.) - in accordance with the cyclical pattern of innovations - , so that spatiotemporal patterns are normally not very stable and sometimes even may display sudden jumps and perturbations. Evidently, a distinction has to be made between initial adjustment effects and structural effects (cf. Pedersen, 1978).

The cyclical pattern of long waves appears to have clear spatial dimensions, especially as far as transportation infrastructure is concerned. It has often been recognized that, for instance, the upswing of the long wave starting in the middle of the last century was accompanied by the introduction of railways and steamships. Similarly, the next upswing (beginning of this century) was accompanied by the construction of extensive road infrastructure and of telephone systems, while the next long cycle (after World War II) was accompanied by an efficient long-distance communication infrastructure (air traffic, telecommunication). In addition to this physical infrastructure, simultaneously also other kinds of infrastructural facilities (such as education, culture, housing etc.) have been introduced. This once more indicates that infrastructure (in a broad sense) is a prerequisite for economic development.

As the abovementioned innovation process has also led to market extensions, large scale operations came into being, leading to geographical concentration and specialization. This has in turn led to new innovations. The literature on city size suggests indeed that innovative ability is a general feature of modern cities (cf. Alonso, 1971, Pred, 1966, Richardson, 1973, and Thompson, 1977). The conventional wisdom indicates that a geographical concentration of economic activities will favour a higher productivity due to its accompanying scale advantages (cf. Kawashima, 1981). Large urban agglomerations appear to be characterized by a higher industrial diversification and a richer social, cultural and educational infrastructure, so that the innovative ability of these areas may be much higher than elsewhere (cf. Nelson and Norman, 1977). Consequently, technological progress may be favoured by large agglomerations (cf. Carlino, 1977). It has been demonstrated by Malecki (1979), that the innovative potential in the U.S. is mainly concentrated in urban areas, but that during the last decade the degree of innovation in the largest urban concentrations has shown a tendency toward decline. This implies that the innovative activity may be suffering from diseconomies of size (cf. also Sveikauskas, 1979). The foregoing observations lead again to the conclusion that innovative ability as a source of regional and/or urban development requires a <u>minimum threshold</u> of infrastructural facilities, while - beyond a critical upper level - it may also suffer from <u>congestion effects</u>.

It is clear that spatial differences in innovative ability may lead to <u>spatial</u> discrepancies in income, employment and sectoral growth rates, not only at the <u>international</u> level between countries, but also at the <u>intranational</u> level between regions or cities. Cyclical long wave patterns do not necessarily run parallel in all regions of a spatial system, depending on the sectoral composition, infrastructure endowments, locational conditions, and the degree of integration of public overhead and private productive capital. In addition, regional development patterns may - apart from exogenous circumstances - be co-determined by national processes (in a top-down structure) and developments in other regions (due to spatial spill-over and/or interaction effects).

According to Myrdal (1957), spill-over effects in a geographical context may be distinguished into spread effects and backwash effects; migration, input-output linkages, capital flows and trade are media through which cumulative spatial processes evolve. These processes may lead - due to multiplier effects - to a sustained growth in central areas. Such spatial processes from a nodal region onward may show a wave-like temporal evolution. It should be added that - due to agglomeration diseconomies - the innovative capacity of economic centres may shift to other areas, as soon as a certain critical congestion effect in the initial centre has been reached (the so-called 'filtering down' effect). This may of course lead to unstable spatial development processes, as is also reflected by some facts and figures in the next section.

4. Spatial Development Patterns in the Netherlands

In this section, some empirical evidence of regional development patterns in the Netherlands will be given. Due to lack of data, it is not possible to identify the existence of spatial waves in the Kondratieff sense; instead, some regional data on certain development indicators (unemployment and migration) will be provided in order to show significant differences in the evolution of regional development (see Meerens, 1981).

Fig. 1 represents the percentage unemployment evolution during the period 1952-1979 for the industrialized central provinces (Utrecht, Noord-Holland and Zuid-Holland) and the peripheral provinces (Groningen, Friesland and Drente). The corresponding lines are denoted by C-C and P-P, respectively. In addition, the province of Drente showing a fairly extreme evolution of umemployment is also included separately (see line D-D).

Fig. 1 shows indeed that development processes demonstrate waves with clear spatial dimensions. Given the pattern of the unemployment process in the central and peripheral provinces, it appears that peripheral areas fluctuate much more than central areas, though all curves have a similar shape. During a boom of a business cycle, the regional discrepancies tend to become smaller. During the recent depression, the regional unemployment figures tend to show slightly less differences than the historical pattern from the past would suggest. This may be caused by the fact that the provision of infrastructure endowments to the peripheral areas has had a balancing effect.

The second indicator concerns net regional migration. This pattern is represented in Fig. 2. This figure again shows significant differences between the peripheral and the central provinces. The positive net inmigration to the central areas during the fifties is followed by a negative net inmigration from the sixties onward. The reverse pattern holds true for the peripheral areas. The abovementioned patterns indicate a high degree of spatio-temporal dynamics of economic development in the Netherlands, in which urbanization and industrialization have been more oriented toward so-called intermediate (semi-peripheral) areas.
It has been mentioned in the preceding sections that innovation processes have a strong sectoral component, so that it may be worthwhile to investigate the regional development patterns of sectors. In Figures 3 and 4, some empirical evidence for the chemical and the textile industry is given, respectively (see also Meerens, 1981). For the ease of presentation, only two provinces have been presented, viz. the semi-peripheral province of Gelderland (reflected by line G-G) and the industrialized province of Zuid-Holland (reflected by line Z-Z). The chemical sector also includes oil technology and can thus be regarded as a highly innovative and strongly expanding industry. The textile industry is a traditional industry characterized by lack of innovation and expansion. The regional and sectoral development indicator selected for the period 1930-1979 is the share of sectoral employment (both male and female) in total regional labour supply (the so-called activity rate).

Figures 3 and 4 indicate that traditional industries such as the textile industry (which used to be located in Zuid-Holland) have left the central areas, while also their development process in more peripheral areas shows a strong tendency to decline. Especially from the sixties onward, traditional sectors are characterized by a structural decline (which has led to the necessity of planning for decline).

Innovative sectors (such as the chemical industry)demonstrate a rapid rise in the central areas, despite the initial lead of the chemical sector in Gelderland. But nowadays, the chemical industry in the less centrally located province of Gelderland is a stagnating sector.

