

Product Differentiation by Bundling Standard Good and Innovative Knowledge. Technological Transfers in the German Plastics Industry from the 1930s to the 1970s¹

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1 Introduction

1.1 The innovation capital of national industries. Since the Second World War in every nation in the OECD there have been particular industries which have dominated international markets for a surprisingly long time (DOLLAR, WOLFF, 1993). I will argue in this paper that this finding can be explained by those industries' comparatively superior capability to innovate. This hypothesis contradicts the often-used assumption that foreign competitors can easily imitate both technological and economic know-how. However, I suspect that the long-term predominance of national industries in international Schumpeterian competition³ tends to justify the opposite assumption that an important part of the capability of an industry to innovate is deeply rooted in its national location and in the people working there. That is why recent surveys (PORTER, 1990, NELSON, 1993) explain the outstanding international Schumpeterian

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³ The term "Schumpeterian competition" combines all entrepreneurial strategies which try to increase profits and market shares by using innovative products, innovative methods or innovative organizations. See SCHUMPETER, 1952, pp. 100-103.

competitiveness of those national industries by the superiority of “national systems of innovation”, thereby neglecting the fact that both internationally successful and scarcely competitive industries coexist in highly developed economies. I claim in this paper that the capability of a national industry to innovate is less based on national peculiarities than on an intangible industry-specific asset called “innovation capital”⁴, which means the part of the human capital of its personnel which enables a firm or industry both to develop inventions at the respective technological forefront and to transform them into economically successful innovations (FREEMAN, SOETE, 1997, p. 202).

To elaborate the meaning of this term I will take a closer look at the innovation process of a firm in which innovation capital serves as an input. It is divided into the planning phase, the R&D phase, and the marketing phase (STREB, 2003c, p. 31). In the planning phase, managers have to decide which of the proposed R&D projects will be carried out without exactly knowing their actual future outcome. That is why the probability of making wrong decisions is high.⁵ The technological uncertainty will be reduced if the firm has already completed some R&D projects in the same area of the technological frontier. In this case, the information obtained from the finished R&D work builds up to technological innovation capital which can be used to assess the current R&D projects. However, technological innovation capital only helps to predict technological results. The managers have also to know whether there is a potential market demand for the possible inventions. This economic uncertainty can be diminished by information obtained within established inter-industry networks which are part of a firm’s economic innovation capital. By learning about actual problems and needs of downstream industries, upstream industries can tell which kind of inventions will be successful innovations (LUNDVALL, 1988). It is also possible that an upstream industry uses the inter-industry network to transfer innovative knowledge to downstream industries, thereby ensuring they will be long-term customers. These flows of innovative knowledge

⁴ TEECE and PISANO (1994) use the term “dynamic capabilities” in a similar meaning.

⁵ PAVITT (1991, p. 42) estimates that only about 10% of all R&D projects will finally lead to a market success.

within inter-industry networks can lead to clusters of national industries being highly competitive in international markets. We will discuss this case in great detail for the example of the West German plastics industry.

After deciding which R&D projects will be carried out, the R&D phase of the innovation process begins: the R&D staff of the firm actually try to discover a new invention. The probability of success of this attempt will be increased by using already existing methods and heuristics which are based on past experiences and are often tacit knowledge (POLYANI, 1966, SENKER, 1995). That is why competitors can hardly imitate this kind of specific knowledge in the short run. If the R&D phase has ended with the development of an invention, the marketing phase will start: the firm now tries to build up a market for its new product. We will see that for this the economic innovation capital plays a crucial role again.

No matter whether a particular innovation process eventually results in a successful innovation or not, the firm will gain new information which will add to the stock of already existing innovation capital. This growing innovation capital may enable the firm both to develop innovations in the technological neighbourhood of familiar products and to imitate innovations of competitors fast (STREB, 2001). The chain of innovations within this limited but progressing field of knowledge will be called the technological path. National industries which enter an established technological path later lack the innovation capital of the first-movers. This means a competitive disadvantage which cannot easily be offset. While laggards are trying to catch up by gaining their own specific knowledge, first-movers themselves are building up additional innovation capital which is used to develop further innovations beyond the technological and economic horizon of the laggards.⁶ This especially explains why particular national industries can maintain their lead in Schumpeterian competition over a long time.

1.2 The international competitiveness of the West German plastics industry. The West German plastics industry is a national cluster which

⁶ FUDENBERG *et al* (1983, pp. 5-9) show for patent races, i.e. for the formation of technological innovation capital, that laggards who cannot hope to catch up drop their own R&D projects.

includes machine makers specialized in plastic manufacturing machines, chemical firms producing plastic materials, and plastics manufacturers. Table 1 shows that these three subindustries impress due to their comparatively high shares in world exports.

In 1980, for example, the average share of West Germany's economy in world exports was 9.6 percent whereas the respective numbers for the makers of plastics manufacturing machines, the plastics producers, and the plastics manufacturers came to 35.1 percent, 21.7 percent and 21.5 percent. What is more, the shares in world exports of the makers of plastics manufacturing machines and the plastics producers also exceeded those of their generic one-digit industries that were known for their outstanding international competitiveness.

However, the West German plastics producers' above-average losses of shares in world exports in the 1970s seems to indicate that this subindustry had already passed the peak of its world market domination at the beginning of this decade. Table 2 confirms these findings.

Table 2 illustrates how the accumulated exports of the eight most important plastics exporters were distributed amongst them at any one time. The development can be subdivided in two periods. In the first period (1950-1970), the founders of the European Coal and Steel

TABLE 1. Shares in world exports of some selected West German industries, 1971 and 1980^a

West German industries	SITC II ^b	Shares in world exports	
		1971	1980
National economy		11.3%	9.6%
Chemical industry	5	18.7%	16.7%
Producers of polymerized plastic materials	583	25.6%	21.7%
Machine and vehicle industry	7	17.8%	16.8%
Producers of rubber and plastics manufacturing machines	72842	37.7% ^c	35.1%
Plastics manufacturers	893	19.9%	21.5%

^a United Nations. *Yearbook of International Trade Statistics*. New York.

^b Standard International Trade Classification, Second Revision.

^c This number refers to the year 1978 in which the share in world exports of this subindustry was published for the first time.

TABLE 2. The distribution of the accumulated exports of the eight most important plastics exporters, 1952-1985

Year	Belgium/ Luxem- bourg ^a	West Germany	France	Great Britain	Italy	Japan	Nether- lands	USA
1952 ^b	2.5%	14.4%	3.1%	30.4%	2.0%	1.2%	3.0%	43.3%
1957	1.8%	23.5%	3.7%	20.6%	5.6%	1.8%	4.6%	38.4%
1962	2.8%	24.6%	6.0%	16.6%	11.3%	5.7%	5.9%	27.1%
1967 ^c	3.5%	27.6%	6.6%	10.2%	12.2%	12.4%	7.4%	20.0%
1970	6.2%	27.7%	7.5%	7.6%	8.7%	16.7%	10.1%	15.5%
1975	9.8%	26.9%	10.0%	7.3%	9.5%	13.0%	12.8%	10.7%
1980	12.4%	25.2%	12.1%	7.3%	8.8%	8.2%	11.9%	14.1%
1985	12.2%	25.2%	12.3%	6.4%	8.2%	10.1%	12.3%	13.4%

^a 1952 - 1962 without Luxembourg.

^b 1952 - 1962 plastic materials in tons, see Hufbauer, G.C., *Synthetic Materials and the Theory of International Trade*, 1966, London p. 129.

^c 1967 - 1985 polymerized plastic materials in 1000 US-\$, see United Nations, *Yearbook of International Trade Statistics*, New York.

TABLE 3. Prices for polyvinylchloride, high pressure polyethylene and polystyrene in West Germany, Great Britain and the USA, 1955 and 1960, in German marks (DM) per kilogram

Plastic materials	Year	West Germany	Great Britain	USA
DM per kilogram				
Polyvinylchloride	1955	2.25	2.25	3.20
	1960	1.75	1.65	1.85
High pressure polyethylene	1955	5.40	4.10	3.75
	1960	3.00	2.70	2.40
Polystyrene	1955	3.00	3.35	2.70
	1960	2.10	2.60	1.60

^a Freeman, Christopher, "The Plastics Industry: A Comparative Study of Research and Innovation." *National Institute Economic Review* 26: 30, 1963.

