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The transmission of knowledge spillovers and its impact on regional economic growth

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**The Transmission of Knowledge Spillovers
and its Impact
on Regional Economic Growth**

by Dirk Dohse
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ABSTRACT

Endogeneous growth theory views externalities and particularly externalities associated with knowledge spillovers as the engine of economic growth. In some influential papers (e.g. Glaeser et al. 1992) it is argued that these knowledge spillovers do not transmit costlessly over space. Rather, location and geographic proximity matter.

In the current paper a simple two country model is developed. Each country consists of a three-stage urban hierarchy: a central city (the core), a number of smaller cities and a rural hinterland. New technical knowledge originates in the core. The transmission of knowledge to the periphery and to the foreign country is impeded by geographic distance and national borders, inter alia. Depending on the relative importance of these obstacles different spatial patterns of knowledge diffusion emerge. The aim of the model is to analyze how different patterns of knowledge diffusion affect regional and national economic growth in the innovating country and in the imitating country.

JEL Classification: C15, O31, R11

INTRODUCTION

There seems to be unanimity among economists that new knowledge is one of the most important sources of economic growth. The spatial dimension of knowledge, however, is often neglected. Obviously, the costs of information transfer over large distances have been rapidly decreasing during the last decades. So, at first glance, in the age of Internet, fax and E-mail spatial aspects may seem of ever decreasing influence. This is, however, not the whole story. There are good reasons to assume that spatial proximity encourages the creation and diffusion of knowledge such that knowledge can be viewed as a special kind of a local public good: Recent empirical studies have shown that knowledge spillovers are geographically localized (Jaffe, Trajtenberg, Henderson (1993), Glaeser et al.(1992), Audretsch and Feldman (1996)). This may be due to the fact that new knowledge is often unstructured and highly complex (tacit knowledge) and can thus best be transferred

face to face (see Polanyi 1958). Furthermore, new knowledge is often produced cooperatively in joint ventures or innovation networks. In these cases the advantage of spatial proximity is not so much the reduction of information costs but the fact that only close personal relationships allow for the evolution of incentive and sanction mechanisms necessary for the keeping of the implicit cooperation contracts (Bröcker 1995).

In what follows I define knowledge as a local public good with dynamic spillover effects. In contrast to a classical (Tieboutian) local public good knowledge that originates in some region does not stick to that region but spreads over regional and national borders in the course of time. I analyze the flow of knowledge and its impact on regional growth in a simple two country model. The setting of my model is similar to the dynamic incubation model by Davelaar and Nijkamp (1991), however, the mechanisms driving knowledge diffusion and growth are quite different.

THE MODEL

There are two countries I and II producing a new, knowledge-intensive commodity X which can be used as a consumption good or as an investment good. I call country I the domestic country and country II the foreign country. Each country has a simple trichotomic spatial structure, i.e. it can be subdivided into a central region (c), an intermediate region (i) and a periphery (p). Population density is highest in the center and lowest in the periphery. New technical knowledge originates in the core regions (the centers) of the two countries. The transmission of knowledge to the periphery and to the other country is impeded by geographic distance and national borders, inter alia.

The world demand for the innovative product is given by eq. 1.

$$(1) X_t^N = X_{t-1}^N + k \cdot \left[\frac{X_{t-1}^N}{X_{\max}} \left(1 - \frac{X_{t-1}^N}{X_{\max}} \right) \right] \cdot X_{\max}$$

Let the maximum demand level (or saturation level) be X_{\max} . World demand in period t increases with the demand proportion already reached in the previous period (X_{t-1}^N/X_{\max}) and with the remaining demand potential ($(1-X_{t-1}^N/X_{\max})$).¹ The parameter k ($0 \leq k \leq 1$) measures the speed of adoption to the maximum demand level. Eq. 1 is a s-shaped function of time typical for complex and expensive innovations (see Alderman 1990 and Davies 1979 for a more detailed discussion on this topic).²

Eq. 2 states that aggregation of regional production (output in the center, in the intermediate region and in the periphery) gives national or aggregate output. Eq. 3 postulates that the sum of aggregate output in country I and country II exactly meets the world demand in each period of time.

$$(2) X_t^A = \sum_r X_{r,t}^A \quad r = c, i, p \quad X_t^{A*} = \sum_{r^*} X_{r^*,t}^A \quad r^* = c^*, i^*, p^*$$

$$(3) X_t^N = X_t^A + X_t^{A*}$$

¹ Eq. 1 is a Verhulst-type equation well-known from chaos theory and fractal geometry. Davelaar and Nijkamp (1991) work with regional demand functions of a similar type.

