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How to win Schumpeterian Competition. Technological Transfers in the German Plastics Industry from the 1930s to the 1970s.

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Abstract

Introducing the concept of innovation capital we will analyse conditions under which a national industry is able to succeed in international Schumpeterian competition. Then we will discuss the significance of this concept for the economic development of the German plastics industry from the 1930s to the 1970s. Using a repeated game model of technological cooperation we will especially focus on technological transfers from chemical firms to plastics fabricators. We will deploy both a microeconomic approach when viewing product innovations transferred by the so-called Kunststoffrohstoffabteilung (KURO) of chemical firm BASF, and a macroeconomic approach when looking at the development of total factor productivity in the German plastics fabricating industry. It will turn out that we can distinguish three subperiods with respect to technological cooperation in the German plastics industry: the beginning in the period of National Socialist dictatorship and post war reconstruction, the developing in the time of the West German economic miracle, and the ending in the decade of the two oil price shocks.

Key words: technological transfer, Schumpeterian competition, repeated game, plastics industry, Germany.

JEL codes: D 83, L 65, N 64, O 31.

1 Introduction

1.1 Innovation capital of national industries

Since the Second World War both per capita income and overall economic productivity of the nations joined together in the OECD have converged. At the same time we can observe that each of these nations has brought forth particular industries dominating international markets by their comparatively superior capability to innovate. Besides general convergence international division of labor has been increasing (DOLLAR, WOLFF, 1993). These findings seem to contradict the often used assumption that both technological and economic knowledge are available in the form of “blueprints” and therefore easily imitable by foreign competitors. The long-term predominance of national industries in international Schumpeterian competition (SCHUMPETER, 1952, pp. 100-103) rather justifies the opposite conjecture 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. Recent surveys (PORTER, 1990, NELSON, 1993) explain the international Schumpeterian competitiveness of national industries by the superiority of “national systems of innovation” thereby neglecting the fact that international successful and hardly competitive industries coexist in highly developed economies. We claim in this paper that the capability of a national industry to innovate is less based on national peculiarities than on an industry-specific asset called “innovation capital.”[1] Innovation capital means the part of the human capital which enables a firm or industry both to develop inventions at the respective technological frontier and to transform them in economically successful innovations (FREEMAN, SOETE, 1997, p. 202). Failed innovations like the British-French supersonic passenger aircraft Concorde do show that technological know-how alone is often not sufficient to make a new product an economic success. Innovators also need knowledge about expected market demand, different sales channels, or alternative financing sources. To succeed in Schumpeterian competition a national industry requires both technological and economic innovation capital.

To elaborate the meaning of these terms we will take a closer look at the innovation process of a firm in which innovation capital serves as an input. The innovation process itself describes the risky attempt of a firm at developing a new market good. It is divided in the planning phase, the R&D phase, and the marketing phase. The planning phase in which the managers have to decide which R&D projects will be actually carried out is characterized by great uncertainty. Because of the increasing diversification and the fast progress of knowledge a firm cannot take the technological lead in every scientific field which may be important for its future economic development. Instead of doing that it has to concentrate its research efforts on small regions

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

of the technological frontier. The outcomes of these R&D projects are unknown ex ante. The probability of failure is high and cannot be exactly quantified. This technological uncertainty will be reduced if the firm has already finished some R&D projects at the same region of the technological frontier. In this case the information obtained from the finished R&D projects 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 the technological outcome of R&D projects. The managers have also to know if there is a potential market demand for the possible technological inventions. This economic uncertainty can be reduced by forming links with government agencies and other industries. To show when these links mean economic innovation capital it is worth to discuss the cases “potential government’s demand” and “inter-industry networks” briefly.