After this brief presentation of some empirical illustrations,the conclusions may be inferred that the evolution of a spatial system may be characterized by unbalanced growth processes with several shocks and perturbations. In the next section, the attention will be focussed on some models explaining the spatio-temporal dynamics of a spatial system.

5. Explanatory Models for Spatio-temporal Dynamics

Several models can be found in the literature describing the spatio-temporal dynamics of a system of regions. In this section, only a limited sample of such models explaining differences in regional growth patterns will be presented.

Van Duijn (1972) has developed an interregional simulation model for a system of 3 regions. This model describes the evolution of activity processes in a spatial system, based on the assumption of geographical immobility of labour and capital between the regions of the system. Private investments induced by the regional activity level determine the cycles of discrepancies among regions. The fluctuations of the regional activity pattern are reduced by imposing upper and lower capacity limits for each region. These capacity limits may induce spread effects (in case of an upper limit) or backwash effects (in case of a lower limit). A balanced outcome (a 'steady state' development) can only be assured by either a centralized planning or by an anti-cyclical policy.

A later version of the model is based on a relaxation of immobility of labour, so that a migration relationship describing migration as a function of regional unemployment, is introduced. Migration movements tend to reduce wild fluctuations in regional unemployment, though in that case regional investments may still demonstrate an unstable growth pattern.

Another spatio-temporal model describing interregional fluctuations is developed by Nijkamp and Paelinck (1976, Ch.7). Their model describes the diffusion of growth processes in regional and urban systems based on the assumption that the regions of a spatial system can be distinguished into growth centres, attraction centres and intermediate regions (transmitters of growth impulses). This model is also a simulation model. The core of the model is formed by a relationship describing the evolution of regional attractiveness as a function of capital endowment (corrected for a congestion effect), infrastructure and information. The capital stock is built up by a series of investments that depend on regional locational vectors, spatial spill-over effects and regional production (determined by intermediate and final demand in all regions). Migration depends inter alia on wage differentials, regional labour markets and regional attractiveness. Given a set of assumptions on growth centres and attraction centres, the evolution of this spatial system can be generated by means of a simulation approach for all spread and backwash effects involved.

A highly interesting model on long-term developments of countries and cities has been developed by Thomas (1972, 1973), who has paid special attention to demographic factors and migration movements.
His model was based inter alia on the following assumptions:

1. the population structure (in terms of age, sex and marital status groups) and external migration determine the population growth rate;
2. a major fraction of total capital investments varies with the rate of change of population growth and internal migration;
3. export capacity is created through population-sensitive infrastructure capital endowment (such as roads, railways, ports, houses and public utilities), so that there is a long-run relationship between a country's infrastructure investment in one phase of a cycle and its export potential in the next.

These assumptions could indeed be validated on the basis of data for several industrialized countries, so that by means of this model the long swings pattern for these countries and their impacts on the cities could be generated.

A final example of a category of models concerns the so-called catastrophe models. Catastrophe theory deals with discontinuous adjustments in dynamic processes (see, among others, Zeeman, 1977, and Poston and Stewart, 1978). It is able to describe sudden space-time disturbances in dynamic systems. In contrast to differential calculus defining changes in the direction or quality of a curvature as singularities on a graphic curve, catastrophes are topological singularities in the form of geometrical projections from one surface to another which - despite distortions of the surfaces - retain their basic qualitative form. Thus, by means of catastrophe theory one may analyze the ways in which equilibrium states of a system display shocks or smooth transitions. Catastrophe models assume that the behaviour of a system can be described by a set of state (endogenous) variables $\underline{x}$ and of external (control) variables $\underline{z}$. These variables are related to each other by means of a dynamic (or potential energy) function. By means of covariations of the state and external variables, a plane in ($\underline{x}$, $\underline{z}$) space can be defined. If one value of $\underline{z}$ produces multiple equilibrium values of $\underline{x}$, the surface is convoluted by folds. Such a surface is a singularity characterizing potential perturbations in the system. In this respect, a catastrophe (a cusp or a butterfly, e.g.) may emerge, when a smooth change of $\underline{z}$ in a critical region causes a sudden jump of $\underline{x}$ to a new value across the fold.

An application of catastrophe models to dynamic environmental systems is found in Van Dijk and Nijkamp (1980). They describe how inertia in the demand and supply behaviour may lead to shocks in a long-term environmental energy system.

Such models might also be extremely helpful in describing the evolution of a system of regions, as normally such a system also demonstrates many fluctuations and shocks (see also Casetti, 1981, and Isard and Liassatos, 1979). An attempt at constructing such a catastrophe model for a long-term spatial dynamic system will be made in the next section.

6. A Catastrophe Model for Spatio-temporal Systems

Discontinuous models for investment behaviour have been developed in the past among others by Arrow (1968) and Arrow and Kurz (1979). These authors have developed a model for irreversible investments in a dynamic setting. Optimization of long-run benefits appears to lead to 'bang-bang' switches implying a discontinuous investment pattern. Such shocks emerge due to the fact that the control variable is included in a linear way, so that noninterior solutions may arise. Alternative versions of such discontinuous investment models can be found in Nijkamp and Verhage (1976).

Such discontinuous investment models can essentially also be described by means of catastrophe-type models. On the basis of the theoretical analyses presented in the preceding sections, a dynamic (multiregional) development model will now be developed characterized by the following features:

- the model describes spatio-temporal development processes without necessarily assuming stability tendencies in the model. Therefore, the following general dynamic model may be assumed:

$$\dot{\underline{x}} = \underline{f}\,(\underline{x}, \underline{z}) \qquad (1)$$

  with $\underline{x}$ and $\underline{z}$ vectors of state variables (economic growth, e.g.) and control variables (infrastructure, e.g.), respectively.