² Davis (1979) and Alderman (1990) call them type B innovations.

Eq. 4 gives the regional production functions which have a similar structure for all domestic and foreign regions. Regional output is a function of capital input (K), labor input (L) and the stock of knowledge (σ) available in that region in each period of time (Uzawa (1965) and Zhang (1991) use a similar production function). It is assumed that capital is perfectly mobile while labor is a fully immobile factor of production

$$(4) X_{r',t}^A = \sigma_{r',t}^\rho \cdot K_{r',t}^\beta \cdot L_{r',t}^\chi \quad r' = r, r^*$$

Since capital is perfectly mobile (interregionally and internationally) the marginal product of capital must be the same everywhere (eq. 5).

$$(5) \frac{\partial X_{c,t}^A}{\partial K_{c,t}} = \frac{\partial X_{i,t}^A}{\partial K_{i,t}} = \frac{\partial X_{p,t}^A}{\partial K_{p,t}} = \frac{\partial X_{c^*,t}^A}{\partial K_{c^*,t}} = \frac{\partial X_{i^*,t}^A}{\partial K_{i^*,t}} = \frac{\partial X_{p^*,t}^A}{\partial K_{p^*,t}}$$

As can be seen from eq. 6 the equilibrium stock of capital in each region and each period of time depends on the world demand in the respective period, on the constant distribution of labor among regions and on the time-dependent distribution of knowledge among regions.

$$(6) K_{r,t} = \left(\frac{X_i^N}{ZW_{r,t}} \right)^{1/\beta} \quad r = r, r^*$$

$$\begin{aligned} ZW_c = & \sigma_c^\rho \cdot L_c^\chi + \sigma_i^\rho \cdot L_i^\chi \cdot \left(\frac{\sigma_c^\rho \cdot L_c^\chi}{\sigma_i^\rho \cdot L_i^\chi} \right)^{(\beta/\beta-1)} + \sigma_p^\rho \cdot L_p^\chi \cdot \left(\frac{\sigma_c^\rho \cdot L_c^\chi}{\sigma_p^\rho \cdot L_p^\chi} \right)^{(\beta/\beta-1)} \\ & + \sigma_{c^*}^\rho \cdot L_{c^*}^\chi \cdot \left(\frac{\sigma_c^\rho \cdot L_c^\chi}{\sigma_{c^*}^\rho \cdot L_{c^*}^\chi} \right)^{(\beta/\beta-1)} + \sigma_{i^*}^\rho \cdot L_{i^*}^\chi \cdot \left(\frac{\sigma_c^\rho \cdot L_c^\chi}{\sigma_{i^*}^\rho \cdot L_{i^*}^\chi} \right)^{(\beta/\beta-1)} \\ & + \sigma_{p^*}^\rho \cdot L_{p^*}^\chi \cdot \left(\frac{\sigma_c^\rho \cdot L_c^\chi}{\sigma_{p^*}^\rho \cdot L_{p^*}^\chi} \right)^{(\beta/\beta-1)} \end{aligned}$$

($ZW_i, ZW_p, ZW_c, ZW_{i^*}$ and ZW_{p^*} are analogously determined).

Eq. 7 shows that regional investment depends on the entrepreneur's expectations with respect to the world demand of the next period, the expected distribution of knowledge (and labor), the given depreciation rate and the given capital stock of the respective region.

$$(7) I_{r,t} = \frac{X_{t+1}^N}{ZW_{r,t+1}^e} - (1-\delta) \cdot K_{r,t}$$

The investments are taken in such a way that a given return to capital is reached which is exogeneously determined by the

return to financial assets. We assume rational expectations such that the expected return to capital is realized in each region and each time period.