Firms may invest some money in risky R&D projects to maintain their chances of finding inventions in new technological fields. They will be willing to do this more likely, if there exists a potential consumer who promises to buy a large amount of the new goods and what is more finances parts of firms’ R&D. In economic history governments often played this role. IBM, for instance, underestimating future private demand was only led to develop computers by military demand in the early 1950s (KATZ, PHILLIPS, 1982, p. 177). Potential government’s demand often causes the development of new market goods because it considerably reduces economic uncertainty in the planning phase of the innovation process. Governments influencing the direction of firms’ R&D should nevertheless be very careful since they do not know the future either. Misleading decisions are always possible.

Inter-industry networks are built up between upstream and downstream industries to exchange information. Within inter-industry networks firms often reveal a good deal of their technological knowledge and their production and sales plans. This information can also be used to harm revealing firms. This is why mutual trust might be a necessary condition for working networks (LUNDVALL, 1988, p. 353). By learning about actual problems and needs of downstream industries, upstream industries can tell which kind of inventions will be successful innovations. Here the demand side determines the choice of the R&D projects in the planning phase. It is also possible that an upstream industry develops both a new product and innovative ways in which it can be used in downstream industries. In this case the supply side decides about the future direction of the technological development. An industry without any own R&D efforts will profit from other industries’ R&D through purchasing their innovations (WOLFF, 1996). Furthermore technological transfers can be the result of communication, i.e. technological cooperation within networks. In both cases innovation capital flows from industries with high R&D to industries with low R&D. This process can lead to clusters of national industries being highly competitive in international markets. We will see that upstream industries can also use technological transfers as a means to bind downstream industries as long-term customers.

After deciding which R&D projects will be carried out the R&D phase of the innovation process begins in which the R&D staff of the firm actually tries to discover a new invention. The probability of success of this attempt will be increased by deploying already existing technological innovation capital. Technological innovation capital is based on past experiences and often tacit. Tacit knowledge (POLYANI, 1966) means here that the employees do know how to solve technical and economic problems occurring on a special region of the technological frontier but cannot explicitly communicate these skills. Tacit knowledge is firmly anchored in people and in the way they work together in a particular organizational structure. 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 in which the firm tries to build up a market for its new product. For this the economic innovation capital plays a crucial role again. The established links to other industries or government agencies help to find new customers. However, economic innovation capital includes not only links but also knowledge about innovative marketing strategies. We will deal with the latter in the following in great detail.

No matter if the innovation process eventually results in a successful innovation or not firms will gain new information which will add to the stock of already existing innovation capital. This growing innovation capital may enable firms both to find innovations in the technological neighborhood of familiar products and to imitate innovations of competitors fastly (NELSON, WINTER, 1982, p. 386). The chain of innovations within this limited but progressing field of knowledge will be called 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 technological innovation capital which is used to develop further innovations beyond the technological and economic capabilities of the laggards.[2] This explains why particular national industries can maintain their lead in Schumpeterian competition over a long time.

In the following section we will briefly deal with the opening of the technological path of the German plastics industry in the 1930s and the role which potential government's demand played in this process. Then

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[2] 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 own R&D projects.

we will discuss technological cooperation and innovative marketing strategies with the main emphasis on the German chemical firm BASF from the 1930s to the 1970s. A game theoretical model described in section 2 will lead the empirical analysis in section 3.

1.2 The innovation capital of the German plastics industry

The German plastics industry is a national cluster including machine makers specialized in plastics fabricating machines, chemical firms producing plastic materials, and plastics fabricators. These three subindustries impress due to their comparatively high shares in world exports in the period after the Second World War. In 1970, for example, West Germany's average share in world exports was 11.1 %. However, the respective numbers for the makers of plastics fabricating machines, the plastic materials producers, and the plastics fabricators were 31.7 %, 24.2 %, and 19.8 % (UNITED NATIONS, 1974). This result cannot be explained by comparatively low prices of the German suppliers (FREEMAN, 1963). It rather verifies the exceptional Schumpeterian competitiveness of the German plastics industry which itself was caused by its high innovation capital primarily accumulated by chemical firms and then transferred to machine makers and plastics fabricators.