- each region of the system needs a minimum endowment of infrastructure (or public overhead capital in a broad sense) so as to guarantee a self-sustained growth; in other words, infrastructure is a prerequisite for regional development processes (see also Hirschman, 1958). This critical threshold level which may be specific for each region r will be denoted by $\underline{z}_r^*$ (cf. Nijkamp, 1982).
- each region needs a fine tuning of infrastructure endowment so as to get a maximum efficiency in the use of public capital; this also implies that synergistic effects among different infrastructure categories may play an important role (cf. also Nijkamp, 1982).
- each region may also have bottleneck factors that hamper a further development; such bottleneck factors may be capacity limits, congestion effects, lack of infrastructure, institutional factors, or locational conditions. This is also a problem studied extensively in threshold analysis. In this respect, threshold costs can act as transition costs leading to rather abrupt changes in a dynamic system. It is evident that - in case of such bottleneck factors - the behaviour of a system is not necessarily symmetric in a period of expansion and of contraction. These threshold limits will be denoted by $\hat{\underline{z}}_r$ in each region r .
- another reason for an asymmetric behaviour of a dynamic system may be found in the existence of indivisibilities in the capital stock (especially in large-scale infrastructure endowment with a long gestation period), so that - instead of smooth adjustments - jumps in investment patterns may occur (cf. Nijkamp, 1981).
- technological progress and innovations may lead to a higher efficiency of more recently installed capital investments (cf. Batten, 1981). Consequently, one often observes so-called vintage effects; this means that the intensity of the use of capital stocks implemented in different time periods will be co-determined by its relative efficiency.
- due to unequal locational and agglomerational conditions, innovative and R & D activities are not equally dispersed in various regions. The differences in the relative advantages in a spatial system may lead to various kinds of spatial spill-over and interaction effects (transfer of capital or know how, e.g.). In this way, smooth transitions in the one region may be affected by perturbations in the other one.

The following dynamic model will now be used to illustrate the presence of jumps in a spatial system. For the ease of presentation, first a single-region version will be presented. The following investment equation will be assumed:

$$\dot{k} = \sigma_1 y - \delta_1 k \qquad , \qquad (2)$$

with :

k = directly productive capital stock per capita

y = income (or product) per capita

σ_1 = rate of investment in directly productive activities

δ_1 = depreciation rate for directly productive capital .

The investments in infrastructure capital (roads, railways, public utilities, educational and cultural facilities, etc.) are determined as follows:

$$\dot{l} = \sigma_2 y - \delta_2 l \qquad , \qquad (3)$$

with:

l = infrastructure capital per capita

σ_2 = rate of investment in infrastructure

δ_2 = depreciation rate for infrastructure .

The stock of infrastructure capital is made up by various components. The coordination of the various infrastructure categories so as to achieve a most efficient outcome is a matter of integrated (regional) development policy. In respect to this, the concept of a regional development potential in combination with a so-called quasi-production function approach may be an extremely helpful analytical tool (see Biehl, 1980, and Nijkamp, 1982).

R & D investments leading to innovations are made up by a part of the directly productive investments and of the infrastructural investments; the successive share coefficients are ν_1 and ν_2 , respectively. In other words:

$$\dot{r} = \dot{r}_1 + \dot{r}_2$$

$$= \nu_1 \dot{k} + \nu_2 \dot{l} \qquad , \qquad (4)$$

with:

r = total R & D capital stock per capita

r_1 = R & D capital stock built up from k

r_2 = R & D capital stock built up from l .

Substitution of (2) and (3) into (4) gives:

$$\begin{aligned} \dot{r} &= (\nu_1 \sigma_1 + \nu_2 \sigma_2)y - \nu_1 \delta_1 k - \nu_2 \delta_2 l \\ &= \nu^* y - \nu_1^* k - \nu_2^* l \end{aligned} \tag{5}$$

It is clear that the following conditions should hold:

$$\left.\begin{array}{l} \sigma_1 + \sigma_2 \leq 1 \\ \sigma_1 , \sigma_2 \geq 0 \\ \nu_1 \leq 1 \\ \nu_2 \leq 1 \\ \nu_1 , \nu_2 \geq 0 \end{array}\right\} \tag{6}$$

The following production function is assumed:

$$y = f\,(k,\ l,\ r) \tag{7}$$

This is a generalization of the development model designed by Hirschman (1958), as in (7) (regional) development is determined by directly productive capital, by social overhead capital and also by R & D capital. Labour is implicitly included, as all variables are measured in units per capita. This model is in agreement with the abovementioned quasi-production function approach.

Finally, the following consumption equation is assumed:

$$c = (1 - \sigma_1 - \sigma_2)\ y \quad , \tag{8}$$

with:

c = consumption per capita.

The following remarks can be made regarding the production function .

1. The existence of a <u>minimum critical threshold level of infrastructure capital</u> implies that a rapid regional growth will take place only beyond a value l^* of infrastructural endowment. Depending on the degree of indivisibility of infrastructural investments, and on the degree of integration of private capital k and social overhead capital l, either a smooth development (see Fig. 5) or a jump (see Fig. 6) will take place. An integrated and co-ordinated infrastructure policy will of course try to avoid perturbations in a regional system. Abrupt changes are more likely in case of

poorly equipped and less integrated infrastructure endowment. If a process of regional decline takes place, the behaviour of the system near l^* is not necessarily symmetric, as inertia in infrastructure policy and rigidity in indivisible infrastructure endowment may prevent the system from a direct adjustment to new circumstances. Thus, the critical limit l^{**} for a declining economy differs from the critical limit l^* during an 'upswing' (see Figures 5 and 6). The combination of Figures 5 and 6 leads to a catastrophe surface in a three-dimensional space (see Fig. 7). The latter figure reflects the existence of divergence, bimodality and hysteresis in the dynamic growth model of the economy.

2. The existence of <u>bottleneck factors</u> (congestion, e.g.) may prevent a further growth in the system, so that a removal of such a threshold limit $\hat{l}$ may be an important task of a regional development policy. In this respect, again a smooth transition (see Fig. 8) or an abrupt shift (see Fig. 9) may take place, depending again on the degree of indivisibility and/or integration of infrastructure endowment l with productive capital k. During a downswing of the economy, the threshold limit may have a different value ($\hat{\hat{l}}$) leading again to an asymmetry in the systems behaviour. Fig. 10 represents again the corresponding three-dimensional catastrophe surface. Here again divergence, bimodal behaviour and hysteresis may occur.

3. In addition to shocks caused by infrastructural investments, <u>innovations</u> (by means of R & D activities) may also lead to jumps in both the k-space and the l-space (depending on whether innovations take place in a smooth or jump-wise way). In this case, not only infrastructure l, but also productive capital k may be a splitting factor causing a discontinuity in system behaviour. The behaviour of the system after innovations (or lack of innovations) can be described by means of similar catastrophe surfaces; this will not be repeated here again. Furthermore, vintage effects in both an upswing or a downswing of the economy can easily be represented by means of catastrophe notions.