THE FLOW OF KNOWLEDGE

New technological knowledge originates in the core regions (the centers) of the two countries where population density is highest. The initial stock of knowledge in the central regions ($\bar{\sigma}_{c,0}$ and $\bar{\sigma}_{c^*,0}$, respectively) is given exogeneously. It grows in a process of learning by doing and learning by imitation as described by equations 8 and 11.

$$(8) \sigma_{c,t} = \bar{\sigma}_{c,0} + \left(\sum_{t'=0}^{t-1} I_{c,t'} \right)^{\alpha} - h \cdot \sigma_{c,t-1} + \frac{1}{1+f_t} \cdot (\sigma_{c^*,t-1} - \sigma_{c,t-1})$$

if $\sigma_{c^*,t-1} > \sigma_{c,t-1}$

$$= \bar{\sigma}_{c,0} + \left(\sum_{t'=0}^{t-1} I_{c,t'} \right)^{\alpha} - h \cdot \sigma_{c,t-1} \quad \text{otherwise.}$$

Following the argumentation in Arrow (1962) cumulative investment is used as an index of *learning by doing* since „ [e]ach new machine produced and put into use is capable of changing the environment in which production takes place, so that learning is taking place with continually new stimuli.“(Arrow 1962, p.157) *Learning by imitation* - the last term on the right hand-side of eq. 9 - only takes place in the domestic center if the foreign center has a technological advantage ($\sigma_{c^*t} > \sigma_{ct}$).

The flow of knowledge between the two countries is impeded by f_t , a ‘frontier’ factor capturing social, cultural and lingual differences between the two countries. It is assumed that these impediments slowly decrease in the period under consideration. Furthermore, equation 8 allows for the possibility of knowledge depreciation with h being the annual depreciation rate.

$$(9) \sigma_{i,t} = (1-h) \cdot \sigma_{i,t-1} + \frac{1}{d_{i,c}} \cdot (\sigma_{c,t-1} - \sigma_{i,t-1}) \quad t=2, \dots, T, \sigma_{i,1} = 0$$

$$(10) \sigma_{p,t} = (1-h) \cdot \sigma_{p,t-1} + \frac{1}{d_{p,c}} \cdot (\sigma_{c,t-1} - \sigma_{p,t-1}) \quad t=2, \dots, T, \sigma_{p,1} = 0$$

Eqs. 9 and 10 characterize the flow of knowledge within the domestic country. The stock of knowledge in the intermediate region grows the faster the greater the 'knowledge-gap' between the center and the intermediate region and the less the mean distance ($d_{i,c}$) between them. An analogous assumption is made for the spread of knowledge from the center to the peripheral region, however, the mean distance from the periphery to the center is greater than the mean distance from the intermediate region to the center.

$$(11) \sigma_{c^*,t} = \bar{\sigma}_{c^*,0} + \left(\sum_{j=0}^{t-1} I_{c^*,j} \right)^{\alpha^*} - h \cdot \sigma_{c^*,t-1} + \frac{1}{1+f_t} (\sigma_{c,t-1} - \sigma_{c^*,t-1})$$

if $\sigma_{c,t-1} > \sigma_{c^*,t-1}$

$$= \bar{\sigma}_{c^*,0} + \left(\sum_{j=0}^{t-1} I_{c^*,j} \right)^{\alpha^*} - h \cdot \sigma_{c^*,t-1} \quad \text{otherwise.}$$

$$(12) \sigma_{i^*,t} = (1-h) \cdot \sigma_{i^*,t-1} + \frac{1}{d_{i^*,c^*}} (\sigma_{c^*,t-1} - \sigma_{i^*,t-1})$$

$$t = 2, \dots, T \quad \sigma_{i^*,1} = 0$$

$$(13) \sigma_{p^*,t} = (1-h) \cdot \sigma_{p^*,t-1} + \frac{1}{d_{p^*,c^*}} \cdot (\sigma_{c^*,t-1} - \sigma_{p^*,t-1})$$

$$t = 2, \dots, T \quad , \sigma_{p^*,1} = 0.$$

Equation 11 characterizes the process of learning by doing and learning by imitation in the foreign center. Equations 12 and 13 postulate that the flow of knowledge within the foreign country is analogous to the flow of knowledge within the domestic country, being determined only by the technological gap and by the mean distance to the foreign center.

A REFERENCE SCENARIO

It is assumed that the domestic country has a higher initial stock of knowledge than the foreign country ($\bar{\sigma}_{c,0} > \bar{\sigma}_{c^*,0}$). In all other respects there is perfect symmetry between the two countries: The efficiency of learning by doing, the efficiency of learning by imitation, the mean distances between the center

and the intermediate region on the one hand and the periphery on the other hand, the partial production elasticities of labor and capital as well as the depreciation rates are the same for both countries. For mere convenience we assume that while population density is highest in the centers and lowest in the peripheries the absolute size of the immobile labor force is the same in all domestic and foreign regions. This assumption is given up later.

Table 1 shows the parameters that were used for the calculation of the reference scenario.