The so-called "Ersatzstoffeuphorie" (substitute euphoria) in Germany in the first half of the twentieth century is the historical background of German chemical firms' early engagement on the technological path of plastics. This "Ersatzstoffeuphorie" was triggered by production of synthetic fertilizers and explosives during the First World War and culminated in striving for autarky in the Third Reich. Early basic innovations were high pressure synthesis of ammonia by the chemical firm BASF in 1913 and industrial production of acetylene on the basis of coal and lime invented by Farbenwerke Hoechst in 1917. The synthesis of ammonia led to independence from Chilean saltpetre imports and was model for synthesis of methanol (1922) which on its part enabled polycondensation of urea-formaldehyde resins. Acetylene also used to produce explosives evolved to an important raw material of plastics production in the 1930s (PLUMPE, 1990), but it was the search for methods of producing synthetic rubber which was the main impetus for opening up the technological path of plastics in Germany.

During the First World War Germany was cut off from markets for natural rubber. In this period synthetic rubber (methylrubber) was produced for the first time by Farbenwerke Hoechst in a total amount of 2350 tons. In 1926 I.G. Farben had taken up again the synthetic rubber research program and succeeded in developing a high quality all purpose rubber on the basis of butadiene and styrene, named BUNA S, in the early 1930s. The technological innovation capital built up in the synthetic rubber research program also enabled discoveries of basic product innovations in the technological neighborhood of BUNA S:

1. Scientists of BASF discovered in 1930 that styrene used for BUNA S can also be polymerized to the plastic material polystyrene.
2. Furthermore polystyrene can be processed to the foamed material “STYROPOR.”This plastic good invented by BASF in 1952 has found above all a use in construction industry.
3. The method of emulsion polymerization also developed in the synthetic rubber research program was used to produce the plastic material polyvinylchloride by BASF in 1931.
4. Copolymerization of butadiene, styrene and acrylonitrile led to latexes which serve among other things for the production of artificial leather.
5. In 1940 I.G. Wolfen invented the synthetic fibre “DRALON” on basis of polyacrylonitrile.
6. 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.
7. The search for synthetic rubber also motivated R&D projects at Bayer which eventually led to the development of the plastic material polyurethane.

This survey shows how the BUNA S project deeply influenced the accumulation of technological innovation capital in the German plastics industry causing thereby the high international competitiveness of this national cluster in the period after the Second World War. But this is ex post knowledge which German chemical firms did not possess in the early 1930s. Because of the low market price of natural rubber in this period (HOWARD, 1947, p. 8) chemical firms hesitated to built up production capacities for synthetic rubber. This technologically producable good seemed not to be successful in economic terms. That is why the German plastics industry owed a good deal of their early technological innovation capital to the National Socialist government whose potential demand for synthetic rubber helped to overcome this economic uncertainty. The National Socialist government contributed to the expenses of R&D and plant construction at Schkopau (BUNA 1) and what is more guaranteed to purchase a certain amount of synthetic rubber at a fixed price.[3] These guarantees reduced market risk of synthetic rubber producers considerably. Synthetic rubber plants in Huels (BUNA II) and Ludwigshafen (BUNA III) followed. Because of government's demand important materials of plastics production (acetylene, acrylonitrile, butadiene, ethylene, styrene) were transferred from research laboratories to large-scale industrial production which accelerated through "learning by doing" (ARROW, 1962) 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 by which this national cluster transformed its technological innovation capital in successful market innovations. We will concentrate on technological cooperation within inter-industry networks.