Community and Japan improved their market position at the expense of the United States and Great Britain whose combined share fell from nearly 74 percent to 23.1 percent in these two decades. In particular, West Germany became market leader. In the second period (1970-1985), the shares in plastic material exports of Belgium/Luxembourg and France kept on increasing while the respective West German numbers were

stagnating. It is also noteworthy that the United States have been able to recover lost ground since the mid-1970s.

Table 3 shows that West Germany's rise to become the world's largest exporter of plastic materials after the Second World War cannot be explained by comparatively low prices. It rather verifies the exceptional innovating capacity of the German plastics producers who communicated their innovative knowledge to the West German machine makers and plastics manufacturers, thereby creating the outstanding international competitiveness of the West German plastics industry documented in Table 1.

The opening up of the technological path of plastics in Germany was originally caused by the search for a natural rubber substitute which as a by-product led to the invention of important plastic materials in the technological neighbourhood of the synthetic rubber BUNA S:⁷

1. Scientists of the chemical firm BASF discovered in 1930 that styrene needed for BUNA S can be polymerized to the plastic material polystyrene too.
2. The method of emulsion polymerization also developed in the synthetic rubber research programme was used to produce the plastic material polyvinylchloride by BASF in 1931.
3. In the 1930s, BUNA S induced the building up of production capacities for ethylene which is a raw material for styrene. After the Second World War these capacities facilitated the fast imitation of high-pressure polyethylene, a plastic material developed by British ICI in 1937. What is more Hoechst discovered a method to produce low-pressure polyethylene in 1955.

This survey demonstrates that the synthetic rubber programme deeply influenced the accumulation of technological innovation capital in the German plastics industry. But this is ex-post-knowledge which German chemical firms did not possess in the early 1930s. Because of the low

⁷ Further plastics inventions found in the technological neighbourhood of the synthetic rubber BUNA S were foamed polystyrene, latexes made from butadiene, styrene and acrylonitrile, a synthetic fibre based on polyacrylonitrile and, last but not least, polyurethane.

market price of natural rubber in this period, chemical firms hesitated to build up production capacities for synthetic rubber. This invention did not seem to be successful in economic terms (STREB, 2003, pp. 39-40). That is why the German plastics industry owed a good deal of their early innovation capital to the National Socialist government's demand for synthetic rubber which helped to overcome this economic uncertainty. The National Socialists contributed to the expenses of R&D and plant construction and, what is more, guaranteed to purchase a certain amount of synthetic rubber at a fixed price.⁸ Because of these guarantees important materials in plastics production (acetylene, acrylonitrile, butadiene, ethylene, styrene) were transferred from research laboratories to large-scale industrial production which, through "Learning by doing" (ARROW, 1962), accelerated the accumulation of technological innovation capital in the German plastics industry.

In the following sections we will turn to the economic innovation capital of the German plastics industry which was needed to transform the plastics inventions mentioned above into successful market innovations. We will concentrate on the plastics producers who were involved in strategic battles with two different groups of participants of their market. First they tried to relax price competition from cheaper foreign plastics suppliers by bundling standard plastic material and innovative knowledge. Secondly, they strove to avoid opportunistic behaviour on the part of the plastics manufacturers by repeated technological transfers.

2 Technological cooperation in inter-industry networks

2.1 Product differentiation by bundling standard good and innovative knowledge. In oligopolistic price competition a firm with comparatively high production costs will be pushed out of the market by more efficient suppliers who may set their prices just below its marginal costs (TIROLE, 1988, pp. 210-211). In the 1950s, it was the West German plastics

⁸ See "Contract about building up the synthetic rubber plant BUNA I at Schkopau from 1937", HOECHST ARCHIVES TEA Akten 1446-1457. For a general discussion of the economic incentives of the National Socialist procurement contracts, see STREB, STREB (1998).

producers who were being threatened by this possibility since they used an inferior technology, producing plastic materials from coal instead of from oil like their American competitors (STOKES, 1994). After making up for this shortcoming by imitating the superior technology, the West German plastics producers had to face the fact that in the 1960s Italian and Dutch firms began to profit from large domestic deposits of natural gas serving as a comparatively cheap raw material for plastic materials (AFTALION, 1991). It was not possible to remove this kind of locational disadvantage.

However, I suspect that in the period after the Second World War the West German plastics producers were able to avoid price competition from cheaper foreign suppliers through product differentiation. In general, product differentiation means that each firm produces an otherwise homogenous product with a special quality which differs from the qualities offered by its competitors. If consumers have unequal incomes and preferences, this strategy will enable each supplier to occupy his own market niche, thereby achieving the ability to alter profitably prices away from marginal costs (SHAKED, SUTTON, 1982). Normally the characteristics defining the quality level are inextricably linked with the product. On the other hand, it is also imaginable that a firm strives to increase the quality of its standard product by bundling⁹ it with an independent second product. This is what the West German plastics producers did when offering the plastics manufacturers standard plastic materials combined with information about innovative plastics applications.

The creation of this kind of knowledge took place in plastics producers' special service departments which were an important invention of the German chemical industry. Since the imitation of this organizational novelty also needed time, foreign competitors were not able to supply similar knowledge in the short term. Therefore the West German plastics producers had a temporary monopoly for this customer service. However, because of the comparatively high transaction costs of the isolated market exchange of information (TEECE, 1980, pp. 226-

⁹ For a general discussion of the "bundling" strategy see ADAMS, YELLEN (1976).

230), it is very difficult to use such a monopoly for rent extracting. Since third persons are hardly able to judge whether information transfer has been correctly carried out or not, the plastics manufacturers are very tempted to refuse the economic service after receiving the innovative knowledge. Bundling information and plastic material makes this kind of cheating not impossible but more difficult as the delivery of tangible goods can be observed more easily than the transfer of immaterial know-how.¹⁰ What is more, if the customers prefer this combination to the sole plastic material, product differentiation by bundling can allow the supplier to put through a higher price than his competitors.

Let us summarize: by bundling, the West German plastics producers avoided at least some of the problems arising from the locational disadvantages of the domestic production and from the high transaction costs of exchanging information. However, this strategy did not promise permanent success. Instead the West German suppliers had to expect that international price competition would increase again as soon as the cheaper foreign plastics producers would have learned to offer innovative knowledge too.

In the next section we will have a closer look at the general economic conditions which are necessary for successfully selling the bundle of standard plastic material and innovative information. I have christened the strategic interaction between the producer and the fabricator of plastic materials the "game of technological cooperation".

2.2 The game of technological cooperation. I will portray technological cooperation in the West German plastics industry as a simple repeated game with two players.¹¹ The following assumptions are stylized facts of the actual conditions in the plastics industry in the period after the Second World War.¹²

The players are a chemical firm representing the few big West German plastics producers and a plastics fabricator representing the many small and medium-sized firms of this subindustry. We suppose that only the chemical

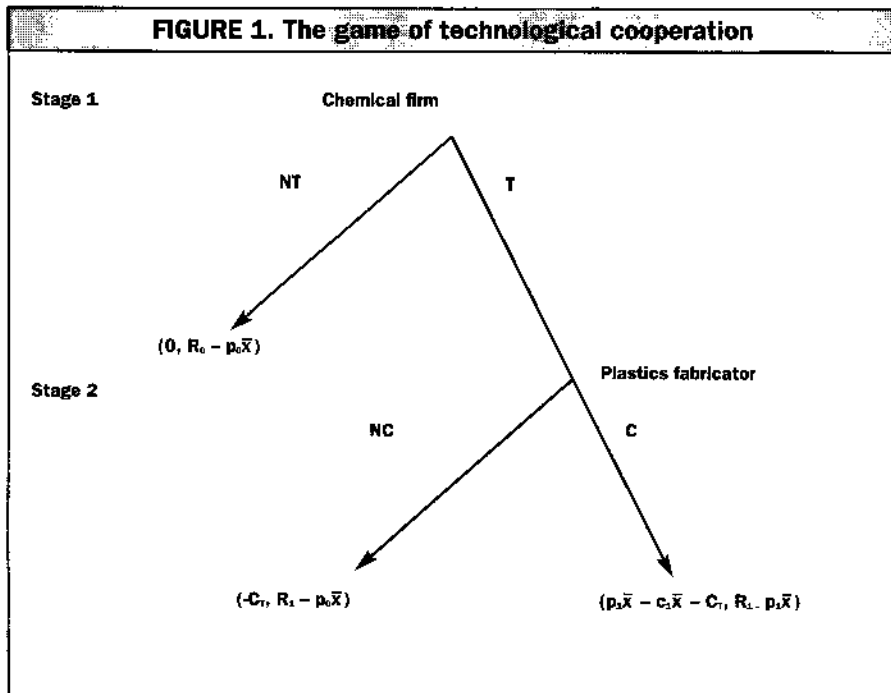
¹⁰ ARORA (1996) discusses this idea in the context of development economics.