In this reference scenario there is no path dependence at all (**diagram 1**). Although the domestic center has an initial advantage (an initially higher stock of knowledge capital) a marginal value analysis shows that for $t \rightarrow \infty$ there is perfect convergence of regional output (as well as output per head). This is not too surprising since knowledge is created with decreasing returns and spreads perfectly in the course of time.

We turn now to some sensitivity analysis investigating the dynamics resulting from parameter changes.

SOME COMPARATIVE DYNAMICS

An increased capital productivity

An increase in the partial production elasticity of capital (β) implies that a given world demand can be satisfied with less factor input. Since labor supply is fully inelastic capital and knowledge have to adapt. This adaption process can only be brought about by a reduction in investment since investment determines both the stock of capital and the stock of knowledge. A reduction in investment leads to less knowledge creation and diffusion as production becomes more capital intensive and less knowledge intensive. So, it takes a longer time span to make up for an initial advantage in the stock of knowledge or, to put it a little differently, the speed of convergence decreases if capital productivity increases.

Depreciation of knowledge

Considering the possibility of knowledge depreciation in the course of time has a twofold effect: Convergence between the two countries is accelerated whereas regional convergence within each country is retarded. The explanation is that depreciation of knowledge accelerates the use up of the domestic centers' initial advantage such that the foreign center needs less time to close the knowledge gap. Or, to put it differently: Newly created knowledge becomes relatively more important than the initial endowment with knowledge. For the same reason the intermediate and peripheral regions are unable to catch up with the centers if knowledge depreciation is high because they cannot create new knowledge themselves but have to appropriate the knowledge produced elsewhere (in the centers) in an indirect and time-consuming fashion (**diagram 2**).

Regional differences in the size of the labor force

Up to now we have assumed that the size of the labor force is the same in all regions although the population density in the centers is highest and the population density in the periphery is lowest. If we allow for different sizes of the labor force the results depend on the parameters χ and β . If we have increasing returns to scale in labor and capital input ($\chi + \beta > 1$) the output per head is the higher the higher the size of the regional labor force. The opposite is true if we have decreasing returns to scale. Only in the constant returns case ($\chi + \beta = 1$) is output per head independent of the regional population size. **Diagram 3** shows the case in which the size of the labor force in the centers is three times the size of the labor force in the periphery and 1.5 times the size of the labor force in the intermediate regions.

A higher efficiency of learning by-doing in the foreign country

If $\alpha < \alpha^*$ learning-by-doing in the foreign country is more efficient than learning by-doing in the domestic country because the same aggregate investment leads to a higher stock of knowledge. As can be seen from **diagram 4** a higher efficiency of learning by-doing in the foreign country leads ceteris paribus to a permanently higher output in the foreign country.

There is, however, a limiting case in which there is a tendency towards convergence in spite of a different efficiency of learning by-doing in the two countries: If the frontier factor f_t approaches zero learning by imitation becomes almost perfect. The lagging country is able to catch up even if its capacity of learning by-doing is permanently below the other countries' capacity. So, a higher efficiency of learning by-doing is sufficient for a permanent advantage if - and only if - integration between the two countries is less than perfect.

An increased speed of adoption

An increase of the adoptiveness parameter k implies a higher speed of knowledge creation since higher investments in earlier periods are necessary to meet the rapidly increasing world demand. The country with the higher efficiency of learning by-doing profits most since production becomes more knowledge intensive.

The possibility of historical lock in

Even if the efficiency of learning by-doing is the same in both countries an initially higher stock of knowledge in one country can matter (lead to a permanent advantage) under very special circumstances: if k is high such that the saturation level is reached relatively early, f is high such that learning by imitation plays only a minor role, α (the efficiency of learning by-doing) is low and capital productivity β is high such that relatively little investment is needed to satisfy the maximum demand level an initially higher stock of knowledge in the domestic country will lead to a permanently higher output in this country (**diagram 5**).