2 The game of technological cooperation

In this section we will model technological cooperation in the German plastics industry as a simple repeated game with two players.[4] The following assumptions are stylized facts of the actual conditions in the German plastics industry in the period after the Second World War. The players are a chemical firm representing the few big German plastics producers and a plastics fabricator standing in for the many small and medium-sized firms of this subindustry. We suppose that only the chemical firm tries to develop product innovations for the plastics industry. The plastics fabricator does not carry out any R&D.[5] Furthermore we assume that the chemical firm cannot succeed in pure price competition because it is not able to produce standard plastic materials (polyethylene, polystyrene, polyvinylchloride) as cheap as its foreign competitors.[6] If the German chemical firm has nothing to offer but the same products at higher prices the profit maximizing German plastics fabricator will buy its inputs abroad. But the chemical firm can improve its competitiveness by supplying not only plastic materials but also free information about innovative plastic goods. The development of innovation capital for downstream industries causes the chemical firm a lot of expenses. If the chemical

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[3] See "Contract about building up the synthetic rubber plant BUNA I at Schkopau from 1937", HOECHST ARCHIVES TEA Akten 1446-1457) For the economic incentives of the National Socialist fixed price or cost plus procurement contracts see STREB, STREB (1998).

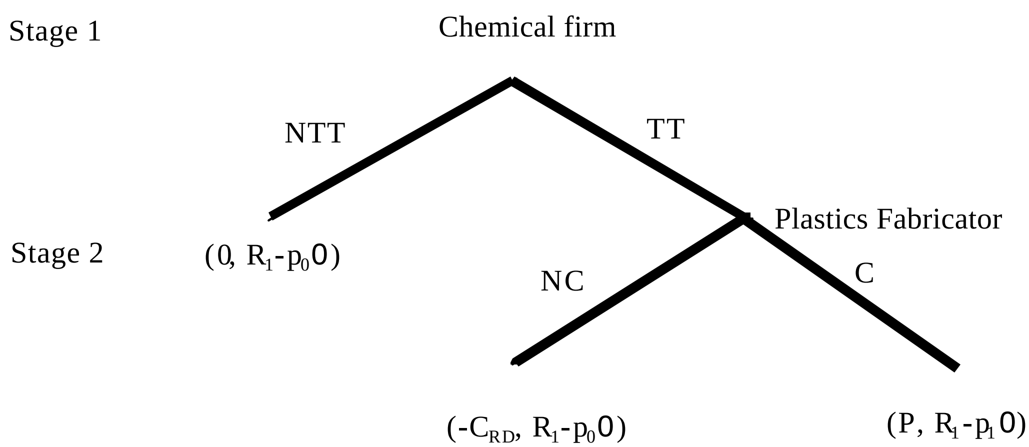
[4] For a survey of repeated game theory see for example AUMANN (1985) and PIERCE (1992).

[5] See FREEMAN (1963) p. 45.

[6] Comparing the prices of several standard plastic materials FREEMAN (1963, p. 30) shows that the German suppliers demanded a higher average price for plastic materials than their competitors in Great Britain and the USA in the 1950s.

firm is likely to gain the plastics fabricator as a customer by offering innovative knowledge in addition to plastic materials it will nevertheless have incentives to produce this.

The chemical firm communicates information about innovations to the plastics fabricator through product demonstrations and customer training. This technological transfer is carried out before the plastics fabricator actually commits itself to buy 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 take the technological transfer as a free lunch and to continue buying its inputs from foreign suppliers at lower prices or to order plastic materials from the chemical firm. Hence the game of technological cooperation has the following extensive form:



The chemical firm moving first has the choice between the two strategies “No technological transfer (NTT)” and “Technological transfer (TT).” The strategy “No technological transfer” means that the chemical firm will leave the market for standard plastic materials and what is more will not communicate any further product innovations 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 revenues from selling fabricated plastic goods, p the price of plastic materials, and x the quantity of plastic materials used by the plastics fabricator. We simplify analysis stating the following three assumptions:

1. The fabricating costs of the plastics fabricator are neglected and set zero. We only take into account expenses for plastic materials.
2. The amount of plastic materials processed by the plastics fabricator is always 0 no matter which particular plastic good is actually produced.
3. The technological transfer increases revenues of the plastics fabricator from R_0 to R_1 since the product innovations cannot be imitated by uninformed competitors of the plastics fabricator.