¹¹ For a survey of repeated game theory see for example AUMANN (1985) and PIERCE (1992).

¹² See FREEMAN (1963).

firm tries to develop product innovations for the markets of the plastics manufacturers. The plastics fabricator does not carry out any R&D. Neither do the foreign plastics producers. Furthermore, we assume that the chemical firm cannot succeed in pure price competition because it is not able to produce standard plastic materials like polyvinylchloride, polystyrene or polyethylene as cheaply as its foreign competitors. The cost difference $c_1 - c_0$ embodies this exogenous locational disadvantage. The chemical firm can nevertheless relax price competition by bundling standard plastic materials and innovative knowledge. It communicates information to the plastics fabricator through product demonstrations and customer training. This technological transfer is carried out before the plastics fabricator actually commits himself to buying plastic materials from the chemical firm.

Therefore the game of technological cooperation is played in two stages. In stage 1 the chemical firm transfers technological knowledge to the plastics fabricator. In stage 2 the plastics fabricator decides either to continue buying its inputs from foreign suppliers at lower prices or to order them from the chemical firm.



The chemical firm moving first has the choice between the two strategies "No Technological Transfer (NT)" and "Technological Transfer (T)". The strategy "NT" means that the chemical firm will leave the market for standard plastic materials and what is more will not communicate any further innovative information to the plastics fabricator. Playing this strategy, the payoff of the chemical firm equals zero. The payoff of the plastics fabricator results from the simple profit function $R - px$, where R denotes the revenues from selling fabricated plastic goods, p the price of plastic materials, and x the quantity of plastic materials used by the plastics fabricator. I simplify analysis by stating the following three assumptions:

1. Except for the expenses of plastic materials, the manufacturing costs of the plastics fabricator are neglected and set at zero.
2. The amount of plastic materials processed by the plastics fabricator is always \bar{x} no matter which particular plastic goods are actually produced.
3. The technological transfer increases revenues of the plastics fabricator from R_0 to R_1 since it enables product innovations which cannot be imitated by uninformed competitors.

If the chemical firm plays the strategy "NT", the plastics fabricator will not achieve any increasing revenues. Buying the necessary plastic materials from foreign suppliers at price p_0 the plastics fabricator gets payoff $R_0 - p_0 \bar{x}$. We further assume that pure price competition between the different foreign plastics producers leads to $p_0 = c_0$.

Playing "T" in stage 1, the chemical firm has unavoidable fixed costs C_T which includes expenses both for R&D and for communicating product innovations to the plastics fabricator. The total payoff of the chemical firm depends on the reaction of the plastics fabricator in stage 2. He may decide to reward the technological transfer by playing "Cooperation (C)" which means purchasing its inputs from the chemical firm at price p_1 , $p_1 > p_0$. However, the costs of the plastics fabricator will rise from $p_0 \bar{x}$ to $p_1 \bar{x}$ then. That is why the minimum requirement for playing "C" is that the payoff of the plastics fabricator is in this case at least as high as in the situation without technological transfer.

$$(1) \quad R_1 - p_1 \bar{x} \geq R_0 - p_0 \bar{x}$$

If the plastics fabricator actually cooperates, the chemical firm will achieve the payoff $p_1\bar{x} - c_1\bar{x} - C_T$. Though the latter will only decide to play "T" if this term is at least as high as zero what the chemical firm can secure for itself by playing "NT". This condition results in the minimum requirement that the price asked by the West German chemical firm should be at least as high as the sum total of the marginal costs of the foreign suppliers, the exogenous locational disadvantage and the unit costs of the technological transfer.

$$(2) \quad p_1 \geq c_0 + (c_1 - c_0) + \frac{C_T}{\bar{x}}$$

If we also take into account that bundling standard plastic material and information could enable the supplier to gain a positive profit m , $m \geq 0$, p_1 , this will be eventually defined by the following equation.

$$(3) \quad p_1 = c_0 + (c_1 - c_0) + \frac{C_T}{\bar{x}} + m$$

However the question remains by which economic constraints the size of profit m is limited.

The plastics fabricator cannot be forced to cooperate. This firm will rather choose "No Cooperation (NC)" as this strategy leads to its highest payoff

$$(4) \quad R_1 - p_0\bar{x} > R_1 - p_1\bar{x}$$

In this instance the chemical firm not selling any plastic materials realizes a negative payoff $-C_T$. Backwards induction shows that the single shot version of this game has a unique Nash equilibrium in strategies "NT" and "NC". The chemical firm knows that, after receiving the technological transfer, a profit-maximizing plastics fabricator will decide to play "NC". The promise in stage 1 to cooperate in stage 2 is not credible since the chemical firm has no possibility to punish the plastics fabricator for deviating from this assurance. If the game of technological cooperation is only played once, a rational chemical firm will choose strategy "NT".

However, technological cooperation is rather a repeated game than

a single shot game. Since the building up of particular R&D capacities needs investment in real and human capital which means sunk costs, at least in parts, the chemical firm surely wants to use this capacity to produce not only one but a permanent stream of product innovations for the plastics manufacturing industry. If the chemical firm succeeds in doing this, it can punish a plastics fabricator playing "NC" by excluding it from further technological transfers. In this case, the latter will fall behind its informed competitors. We need three further assumptions to describe this repeated game completely:

1. The repeated game has an infinite time horizon. Since players cannot exactly predict at any point in time for how many periods technological cooperation will still continue, they are not able to choose their strategies through backwards induction (RUBINSTEIN, 1992).
2. Players discount their future payoffs with the help of a discount factor α , $\alpha \in (0,1)$. The discount factor is a measure for the "patience" of players. The higher α is, the more players take into account payoffs occurring in the far future when choosing their strategies in the present.
3. A particular technological transfer from the chemical firm to the plastics fabricator increases the revenues of the latter to R_1 only for one period. If the plastics fabricator does not again receive information about "new" product innovations, its revenues will return to R_0 .

Now we will check whether it is possible to implement combination "T" and "C" as an equilibrium of the repeated game which is Pareto superior to the single shot Nash equilibrium "NI" and "NC".¹³ We suppose that the chemical firm playing the game of technological cooperation with several plastics manufacturers follows a simple trigger strategy each time:

1. In period 0, the chemical firm always plays strategy "Technological transfer".

¹³ For the general approach, see FRIEDMAN (1971).

2. In period t , the chemical firm will play strategy "Technological transfer" if, and only if, the plastics fabricator has played strategy "Cooperation" in all past periods $0, \dots, t-1$.
3. If the plastics fabricator has chosen strategy "No cooperation" in any period t the chemical firm will play strategy "No technological transfer" in every future period starting from period $t+1$. In this way the chemical firm does punish the non-cooperative plastics fabricator through returning to the single shot Nash equilibrium.