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Table 1

| | domestic country | foreign country |
|--|------------------|-----------------|
| initial stock of knowledge in the center | 1 | 0,1 |
| mean distance between center and intermediate region | 5 | 5 |
| mean distance between center and periphery | 10 | 10 |
| efficiency of learning by doing | 0,5 | 0,5 |
| depreciation rate on capital | 0,5 | 0,5 |
| depreciation rate on knowledge | 0 | 0 |

| | |
|----------------------------------|---|
| world demand of the first period | 1 |
| maximum demand level | 100 |
| adoptiveness parameter | 0,2 |
| frontier factor f_1 | $\max\{[f_0 - \epsilon t]; 5\}$ |
| initial frontier factor f_0 | 25 |
| partial production elasticities: | $\beta=0,4$ $\chi=0,4$ $\rho=0,7$ |

diagram 1

The reference scenario

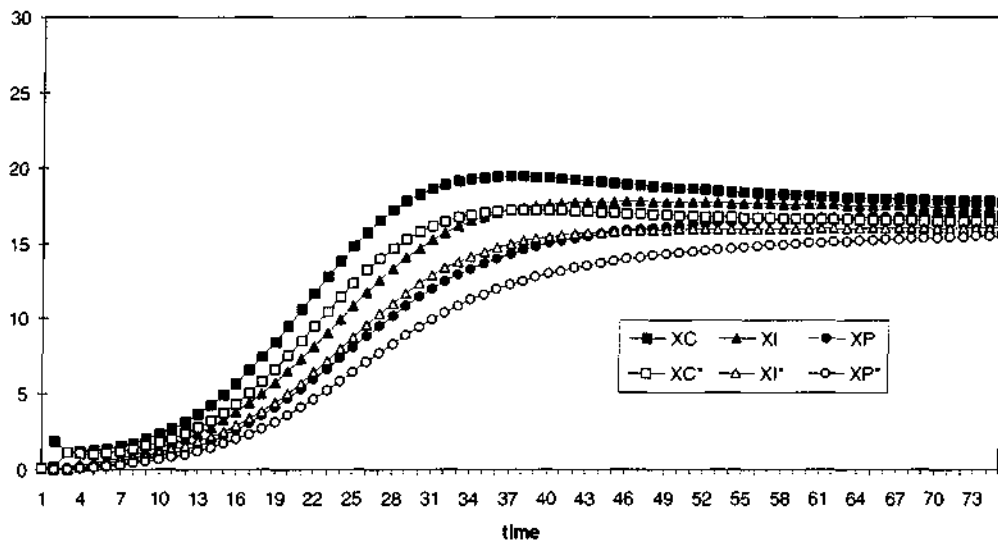


diagram 2

depreciation of knowledge

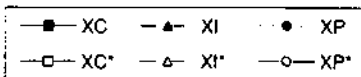
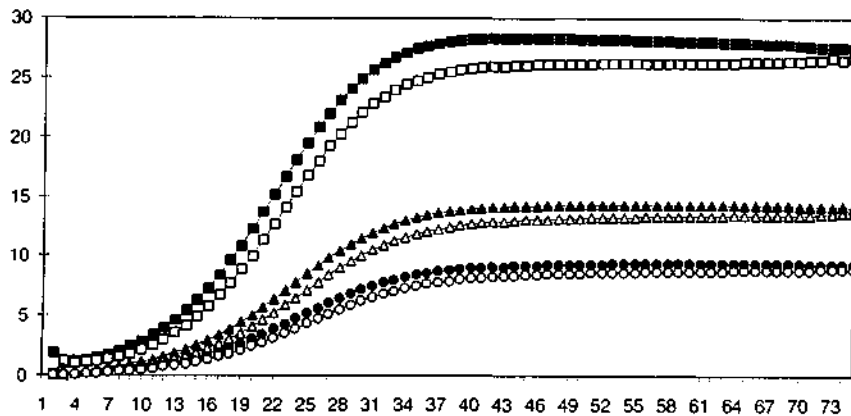