4. A final cause of discontinuities in the system concerned may be found in the planning context, especially when multiple objectives are taken into account. Suppose the existence of the following multitemporal preference function:

$$\max \omega = \int_{0}^{T} \varphi\,(c,\ 1)\ e^{-\rho t}\,dt\ , \tag{9}$$

where ρ is the social rate of discount within a time horizon of T periods. Then the following Hamiltonian H for this optimal control model can be specified:

$$H = \varphi\, e^{-\rho t} + \lambda_1\ (\sigma_1 y - \delta_1 k) + \lambda_2\ (\sigma_2 y - \delta_2 1) + \lambda_3\ (\nu^* y - \nu_1^* k - \nu_2^* 1) \tag{10}$$

If σ_1 and σ_2 are regarded as control parameters, the following optimality conditions hold for an interior solution for the motion of the system:

$$\left.\begin{aligned} \frac{\delta H}{\delta \sigma_1} &= 0 \\ \frac{\delta H}{\delta \sigma_2} &= 0 \end{aligned}\right\} \quad , \tag{11}$$

as well as the following conditions for the adjoint system:

$$\left.\begin{aligned} \dot{\lambda}_1 &= -\frac{\delta H}{\delta k} \\ \dot{\lambda}_2 &= -\frac{\delta H}{\delta 1} \\ \dot{\lambda}_3 &= -\frac{\delta H}{\delta r} \end{aligned}\right\} \tag{12}$$

Since, however, the control parameters are linear in the state space, various corner solutions may occur (see also Nijkamp and Paelinck, 1973). The feasible control space is represented in Fig. 11. For instance, suppose that the gradient of H with respect to σ_2 is larger than that with respect to σ_1, i.e.,

$$\frac{\delta H}{\delta \sigma_2} > \frac{\delta H}{\delta \sigma_1} \tag{13}$$

This implies:

$$-e^{-\rho t}\frac{\delta\varphi}{\delta c}\,y + (\lambda_2+\lambda_3\nu_2)\,y > -e^{-\rho t}\frac{\delta\varphi}{\delta c}\,y + (\lambda_1+\lambda_3\nu_1)\,y \qquad (14)$$

or :

$$\lambda_2+\lambda_3\nu_2 > \lambda_1+\lambda_3\nu_1 \qquad (15)$$

The latter condition states that the dual price of infrastructure capital plus the dual value of R & D overhead capital exceeds the dual price of directly productive capital plus the dual value of R & D private productive activities. Then the evident optimal control is :

$$\left.\begin{array}{l}\sigma_2 = 1\\ \sigma_1 = 0\end{array}\right\} \qquad (16)$$

It is clear that this extreme solution will - after some time - affect the productive capacity of the economy (and hence its income and consumption level), so that after some time a switch toward another optimal control solution will take place. This may either be an interior or a corner solution. Evidently, such 'bang-bang' strategies will cause shocks in the behaviour of the system, which may again be represented by means of the abovementioned catastrophe surfaces. Clearly, in a similar way, all other corner solutions can be analyzed. This will not be dealt with here any further.

In a multiobjective setting, one may also observe various kinds of catastrophes. Suppose the existence of multiple objective functions $\omega_1,\ldots,\omega_N$, which may include income, productive capital, social overhead capital, environmental capital, R & D capital etc. as arguments. The relative weights (or trade-offs) for these elements depend inter alia on the state of the economic system during a previous stage. This implies that, in an interactive (or learning) framework, shifts in weights may occur, which will evidently affect the decisions and hence outcomes of the system in a shockwise way (leading again to catastrophes).

Finally, it has to be added that spill-over and interaction effects in a spatial system may also lead to a transmission of shocks from one region to another, so that waves of shocks may be observed. Suppose the following regional production function which includes - in addition to k , l , and r - also contiguity effects due to innovation diffusion and infrastructure endowment in adjacent regions:

$$y_i = f_i\,(k_i\,,\, l_i\,,\, r_i\,,\, l_i^c\,,\, r_i^c) \qquad (17)$$

where the subscript i refers to region i $(i=1,\ldots,I)$ and the superscript c to contiguity effects. In an interdependent spatial system, such contiguity effects may lead to a spatial diffusion of economic growth and decline processes. Especially during a period of economic recession such a series of waves may have a deep-going effect on all regions of a spatial system leading to a spiral downswing. This can formally be described by means of similar catastrophe models. It has to be mentioned - however - that much more empirical work has to be done in the area of discontinuous regional development paths. The model developed in this section is only a first attempt to provide a more satisfactory basis for the analysis of potential drastic changes in regional growth and decline patterns. Such a model is, however, able to generate a series of growth patterns for a spatial system, so that - depending on the specific conditions of the system - the existence of equilibrium or disequilibrium processes can be studied (cf. also Andersson, 1981). In this respect, the abovementioned model may provide a starting-point for a testable analytical framework for regional development processes.