The chemical firm uses this trigger strategy to motivate the plastics fabricator to choose long-term cooperation. This aim will only be achieved if the trigger strategy implements combination "T" and "C" as a subgame perfect Nash equilibrium of the repeated game, which implies that the plastics fabricator cannot increase its discounted long-term payoff by deviating from equilibrium strategy once. Under which economic circumstances is this condition fulfilled? Let us assume that the plastics fabricator chooses strategy "NC" in period t after playing "C" until period $t-1$. Because of this deviation the plastics fabricator will be excluded from any future technological transfer from period $t+1$ on. The trigger strategy will only implement the cooperative solution as a subgame perfect Nash equilibrium if the discounted long-term payoff of deviating is not bigger than the plastics fabricator's discounted long-term payoff when always playing "C".

$$(5) \quad \frac{1-\alpha^t}{1-\alpha} [R_1 - p_1 \bar{x}] + \alpha^t [R_1 - p_0 \bar{x}] + \frac{\alpha^{t+1}}{1-\alpha} [R_0 - p_0 \bar{x}] \geq \frac{1}{1-\alpha} [R_1 - p_1 \bar{x}]$$

Transforming this inequality finally leads to

$$(6) \quad \alpha \geq \frac{\bar{x}(p_1 - p_0)}{R_1 - R_0}$$

From $\alpha < 1$ also follows

$$(7) \quad R_1 - R_0 > \bar{x}(p_1 - p_0)$$

As a result the plastics fabricator will be willing to cooperate in the long term if, and only if, the increase in its revenues is higher than its additional costs when buying plastic materials from the West German chemical firm. What is more, given a certain price difference, the lower the discount factor α the higher the increase in revenues has to be to implement strategies "T" and "C" as a subgame perfect Nash equilibrium. Let us assume that the chemical firm tries to play the game of technological cooperation with N plastics manufacturers simultaneously. If their individual discount factors $\alpha_i, i = 1 \dots N$, are normally distributed over the interval (0,1) the number of plastics manufacturers actually cooperating will grow with increasing additional revenues caused by the technological transfers.

Fitting equation (3) and assumption $p_0 = c_0$ into equation (7) we will get an answer to the question asked above by which economic constraints the size of the chemical firm's profit m arising from product differentiation is limited.

$$(8) \quad m < \frac{R_1 - R_0}{\bar{x}} - (c_1 - c_0) - \frac{C_T}{\bar{x}}$$

Equation (8) shows that, given the exogenous cost parameters, the size of profit m is endogenously determined by the amount of additional revenues caused by the technological transfers.

Until now we have implicitly assumed that the differences $R_1 - R_0$ and $c_1 - c_0$ are constant. Allowing these quantities to change in time we are able to distinguish two reasons for the ending of a former successful technological cooperation.

1. A diminishing capability of the chemical firm to create innovative knowledge can lead to decreasing additional revenues of the plastics fabricator $R_1 - R_0$, so that those will no longer be sufficient to compensate the additional costs of playing "C". In this case the plastics fabricator will switch to strategy "NC".
2. An increasing locational disadvantage $c_1 - c_0$ can result in a negative profit m which the chemical firm will forestall by changing to "NT".

However, expectations may also matter. Players who expect that one

of the above cases will occur in the near future may stop playing cooperatively at a point in time when economic conditions still seem to support further cooperation.

3 Technological cooperation in the German plastics industry

In this section we will discuss the beginning, the development, and the at least partial ending of technological cooperation within the network of the West German plastics industry from the 1930s to the 1970s. This period covers firstly the National Socialist dictatorship and the post war reconstruction, secondly the so-called West German economic miracle, and thirdly the decade of oil price shocks. I will show that the terms beginning, development and ending can be at least roughly assigned to these three subperiods. I will focus especially on the "Kunststoffrohstoffabteilung" (plastic materials department) of the German chemical firm BASF which was responsible for carrying out technological transfers to plastic manufacturers and machine makers.

3.1 The beginning of technological cooperation. Completing trigger strategies, it is usually assumed in repeated game models that the player moving first chooses a cooperative strategy in period 0 which has by definition no own "history". That is what we also did in section 2.2 when supposing that the chemical firm starts the game of technological cooperation by playing "1". However, in reality a chemical firm will only take the risky first step to set up the capacities for developing and communicating product innovations if it has a prior belief that the plastics fabricator is likely to cooperate after receiving the technological transfer. In my opinion, in the late 1940s the German chemical firms had good reasons to suppose that technological cooperation with a downstream industry could be successfully carried out. Encouraging examples from their own history were, on the one hand, the innovation of coal tar dyes in cooperation with the textile industry in the second half of the nineteenth century and, on the other hand, the inter-industry R&D projects in the field of plastic materials within the I.G. Farben concern. From the innovation of coal tar dyes, German chemical firms learned how to

organize the institutional framework of technological cooperation with independent firms. The successful inter-industry R&D projects in the field of plastic materials increased the chemical firms' confidence in their own innovativeness and in the willingness of plastics manufacturers to cooperate.

First of all let us view the example of coal tar dyes.¹⁴ The meteoric rise of the German chemical industry to a position dominating the worldwide market of coal tar dyes in the second half of the XIXth century is usually explained by the excellent education of German chemists and the systematic use of industrial research laboratories. It is less noticed that the German producers of coal tar dyes also owed their success to the two new marketing strategies "customer consulting" and "customer training" (BEER, 1959, pp. 91-94, STOKES, 1994, p. 20) which were used to transfer technological knowledge to long-term customers. The German chemical firms of the late nineteenth century had both technological and economic innovation capital.

The so-called "Coloristische Abteilungen" (dye departments) of chemical firms established to open up new markets for product innovations in the field of coal tar dyes were responsible for carrying out these new marketing strategies. That is why the *Coloristische Abteilungen* were affiliated with industrial research laboratories and had both commercial and technical staff. Customer consulting was done by chemists who not only knew the special characteristics of new coal tar dyes but had also learned how to dye and print textiles.¹⁵ Hence these chemists were able to understand the problems and the "language" of textile producers.¹⁶ They explained in advance of sales how to use the offered coal tar dyes in the production plants of textile producers and also provided technical help in cases of actual processing problems after

¹⁴ Quite similar to the reasons for the opening up of the technological path of plastics, it was both decreasing imports of natural dyes during the German-French War of 1870/71 and the government's demand for dyed tunics which accelerated the innovation of coal tar dyes in Germany. See ZOHLEN, OTTO, "Geschichte der AWETA 1865-1939", BASF-ARCHIVES Q 001.

¹⁵ See ZOHLEN, OTTO, "Geschichte der AWETA 1865-1939", BASF-ARCHIVES Q 001.

¹⁶ To improve communication between chemists selling coal tar dyes and customers even more, *Coloristische Abteilungen* employed native speakers abroad.

sales. About 1900 the *Coloristische Abteilungen* developed the idea of customer training. In special courses they taught employees of textile firms to handle the latest techniques of dyeing and printing. Obviously this was advantageous for the textile producers. The chemical firms for their part won the loyalty of future customers. What is more, they informed the trainees only about their own products, thereby creating preferences. Half a century later German chemical firms recalled the marketing strategies of customer consulting and customer training when playing the game of technological cooperation with plastics manufacturers.

I have explained in section 1.2 how following the technological path of synthetic rubber led German chemical firms to the discovery of new plastic materials like polystyrene and polyvinylchloride. However, while synthetic rubber was demanded by the National Socialist government, possible economic uses for the new plastic materials in downstream industries and even manufacturing machines hardly existed.¹⁷ To close this gap, the chemical firm BASF set up the "Kunststoffrohstoffabteilung" (KURO) as a new department of the well-tried *Coloristische Abteilung* in 1938.¹⁸ Since the most important German chemical firms had formed the I.G. Farben concern in the meantime,¹⁹ KURO had to open up new markets not only for BASF but for all I.G. Farben firms.