diagram 3a

An uneven size of the labor force -
Output per head in the constant returns case

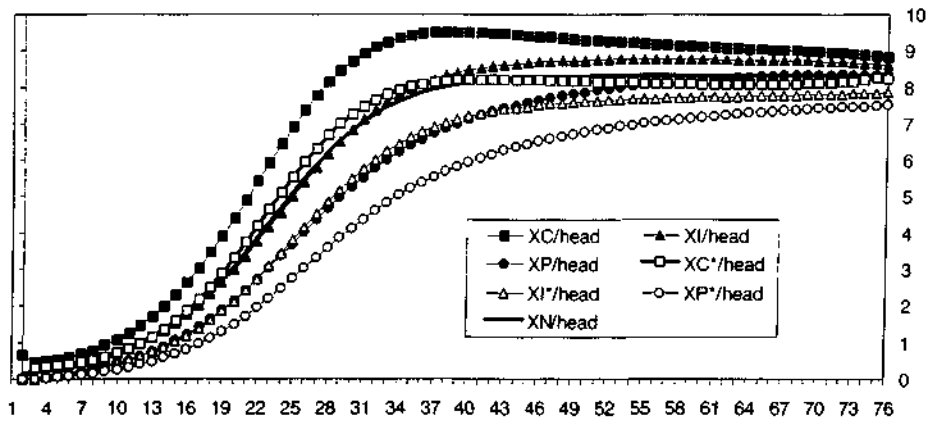


diagram 3b

Output per head in the decreasing returns case

25

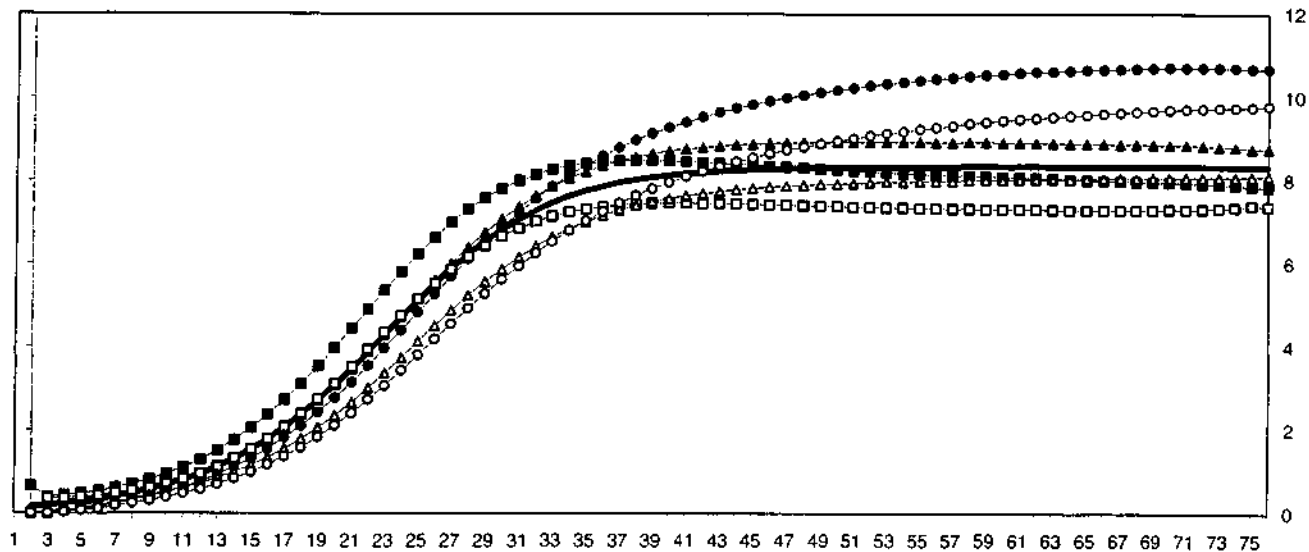


diagram 4

A higher efficiency of learning
by doing in the foreign country

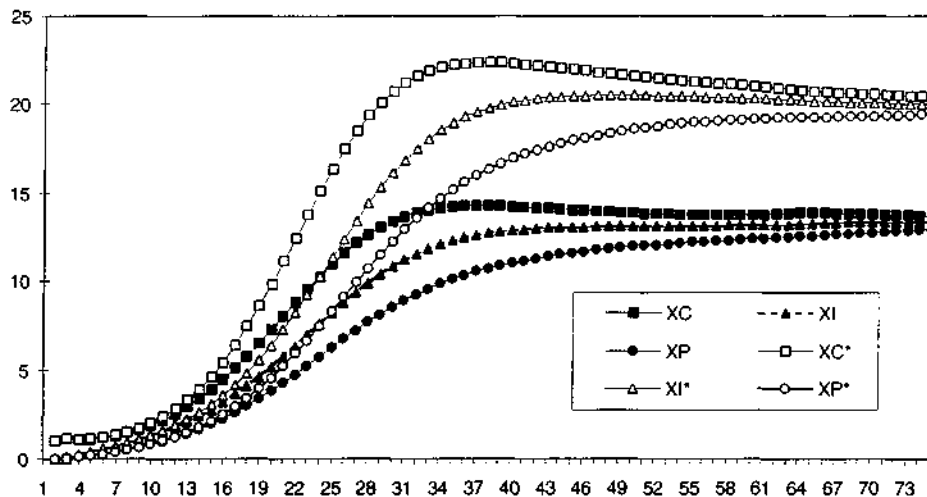


diagram 5

Historical 'lock in'