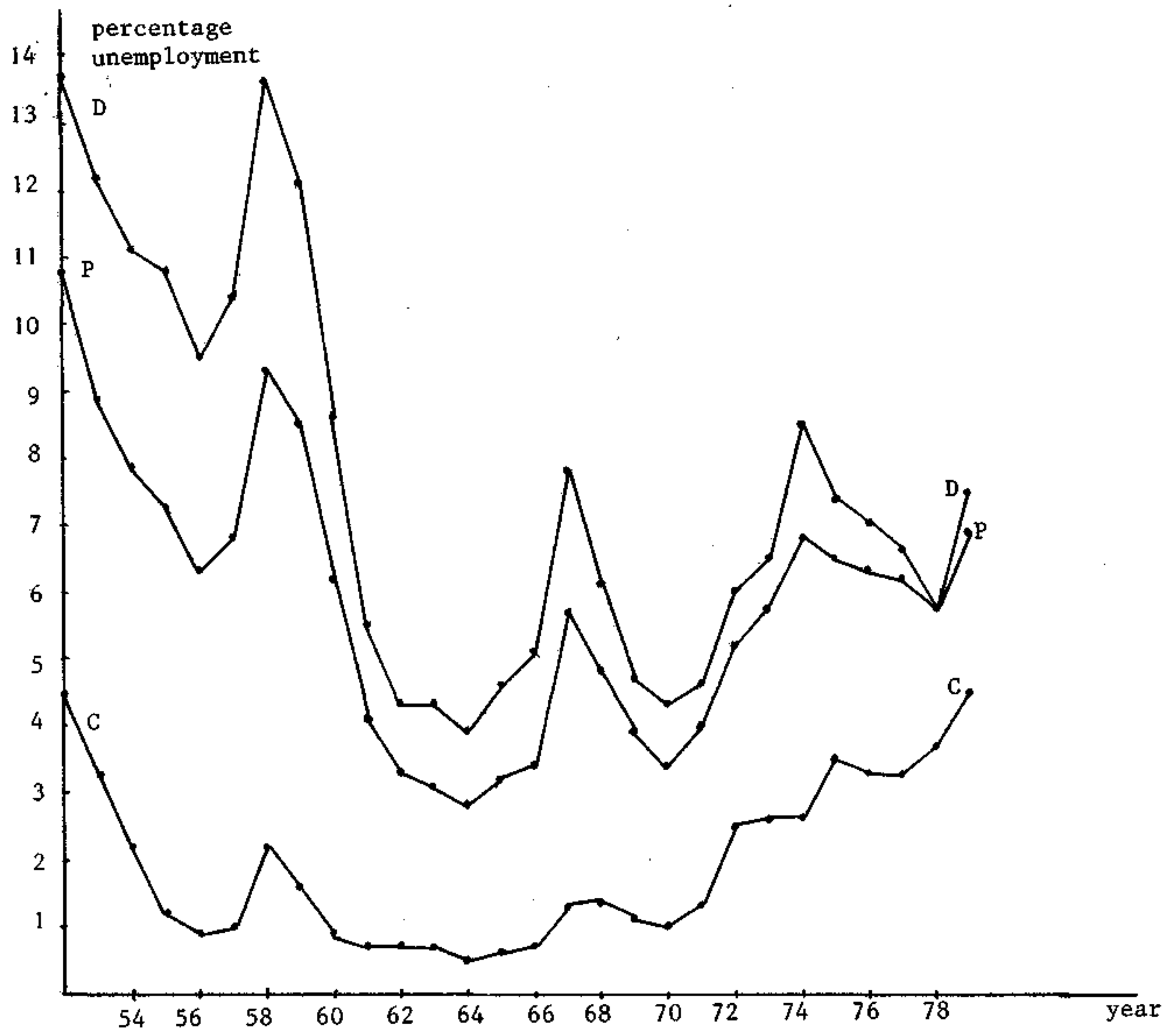

Fig. 1. Evolution of unemployment in various regions
(1952 - 1979)

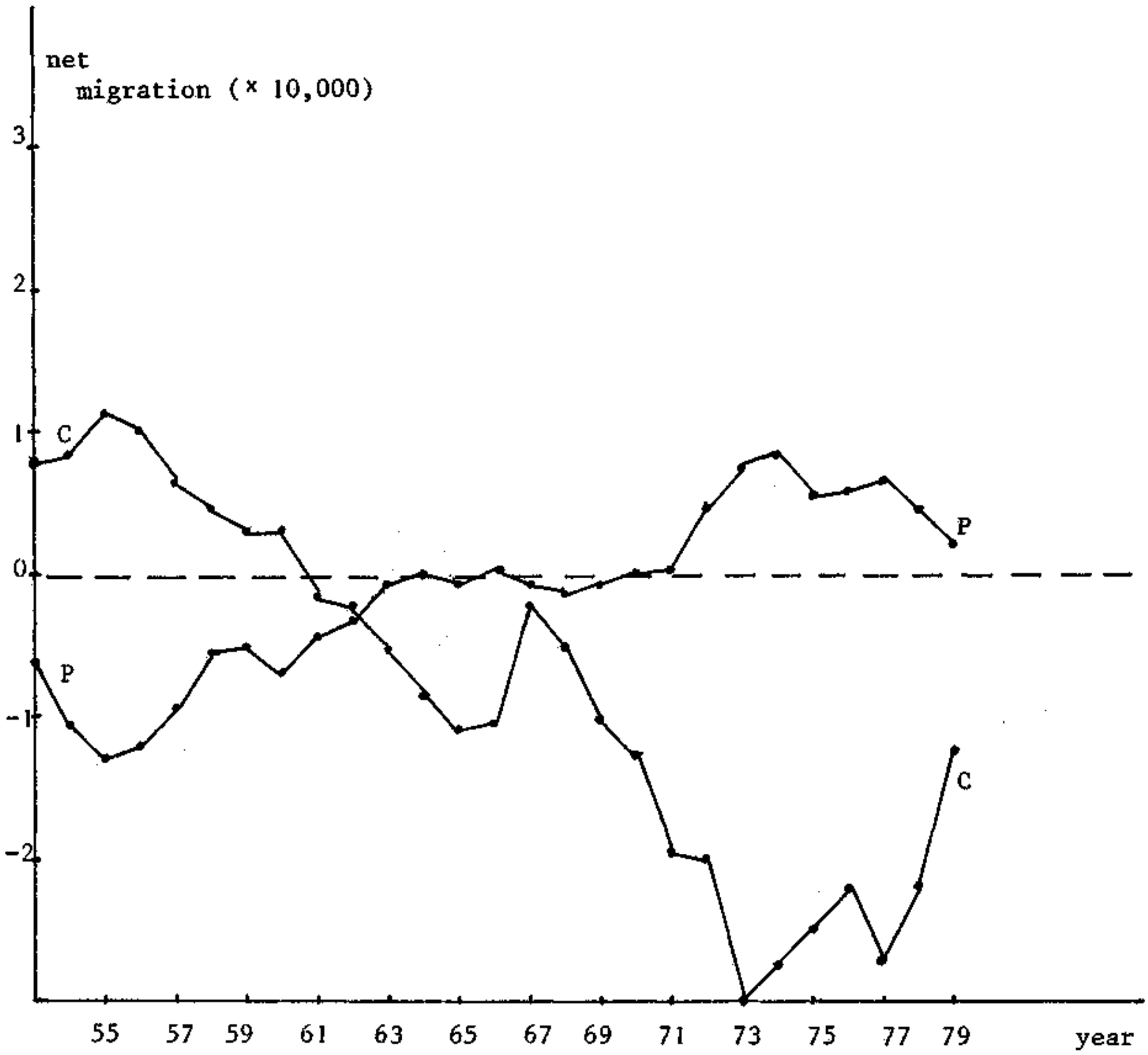

Fig. 2. Evolution of net migration in various regions (1953 - 1979)