I.G. Farben not only included chemical firms but also machine makers like Eckert & Ziegler and plastics manufacturers like Dynamit Nobel AG Troisdorf which was famous for its high degree of innovativeness in this period (TER MEER, 1953, p. 97). This vertical integration created optimal conditions for the activities of KURO (DEBELL, GOGGIN, GLOOR, 1946, p. 317). KURO was able to develop plastics manufacturing machines

¹⁷ Polyvinylchloride, for example, was only used for disposing of toxic chlorine first. See BASF-ARCHIVES Q 006, "Diskussion Nr. 5 zwischen Chemiker und Ingenieur ueber Kunststoffwerkstoffe. Polyvinylchlorid (PVC), Anwendungstechnische Mitteilungen aus Werk und Praxis Bd III AWETA K und AWETA K3", June 1972.

¹⁸ See KUCKERTZ, HEINRICH. "Geschichte der AWETA 1896-1961" BASF-ARCHIVE Q 001.

¹⁹ I.G. Farbenindustrie AG founded in 1925 comprised Bayerwerke Leverkusen, BASF Ludwigshafen, AGFA Berlin (Dreibund 1904), Farbenwerke Hoechst Frankfurt/Main, Cassela Farbwerke Mainkur Frankfurt/Main, Kalle & Co AG Wiesbaden Biebrich (Dreiverband 1904/06), Chemische Fabriken Lerdingen and Chemische Fabrik Griesheim. See STOKES (1988) pp. 11-13.

together with I.G. Farben machine makers and furthermore was able to make I.G. Farben plastics manufacturers test both those machines and the new plastic materials of I.G. Farben chemical firms. Within I.G. Farben there was no danger that the giver of some technological information was cheated by the recipient out of its economic service in return.

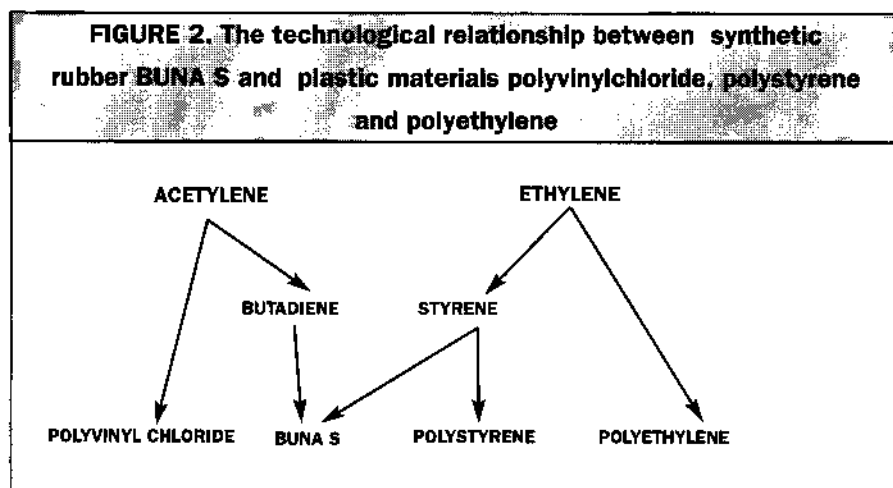
I do not hesitate to conclude that chemical firms recalling successful technological cooperation within I.G. Farben were more likely to dare to communicate technological knowledge to current independent plastics manufacturers in the immediate post-war period. Positive past experiences created trust in the future willingness of plastics manufacturers to cooperate. Nevertheless, the example of I.G. Farben also taught German chemical firms that vertical integration could be a less risky alternative to playing the game of technological cooperation with independent firms. Vertical integration may improve the flow of information between chemical firm and plastics fabricator (ARROW, 1975) and what is more may induce a more efficient R&D investment level of the chemical firm (GROSSMAN, HART, 1986). However, I suspect that the limits of vertical integration could be defined by the existing economic innovation capital of the integrating firm. If the chemical firm lacks the links and marketing strategies to deal with the customers of plastics manufacturers in secondary markets, it may be appropriate not to integrate. What is more, vertical integration does not help to overcome the disadvantages of the chemical firm in pure price competition, since the integrated firm will also increase its profit by buying plastic materials from cheaper foreign suppliers instead of producing them itself. However, because of the political circumstances, in the post-war period vertical integration was simply not feasible.

3.2 The development of technological cooperation. After the Second World War the Allied Control Council forbade the production of synthetic rubber as well as butadiene and limited the capacities of styrene and chlorine, a raw material for producing polyvinylchloride, by Law Number 24, 3 March, 1950, and its predecessors (KOLLEK, 1951). Trying to save their real and human capital accumulated in the field of synthetic rubber German chemical firms looked for "peaceful" ways to use it.²⁰ Because

of the close technological relationship between synthetic rubber and plastic materials, shown in figure 2, the obvious thing to do was to search for alternatives in the latter field.

The chemical products styrene and acetylene are necessary inputs for the production of the synthetic rubber BUNA S. But styrene can also be processed to produce the plastic material polystyrene; acetylene combines with hydrochloric acid to form vinylchloride which can be polymerized to produce the plastic material polyvinylchloride. Using their styrene and acetylene plants for the production of plastic materials German chemical firms could protect them from being dismantled. What was lacking was a sufficient number of plastics manufacturers demanding these products. This is why chemical firms started to support the development of the German plastics manufacturing industry.²¹

Let us focus on the activities of KURO. After the breaking up of I.G. Farben KURO could no longer cooperate with dependent downstream firms within the well-ordered organization of a concern. Henceforth KURO had to play the game of technological cooperation with



²⁰ See BASF-ARCHIVE F9/15, Long-term [Production] Plan June 15, 1949.

²¹ In the late 1940s, for instance, KURO encouraged some small plastics manufacturers to install machines for processing the quite unknown plastic material polyethylene. See SCHMITT, BERNHARD, "Die Geschichte der KURO bis zum Jahre 1958," BASF-ARCHIVE Q 001 (002). Polyethylene became especially useful for the packaging industry at the time.

independent firms which had the possibility to act in a non-cooperative way.²² To forestall this KURO started to deploy the well-known customer consulting and customer training strategy.

First of all KURO members reestablished their contacts with already existing or potential plastics manufacturers known from the I.G. Farben era. KURO granted these plastics manufacturers initial aid by supplying plastic materials and technological advises for free. In the 1960s KURO refined its customer-consulting procedures. Exploring downstream markets for plastic goods, KURO started developing so-called "finished solutions", i.e. complete strategies for plastic manufacturers including information about how to produce an innovative plastic good and where to sell it.²³ In addition KURO offered to optimize its customers' expensive moulds for free.²⁴ The new plastic goods of long-term customers were tested regardless whether the plastic materials were bought from BASF or from other suppliers.²⁵ KURO also used the well-known customer training method.²⁶ What is more KURO trained plastics engineers in a two-year programme. These were destined to be

²² If the chemical firm took out a patent on a particular plastics manufacturing process there could also be another way to promote the sales of its own products. In this case the chemical firm had the possibility to let the plastics manufacturer choose between not paying a license fee when using the plastic materials of this supplier or paying a license fee when processing products from competitors. That is what BAYER did. See FREUDENBERG-ARCHIVE 3/03145, Vulkollan-Vertrag zwischen Farbenfabriken Bayer AG, Leverkusen, und Carl Freudenberg K.G. a.A., Weinheim, vom 22 September 1953; FREUDENBERG-ARCHIVE 3/04802, Frelen-Lizenzvertrag zwischen BAYER AG Leverkusen-Bayerwerk und Firma Carl Freudenberg, Weinheim, 16. u. 23 July 1973. See also Streb, 2003b.

²³ For instance, KURO developed a plastic good for the furniture industry. When a furniture manufacturer became interested in this invention, KURO introduced it to a plastics manufacturer who was able to carry out production and, what is more, usually bought its plastic materials from BASF. See BASF-ARCHIVE Q 002/4 1967-1971, Taetigkeitsbericht der AWETA K fuer das Arbeitsjahr 1971, Fachreferat Markterschliessung Maschinenbau, p. 91.

²⁴ See BASF-ARCHIVE Q 002/2 1962-1964, Taetigkeitsbericht 1964, AWETA II, Gruppe 4 Fachreferat Verarbeitungstechnik, p. 114.