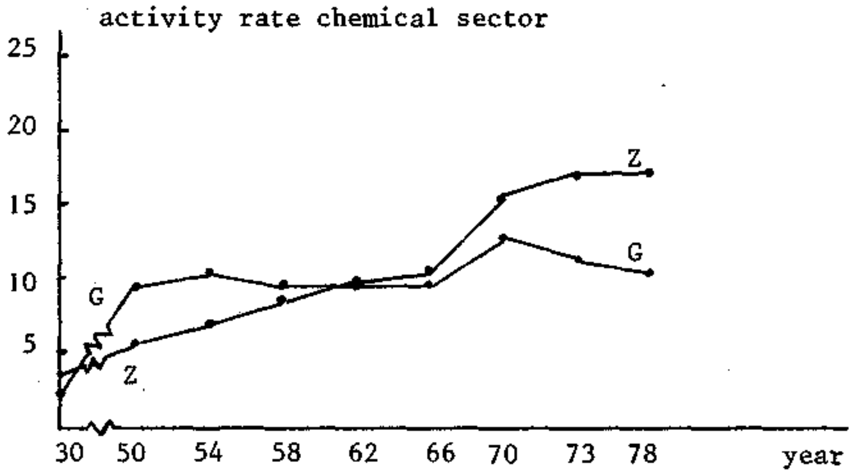

Fig. 3. Evolution of activity rate in the chemical sector

Fig. 4. Evolution of activity rate in the textile sector

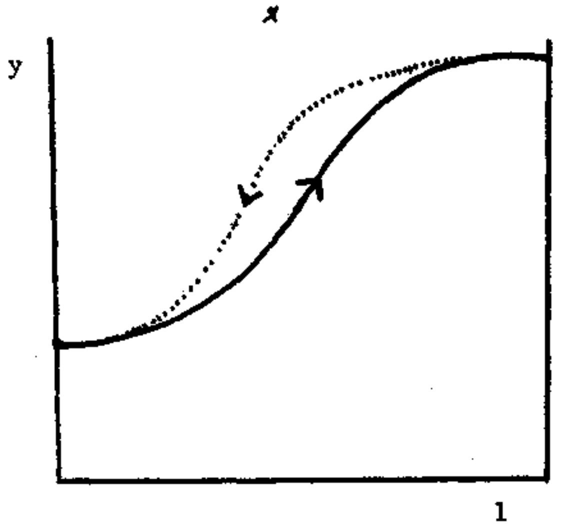

Fig. 5. Smooth threshold curve for income growth.

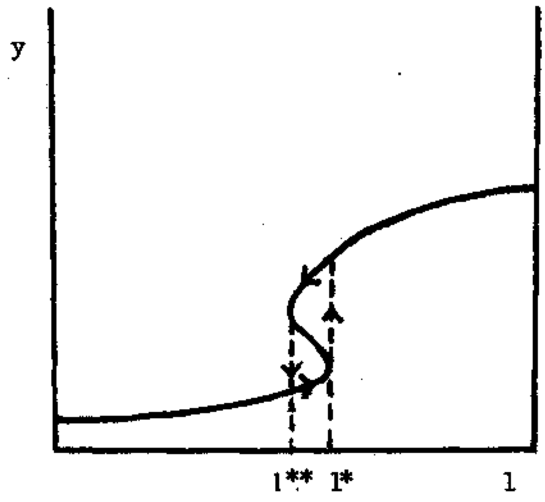

Fig. 6. Cusp threshold for income growth.

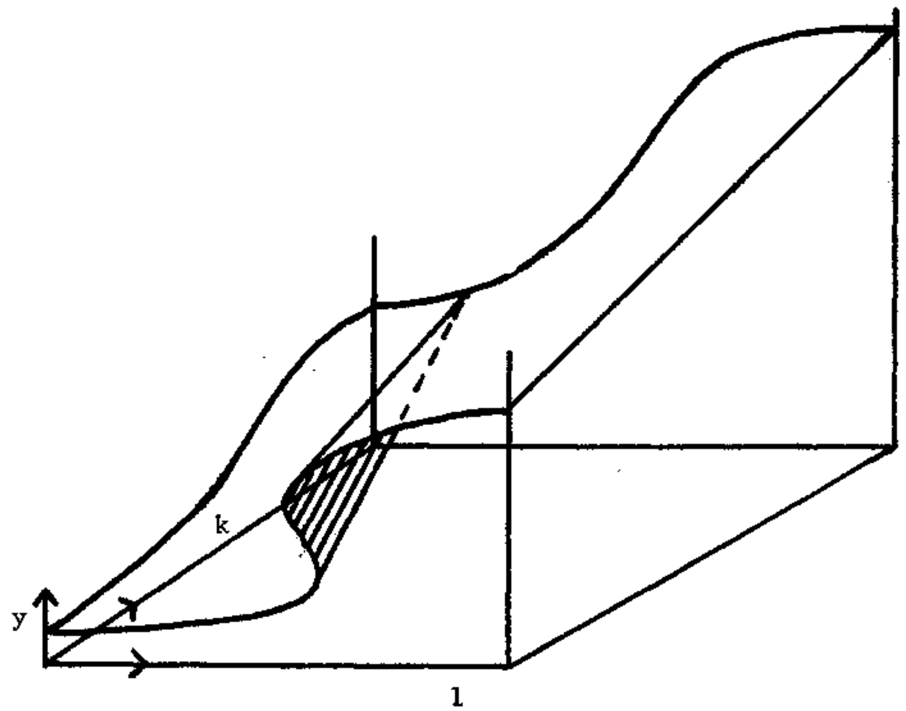

Fig. 7. Cusp catastrophe surface for income growth in case of thresholds.

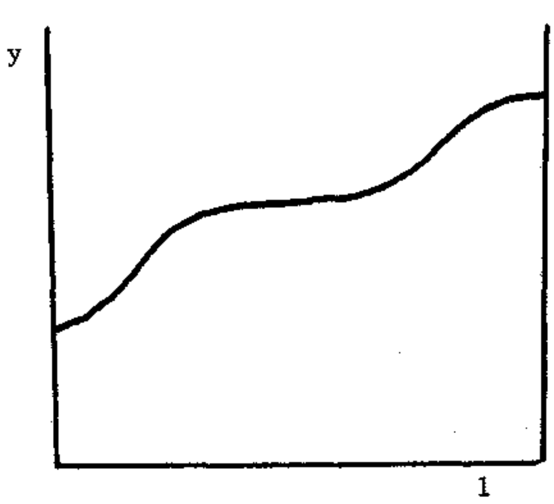

Fig. 8. Smooth bottleneck curve for income growth.

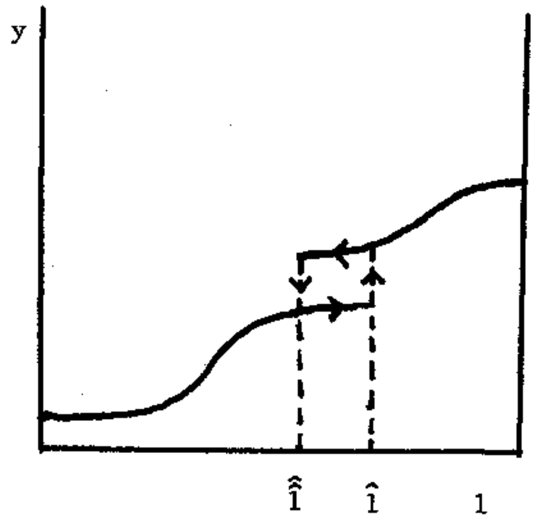

Fig. 9. Cusp bottleneck for income growth

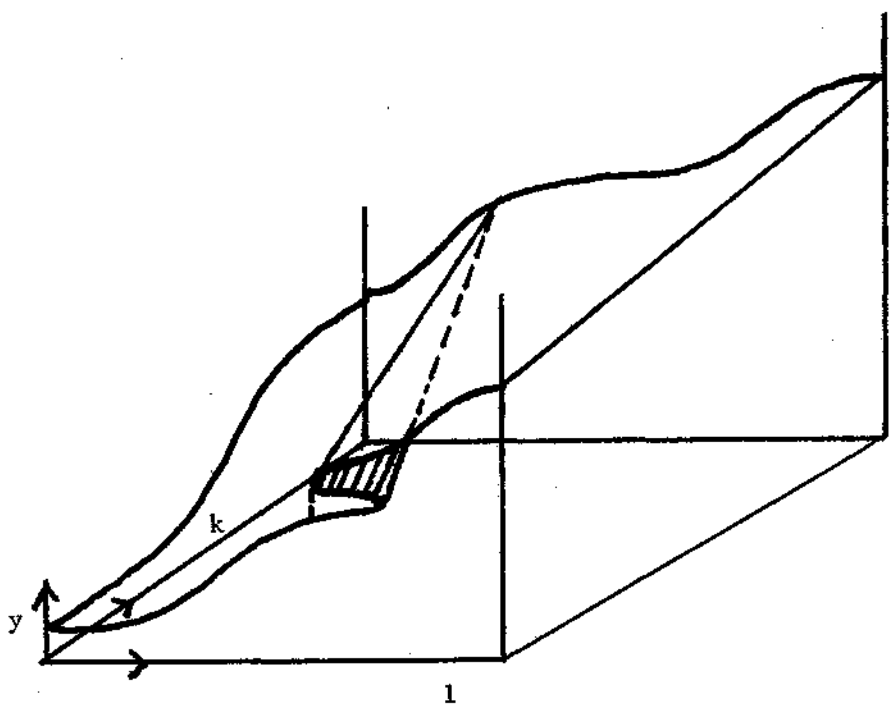

Fig. 10. Cusp catastrophe surface for income growth in case of bottlenecks.

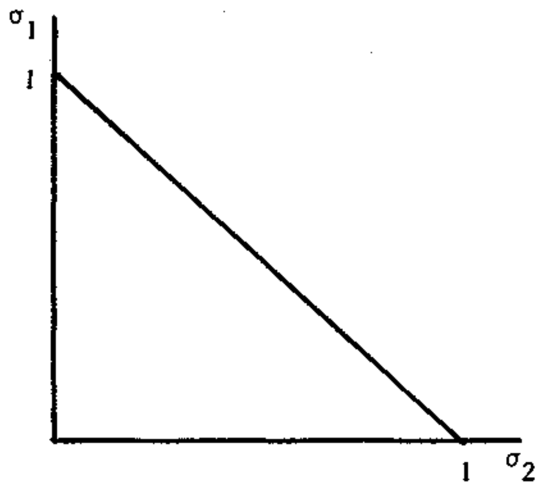

Fig. 11. Feasible control space.

Andersson, A.E., Structural Change and Technological Development, Regional Science and Urban Economics, vol. 11, no3, 1981, pp. 351-362.

Adelman, I., Long Cycles - Fact or Artifact?, American Economic Review, June, 1965, pp. 444-463.

Alonso, W.A., The Economics of Urban Size, Papers of the Regional Science Association, vol. 26, 1971, pp. 67-83.

Arrow, K.J., Optimal Capital Policy with Irreversible Investment, Value, Capital and Growth (J.N. Wolfe, ed.), Edinburgh University Press, Edinburgh, 1968, pp.1-20.

Arrow, K.J., and M. Kurz, Optimal Growth with Irreversible Investment in a Ramsey Model, Econometrica, vol.38, 1970, pp.331-344.

Batten, D.F., On the Dynamics of Industrial Evolution, Research Paper Umeå Economic Studies No.97, University of Umeå, Umeå, 1981.

Biehl, D., Determinants of Regional Disparities and the Role of Public Finance, Public Finance, vol.35, 1980, pp.44-71.

Brinner, R. and A. Alexander, The Role of High Technology Industries in Economic Growth, Data Resource, Cambridge, Mass., 1977.

Buhr, W., and P. Friedrich, eds., Lectures on Regional Stagnation, Nomos, Baden-Baden, 1981a.

Buhr, W., and P. Friedrich, eds., Regional Development under Stagnation, Nomos, Baden-Baden, 1981b.

Carlino, G.A., Economies of Scale in Manufacturing Location, Kluwer Nijhoff, Boston, 1977.

Cassetti, E., Technological Progress, Exploitation and Spatial Economic Growth: A Catastrophe Model, Dynamic Spatial Models (D.A. Griffith and R. MacKinnon, eds.), Sijthoff and Noordhoff, Alphen aan den Rijn, 1981, pp. 215-227).

Chatterji, M., Regularities in Growth Rates of Some U.S. Cities, Northeast Regional Science Review, vol.1, 1971, pp.28-62.

Clark, J., A Model of Embodied Technical Change and Employment, Technological Forecasting and Social Change, vol.16, 1980, pp.47-65.