²⁵ See BASF-ARCHIVE Q 002/2 1962-1964, Forschungs- und Entwicklungsarbeiten I. Halbjahr 1964, AWETA II, pp. 46-48. KURO also checked new plastics-making machinery for the machine makers. See BASF-ARCHIVE Q 002/3 1965-1966, Taetigkeitsbericht 1965 AWETA II, 5. Fachreferat Schaumpolystyrole, p. 44.

²⁶ See BASF-ARCHIVE Q 002/4 1967-1971, Taetigkeitsbericht der AWETA K fuer das Arbeitsjahr 1970, Technischer Kundendienst Spritzguß und Hohlkoerperblasen, p. 71.

exclusively employed by important customers of BASF (BASF, 1989, p. 52).

Members of the KURO staff pointed out that customer consulting and customer training had considerably increased the loyalty of plastics manufacturers to BASF in the post-war period. They concluded that for this reason domestic and foreign competitors had not succeeded in penetrating BASF's market despite lower prices (KOLLEK, STANGE, 1985, pp. 284-285).²⁷ However, the repeated game model of technological cooperation has shown that chemical firms with comparatively high prices can only maintain their customers' loyalty by permanently transferring technological knowledge which raises the revenues of plastics manufacturers. So the marketing strategies of customer consulting and customer training will generate loyalty if, and only if, they communicate economically usable information which plastics manufacturers cannot get as cheaply in any other way. Actually KURO developed several very successful product innovations in the period of the West German economic miracle.

First of all we should name the screw in-line injection moulding machine²⁸ which was made ready for market by KURO in technological cooperation with machine maker Ankerwerke Nuremberg (BASF, 1989, pp. 22, 42). This innovation helped not only West German machine makers but also West German plastics manufacturers to gain competitive advantages in world markets since they had been informed about its usefulness by KURO early and in great detail. Even though the chemical firm BASF was equally interested in domestic and foreign long-term customers it was the West German plastics producers who especially benefited from technological cooperation because of their spatial, linguistic and cultural proximity to the supplier of innovative knowledge (LUNDVALL, 1988, p. 355). A second example for the innovativeness of KURO comes from the field of construction. In the

²⁷ In the 1960s, for example, BASF was able to sell the plastic material styrene acrylonitrile at a price which was 5 % higher than the world market price. See BASF-ARCHIVE T 06, Informationsbriefe des Verkaufs Nr. 14. See also BASF-ARCHIVE F 9/159, Verkauf an Zentralbuero 6 May 1958, Preistellung fuer Monostyrol und Polystyrol.

²⁸ This machine heats plastic materials more regularly and more precisely than conventional moulding machines which allows the production of bigger plastic goods. See Gaeth, Rudolf. "Entwicklungsgeschichte AWETA II im Jahr 1960." BASF-ARCHIVE Q 001 (002).

post-war period the German construction industry had the highest consumption of plastic goods in this sector in the world; for example, it was the largest user of plastic pipes for water supply (FREEMAN, 1963, p. 47). Hence it may not be surprising that input-output analysis for the first time carried out in West Germany for the year 1965 reveals that the construction industry was the most important industrial customer of German plastics manufacturers. In 1965 they sold 28.7 % of all plastic goods which were used as inputs in downstream industries to the construction industry, 18.7 % to machine makers, and 11.9 % to the electrical engineering industry (STATISTISCHES BUNDESAMT, 1972, pp. 60-71). KURO led the field in this development. Foamed polystyrene ("Styropor"), for instance, invented by KURO employees Stastny and Gaeth in the early 1950s, was used as an insulating material in the construction industry (HOELSCHER, 1972, p. 49). This product innovation meant that BASF could carry on making profits out of its styrene plants formerly used for the production of BUNA S. The same argument holds for new productions of robust polystyrene for which KURO found uses in the construction of household and electrical appliances and in the car industry.

3.3 The ending of technological cooperation. In the 1970s KURO realized that plastics manufacturers increasingly chose to switch to strategy "NC" in the repeated game of technological cooperation. Plastics manufacturers continued to seek new technological information from KURO but refused the economic service in return, buying plastic materials from suppliers with lower prices.²⁹ BASF reacted against this behaviour, as assumed for the trigger strategy in the repeated game model in section 2.2: Non-cooperative plastics manufacturers were punished by being excluded from any further technological transfer. What is more KURO started selling new technological information instead of giving it away for free as before.³⁰ Setting up the plastics manufacturer Delta Plastics, BASF finally recalled vertical integration as an alternative to playing the

²⁹ After successfully developing a polyethylene bottle for milk in technological cooperation with KURO, the plastics manufacturer changed to cheaper suppliers of this plastic material. See BASF-ARCHIVE Q 002/4 1967-1971, Taetigkeitsbericht der AWETA II fuer das Arbeitsjahr 1969, Fachreferat Marktentwicklung Verpackung, p. 90.

³⁰ See BASF-ARCHIVE Q 002/5 1972-, Taetigkeitsbericht der AWETA KT 1974, Fachreferat Maschinenbau und Elektrotechnik, p. 60.

game of technological cooperation with independent firms (BASF, 1989, pp. 93-96, KOLLEK, STANGE, 1985, pp. 297-300).

In the remaining part of this paper I will try to answer the question why in the 1970s many West German plastics manufacturers³¹ decided to end technological cooperation with West German chemical firms after benefiting from this inter-industry network for two decades. We know from analyzing the repeated game model that plastics manufacturers will be more likely to play a non-cooperative strategy if the additional revenues caused by technological transfers decrease. This is why we have to look for empirical facts indicating a declining economic value of the communicated product innovations. Therefore, in a more macroeconomic approach, I will now turn my attention to long-term growth of total factor productivity in the plastics manufacturing industry as a whole. In a multiperiod examination total factor productivity measures which share of an increase in output of an industry cannot be explained by the quantitative increase in inputs with remaining qualities. Total factor productivity will particularly grow if an industry is able to produce due to technological progress either a certain good with less inputs or with the same amount of inputs a higher preferred good than in the period before. The first case rather refers to process innovations, the second one rather to product innovations.

We have seen it was the big chemical firms and not the small or medium-sized plastics manufacturers which did most of R&D in the German plastics industry in the post-war period. Hence there are grounds for believing that the development of total factor productivity of German plastics manufacturers was mostly determined by the R&D of upstream chemical firms. On this assumption the total factor productivity of the plastics manufacturing industry can be used to provide at least a rough answer to the question as to whether or not technological cooperation in this inter-industry network resulted in sufficient increases in the revenues of plastics manufacturers.³²

³¹ Following LUNDVALL's hypothesis we will concentrate on the West German plastics manufacturers who should especially gain from technological cooperation with the West German chemical firms because of their proximity to them.

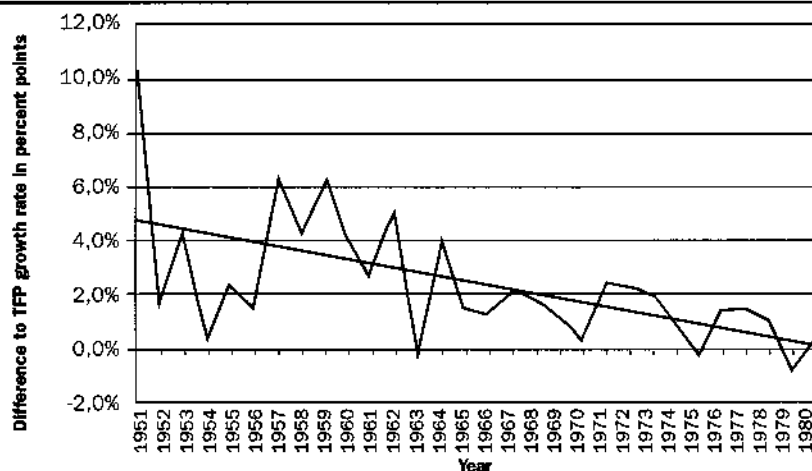
³² I have calculated total factor productivity on the basis of a Cobb-Douglas production function which is homogeneous to degree 1 in the inputs labour and capital. For this method see SOLOW (1957) and NELSON (1964).