Clark, J., C. Freeman, and L. Soete, Long Waves and Technological Developments in the 20th Century, Konjunktur, Krise, Gesellschaft (D. Petzina and G. van Roon, eds.), Klett-Cotta, Stuttgart, 1981, pp. 132-179.

Czamanski, S., Industrial Location and Urban Growth, Town Planning Review, vol.36, 1966, pp.166-180.

Delbeke, J., Recent Long-Wave Theories: A Critical Survey, Futures, vol. 13, no.4, 1981, pp. 246-257.

Duijn, J.J. van, De Lange Golf in de Economie, Van Gorcum, Assen, 1979.

Duijn, J.J. van, An Interregional Model of Economic Fluctuations, Saxon House, Farnborough, 1972.

Dijk, F. van, and P. Nijkamp, An Analysis of Conflicts in Dynamical Environmental Systems via Catastrophe Theory, Regional Science and Urban Economics, vol.10, 1980, pp.429-451.

Forrester, J.W., Growth Cycles, De Economist, vol.125, no.4, 1977, pp.525-543.

Freeman, C., The Economics of Industrial Innovation, Penguin, Hammondsworth, 1974.

Giersch, H., Aspects of Growth, Structural Change and Employment, Weltwirtschaftliches Archiv, vol.115, 1979, pp.629-651.

Graham, A.K., and P.M. Senge, A Long Wave Hypothesis of Innovation, Technological Forecasting and Social Change, vol. 16, 1980, pp.283-311.

Haustein, H.-D., H. Maier and L. Uhlmann, Innovation and Efficiency, Research Report RR-81-7, IIASA, Laxenburg, 1981.

Heertje, A., Technical Change and Economics, Man, Environment, Space and Time, vol. 1, no.2, 1981, pp.59-76.

Hirschman, A.O., The Strategy of Economic Development, Yale University Press, New Haven, 1958.

Isard, W., and P. Liossatos, Spatial Dynamics and Optimal Space-Time Development, North-Holland, Amsterdam, 1979.

Kawashima, T., Urban Optimality, Cities in Transition (P. Nijkamp and P. Rietveld, eds.), Sijthoff & Noordhoff, Alphen a/d Rijn, 1981, pp.141-156.

Kleinknecht, A., Observations on the Schumpeterian Swarming of Innovations, Futures, August 1981, pp.293-307.

Mahdavi, K.B., Technological Innovation, Beckmans, Stockholm, 1972.

Malecki, E.J., Locational Trends in R&D by large U.S. Corporations, 1965-1977, Economic Geography, vol.55, 1979, pp.309-323.

Mandel, E., Long Waves of Capitalist Development, Cambridge University Press, Cambridge, 1980.

Mass, N.J., Monetary and Real Causes of Investment Booms and Declines, Socio-Economic Planning Sciences, vol.14, 1980, pp.281-290.

Meerens,F., Lange Golven en Innovatie, Working Paper, Dept. of Economics, Free University, Amsterdam, 1981 (mimeographed).

Mensch, G., Stalemate in Technology, Ballinger, Cambridge, 1979.

Mowery, D., and N. Rosenberg, The Influence of Market Demand on Innovation, Research Policy, vol.8, 1979, pp.102-153.

Myrdal, G., Economic Theory and Underdeveloped Regions, Duckworth, London, 1957.

Nelson, R.R., and V.D. Norman, Technological Change and Factor Mix over the Product Cycle, Journal of Development Economics, vol.4, 1977, pp.3-24.

Nelson, R.R., and S.G. Winter, In Search of Useful Theory of Innovation, Research Policy, vol.6, 1977, pp.36-76.

Nijkamp, P., Perspectives for Urban Analyses and Policies, Cities in Transition : Problems and Policies, (P. Nijkamp and P. Rietveld, eds.), Sijthoff and Noordhoff, Alphen a/d Rijn, 1981, pp.67-98.

Nijkamp, P., A Multidimensional Analysis of Regional Infrastructure and Economic Development, Structural Economic Analysis and Planning in Time and Space, (A. Andersson and T. Puu, eds.), North-Holland Publ. Co., Amsterdam, 1982 (forthcoming)

Nijkamp, P., and J.H.P. Paelinck, Operational Theory and Method in Regional Economics, Gower, London, 1976.

Nijkamp, P., and J.H.P. Paelinck, Some Models for the Economic Evaluation of the Environment, Regional Science and Urban Economics, vol.3, no.1, 1973, pp.33-62.

Nijkamp, P., and C. Verhage, Cost-Benefit Analysis and Optimal Control Theory for Environmental Decisions, Environment, Regional Science and Interregional Modeling (M. Chatterji and P. van Rompuy, eds.), Springer, Berlin, 1976, pp.74-110.

Pedersen, P.O., Interaction between Short- and Long-run Development in Regions, Regional Studies, vol.12, 1978, pp.683-700.

Poston, T., and I. Stewart, Catastrophe Theory and its Applications, Pitman, London, 1978.

Pred, A.R., The Spatial Dynamics of U.S. Urban-Industrial Growth, 1800-1914, MIT Press, Cambridge, 1966.

Richardson, H.W., The Economics of Urban Size, D.C. Heath, Lexington, 1973.

Rostow, W.W., The World Economy, MacMillan, London, 1978.

Rothwell, R., Small and Medium Sized Manufacturing Firms and Technological Innovation, Management Decision, vol.16, 1979, pp.362-370.

Sveikauskas, L., Interurban Differences in the Innovative Nature of Production, Journal of Urban Economics, vol.6, 1979, pp.216-227.

Schumpeter, J.A., Business Cycles, McGraw-Hill, New York, 1939.

Terleckyj, N.A., What Do R&D Numbers Tell us about Technological Change?, Papers and Proceedings, American Economic Review, vol.70, 1980, pp.55-61.

Thomas, B., Migration and Urban Development, Methuen, London, 1972.

Thomas, B., Migration and Economic Growth, Cambridge University Press, Cambridge, 1973.

Thomas, M.D., Growth and Change in Innovative Manufacturing Industries and Firms, Collaborative Paper CP-81-5, IIASA, Laxenburg, 1981.

Thompson, W.R., The Urban Development Process, Small Cities in Transition (H.J. Bryce, ed.), Ballinger, Cambridge, 1977, pp.95-112.

Zeeman, E.C., Catastrophe Theory, Addison-Wesley, Reading, 1977.