Figure 3 shows the annual differences between the growth rates of total factor productivity in the West German plastics manufacturing industry and in West German manufacturing industry from 1951 to 1980.

I want to stress three results:

1. Except for the years 1963, 1975 and 1979 the annual growth rates of total factor productivity of the plastics manufacturers were always higher than those of manufacturing industry. This might indicate an above-average technological progress in the plastics manufacturing industry.
2. However, annual growth rates converged over time. In the first decade the average annual growth rate of total factor productivity of plastics manufacturers amounted to over 350 percent of that of manufacturing industry. In the following this number fell to 230 percent in the second decade and to a mere 160 percent in the last decade.
3. What is more, the average annual growth rate of total factor productivity of the plastics manufacturers also decreased in its

FIGURE 3. The difference between the growth rates of total factor productivity of the West German plastics manufacturers and West German manufacturing industry, 1951-1980, in percent points*



* For data see Kregel *et al* (1973), Kregel *et al* (1975) and Görzig *et al* (1986).

value from 5 percent (1951-1960) via 2.1 percent (1961-1970) to 1.3 percent (1971-1980). West German plastics manufacturers were not able to repeat the ample increases in productivity of the first two decades of the 1970s.

These results suggest that the flow of product innovations from chemical firms to plastics manufacturers became much thinner in the 1970s.³³ This may not be surprising since many important markets for plastic goods³⁴ had already been developed thirty years after the discovery of standard plastic materials. There is also the fact that consumers started to reject plastic goods in new uses and what is more began to prefer "natural" goods in markets where plastic goods were established due to both an increase in per capita income and an awakening care about environmental problems in the 1970s.³⁵

Figure 4 gives us an idea about the different trends in total factor productivity in the West German and the US-American plastics manufacturing industries for the period from 1951 to 1976.³⁶

It is striking that in the 1950s the annual growth rates of total factor productivity of West German plastics manufacturers were considerably

³³ An indicator for the decreasing innovativeness of German plastics producers is also the fact that KURO itself had to recognize in 1970 that some foreign producers of polystyrene were already superior in Schumpeterian competition. See BASF-ARCHIVE Q 002/4 1967-1971, *Taetigkeitsbericht der AWETA K fuer das Arbeitsjahr 1970*, Fachreferat Styrolpolymerisate, p. 9.

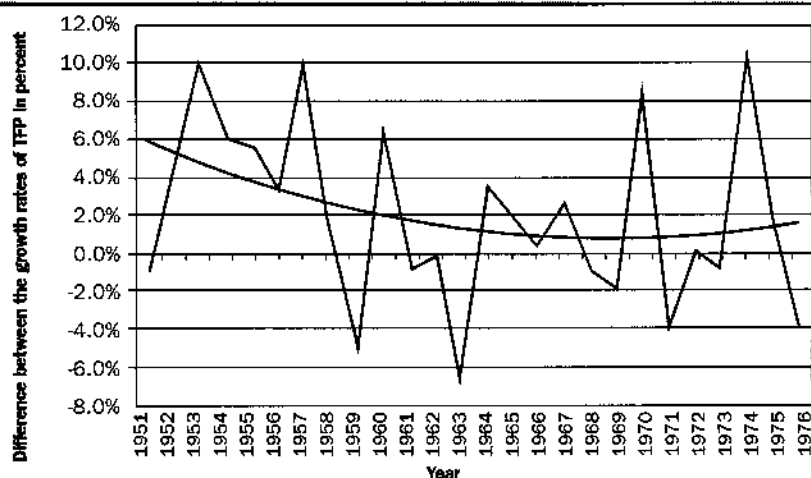
³⁴ For example the markets for packaging and containers, building materials, electronic equipment, household goods and toys.

³⁵ In the early 1970s, for example, KURO had to deal with customers who suddenly rejected polyvinylchloride because of news about its possible toxicity. See BASF-ARCHIVE Q 002/5 1972-, *Taetigkeitsbericht der AWETA KI, Fachreferat Polyvinylchloride*, p. 27.

³⁶ The US-American data are taken from KENDRICK and GROSSMAN (1980), p.151. Two reasons prevent direct comparison of German and US-American figures. First KENDRICK and GROSSMAN deployed a slightly different method for calculating total factor productivity. Among other things they used a weighted arithmetic average of labour and capital to avoid the implications of a Cobb-Douglas production function (linear homogeneity with unit elasticity of substitution). For a discussion of their calculating method see KENDRICK (1973), pp. 11-15. Second the underlying Major Group 30 of Standard Industrial Classification includes not only plastics manufacturers but also rubber manufacturers. Nevertheless, we should at least be able to identify the main differences between the two industries.

higher than that of their US-American competitors. We understand this difference partly as a catching-up process of the West German plastics manufacturers and partly as a result of the lead they take in special fields like plastic goods used by the construction industry. During the 1960s and the early 1970s the average annual growth rates of total factor productivity of German and the US-American plastics manufacturing industries were almost equal. This observation seems to show that in this period technological cooperation with German chemical firms no longer helped the German plastics manufacturers to gain competitive advantages over US-American suppliers. This assumption is also supported by the fact that US-American chemical firms themselves started cooperating with plastics manufacturers by building up departments

FIGURE 4. The difference between the growth rates of total factor productivity of the West German and the US-American plastics manufacturers, 1951-1980, in percent points*



* For data see Krengel et al (1973), Krengel et al (1975), Görzig et al (1986), Kendrick, Grossman (1980).

³⁷ A speech by David H. Dawson of Du Pont from May 2nd 1961 illustrates that point very well: "Nowadays, with more complex products and heightened product competition, the need for technical aid has grown greatly. The customer will give his business to the producer who helps him solve his problems and enhance his earnings. That this is proceeding to great length is evident from the magnitude and rapid growth of our new Chestnut Run end-use and technical service establishment near Wilmington ... Much

similar to KURO in the early 1960s.³⁷ Successful marketing strategies can also be imitated.³⁸

Because of the increasing similarity between the West German and the US-American plastics producers' capabilities both with regard to produce and to transfer technological information, it became much more difficult for West German suppliers to relax price competition by bundling standard plastic material and innovative knowledge. That is why we ought to observe diminishing price differences in the 1970s at the latest. However, Figure 5 seems to contradict this conjecture. It shows that the "terms of trade"³⁹ between West Germany and the USA for polyvinylchloride and polyethylene increased by approximately 50 percent from 1968 to 1980. However, according to equation (3) an increasing price difference can be caused not only by rising profits but also by a growing exogenous locational disadvantage.

I have already mentioned the locational disadvantage of the West German plastics producers resulting from the large deposits of natural gas found in Italy and the Netherlands. In the 1970s it was especially the collapse of the Bretton Woods regime of fixed exchange rates which led to additional problems in international competition. As a consequence of this monetary crisis the German Mark was revalued with regard to the

of the work in these laboratories is directed toward the cultivation of markets once or twice removed from our own ... In plastics, especially the newer types, it is often necessary to work out design of a plastic component for use in an automobile or a washing machine and only then go to work with our immediate customer, the supplier of molded or extruded parts, on methods of producing the parts." Cited after BACKMAN (1965), p. 44. At the same time US-American firms intensified customer consulting and customer training in Europe. In 1960 Du Pont opened a sales department in Geneva which was responsible for technological consulting among European customers. See BASF-ARCHIVE Q 006 Ordner I, Anwendungstechnische Mitteilungen aus Werk und Praxis Band III, AWETA II, KUROLARO-SPEZIAL, Jahrgang 1960, Dezember-Heft. The Goodrich Chemical Comp. established a similar department in the Hague the same year. See FREDDENBERG-ARCHIVE 3/01250, Bericht ueber den Besuch bei der Firma B.F. Goodrich Chemical Comp., Cleveland am 28 March 1960.

³⁷ It was in the late 1960s when KURO's customer consultants actually noted that competition had increased because of other suppliers imitating their marketing strategies. See BASF-ARCHIVE Q 002/4 1967-1971, Tactigkeitsbericht der AWETA II fuer das Arbeitsjahr 1967, 7. Fachreferat Technischer Kundendienst Extrudieren, p. 29.

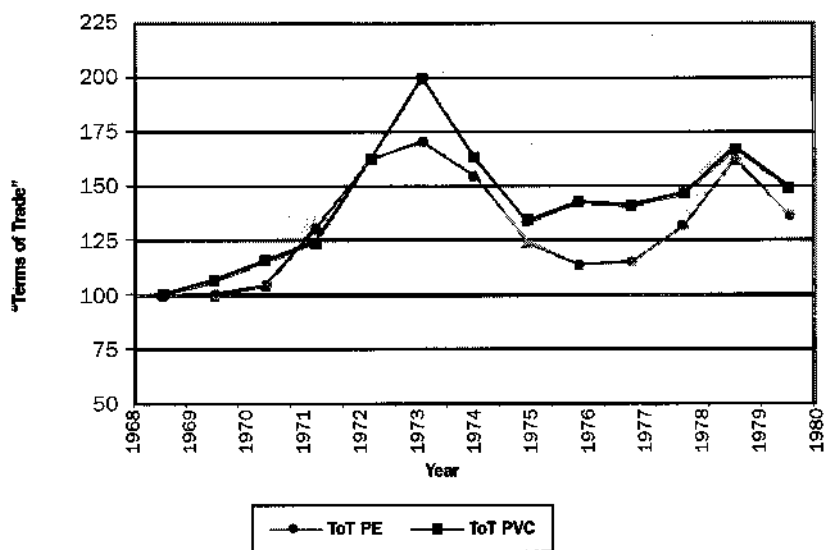
³⁸ These "terms of trade" are calculated as the quotient between West German producer prices and US-American producer prices multiplied by the actual exchange rate.

US-Dollar by 120 percent between 1968 and 1980 (DEUTSCHE BUNDESBANK, 1995, p. 10). It is imaginable that the changes in international price ratios caused by this revaluation conceal the fact that at the same time the West German plastics producers' ability to adjust prices was decreasing. To distinguish both effects we will assume that the exchange rate between German Mark and US-Dollar was constant between 1968 and 1980. Figure 6 shows the result of this counterfactual hypothesis.

Assuming a constant exchange rate the "terms of trade" between West Germany and the USA for polyvinylchloride and polyethylene considerably decreased after the first oil price shock. This may indicate that the economic value of the technological transfers from West German plastics producers to plastics manufacturers were diminishing on a similar scale.

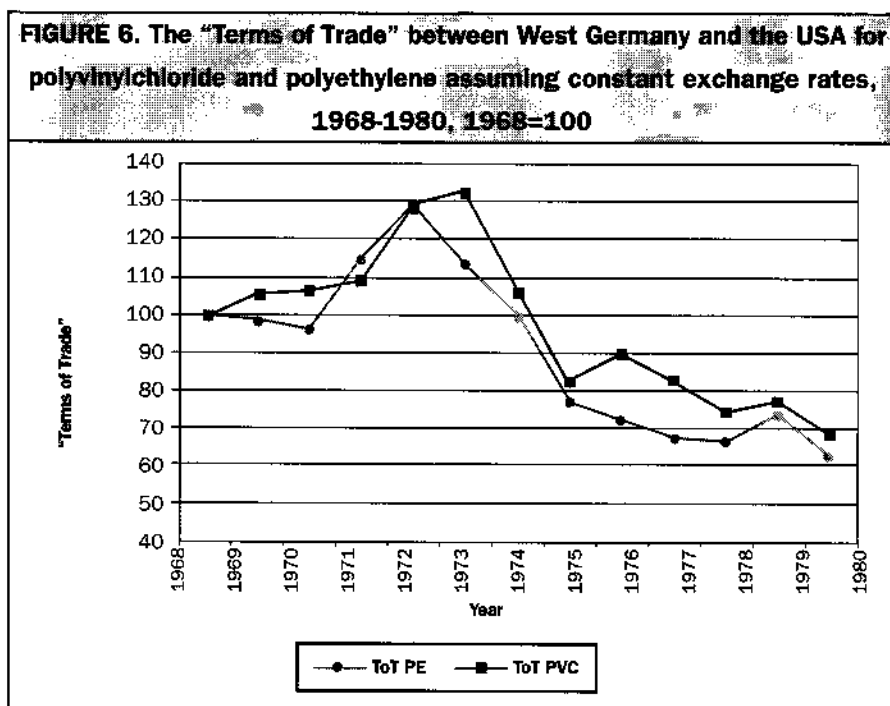
Let us summarize. In the 1970s the threat of West German chemical firms to exclude non-cooperating plastics manufacturers from

FIGURE 5. The "Terms of Trade" between West Germany and the USA for polyvinylchloride and polyethylene, 1968-1980, 1968=100*



* For data see Statistisches Bundesamt, "Preise und Preisindizes für industrielle Produkte, Index der Erzeugerpreise", Statistisches Bundesamt, "Preise und Preisindizes im Ausland.", Deutsche Bundesbank (1995).

technological transfers lost a good deal of its edge since product innovations developed by the former obviously became rarer and did not lead so often to additional revenues as they had in the past. What is more, foreign chemical firms had learned to offer new technological information too. Perhaps the plastics manufacturers felt a further economic incentive to end technological cooperation. It is conceivable that intensifying competition for the rather stagnating demand for plastic goods caused plastics manufacturers to become more "impatient" which meant that they strove primarily to maximize short-term profits. Hence their discount factors were not constant but decreased. All other things being equal, decreasing discount factors themselves would have increased the number of plastics manufacturers playing "NC" in the 1970s.⁴⁰



⁴⁰ All this does not imply that German chemical firms completely stopped playing the game of technological cooperation in the field of plastics in the 1970s. But they turned their attention to more advanced plastic materials and to new partners. This again illustrates KURO which successfully developed the plastic fuel tank for the car industry.

4 Conclusion

The starting point of this paper was the hypothesis that a national industry needs both technological and economic innovation capital to succeed in international Schumpeterian competition for the long term. It is technological innovation capital that enables a national industry to invent products on the respective frontier of knowledge. Economic innovation capital means the capability to transform these inventions into successful innovations. A national industry can improve this capability by forming networks with downstream industries. Technological transfers within such an inter-industry network can lead to a cluster of national industries all being highly competitive in international markets. In the decades after the Second World War such a cluster was the West German plastics industry including machine makers specialized in plastics manufacturing machines, chemical firms producing plastic materials, and plastics manufacturers.

In section 2 I showed first that plastics producers with comparatively high production costs may be able to relax international price competition by bundling standard plastic material and innovative knowledge. Then I deployed a repeated game model of technological cooperation in order to explain under which economic circumstances this kind of bundling would be a successful strategy. It turned out that a chemical firm can gain plastics manufacturers as long-term customers despite its higher prices if the increase in their revenues caused by technological transfers is higher than their additional costs when buying plastic materials from the more expensive supplier.

In section 3 we viewed the historical development of technological cooperation in the West German plastics industry from the 1930s to the 1970s. After the Second World War West German chemical firms supported the development of the plastics manufacturing industry using the marketing strategies customer consulting and customer training which had been learned during the coal tar dyes boom in the nineteenth century. Technological cooperation in the decades of the economic miracle drove the West German plastics industry to a leading position in world markets. However, in the 1970s a decreasing economic value in technological

transfer caused many plastics manufacturers to switch to a non-cooperative strategy in the repeated game of technological cooperation.

The concepts of inter-industry technological cooperation in particular and non-imitable innovation capital in general can help to explain why certain national industries dominate international markets for a long time.

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BASF Unternehmensarchiv (BASF-ARCHIVE), Ludwigshafen, Germany.

FREUDENBERG & Co FIRMEN- und FAMILIENARCHIV (FREUDENBERG-ARCHIVE), Weinheim, Germany.

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