However, if the chemical firm plays the strategy “No technological transfer” the plastics fabricator will not realize increasing revenues. In this case the plastics fabricator buying the necessary plastic materials from foreign plastics producers at price p_0 gets payoff $R_0\&p_0 0$. Playing ”Technological transfer” in stage 1 the chemical firm has costs C_{RD} which includes both expenses for R&D and costs of communicating production innovations to the plastics fabricator. The payoff of the chemical firm depends on the reaction of the plastics fabricator in stage 2 whose revenues increases from R_0 to R_1 anyway. The plastics fabricator may decide to reward the technological transfer by playing “Cooperation” and purchasing its inputs from the chemical firm at price p_1, $p_1 > p_0$. But then costs of the plastics fabricator rise from $p_0 0$ to $p_1 0$. A first minimum requirement for playing “Cooperation” is that the payoff of the plastics fabricator is in this case at least as high as in the case without technological transfer.

(1)

$$R_1\&p_1 0 \ \$ \ R_0\&p_0 0.$$

If the plastics fabricator cooperates the chemical firm will realize a positive payoff P. This assumption implies that the revenues from selling plastic materials are higher than the costs of producing them in stage 2 plus the costs of technological cooperation C_{RD} in stage 1.[7] But the plastics fabricator cannot be forced to cooperate. Choosing “No cooperation” the plastics fabricator gets the payoff $R_1\&p_0 0$ with

(2)

$$R_1\&p_0 0 > R_1\&p_1 0.$$

[7] If the chemical firm successfully cooperates with more than one plastics fabricator it can spread its fixed costs over all buyers.

In this instance the chemical firm not selling any plastic materials realizes a negative payoff $-C_{RD}$. Backwards induction shows that the single shot version of this game has a unique Nash equilibrium in strategies "No technological transfer" and "No cooperation." The chemical firm knows that after receiving the technological transfer a profit maximizing plastics fabricator will choose to produce the product innovations using cheaper foreign plastic materials. The promise of the plastics fabricator 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 promise. If the game of technological cooperation is only played once a rational chemical firm will choose strategy "No technological transfer."

However, it is not realistic to interpret technological cooperation as a single shot game. Let us suppose that the chemical firm has decided for some reasons[8] to built up capacities for developing product innovations for the plastics fabricator. The building up of these particular R&D capacities needs investment in real and human capital which means sunk costs at least in parts. Hence the chemical firm surely wants to use these capacities for a long term producing not only one but a permanent stream of product innovations. If the chemical firm succeeds in doing this it can punish a plastics fabricator playing "No cooperation" by excluding it from future technological transfers. This threat will gain both credibility and power if the chemical firm plays the game of technological cooperation not only with one but with many plastics fabricators, which is the case in reality. In this instance the credibility of threat is higher since the chemical firm is able to afford losing one of its customers. The power of threat increases as a plastics producer has to fear falling behind its informed competitors after being excluded from the technological transfers.[9]

Technological cooperation is not a short-term single shot game but a long-term repeated game. 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 how many periods technological cooperation will still continue they are not able to choose their strategies through backwards induction (RUBINSTEIN, 1992).

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[8] We will discuss these reasons in great detail in section 3.

[9] However, the plastics fabricator Freudenberg & Co, Weinheim, for instance, complained about the wide spreading out of innovation capital by the chemical firms. If too many plastics fabricators were informed price competition would diminish the additional revenues. To maintain its competitiveness Freudenberg was nevertheless forced to cooperate. See FREUDENBERG-ARCHIVE 3/03233, Unterlagen zur Sitzung der Unternehmensleitung am 25. September 1984. Standortbestimmung CEEFORM und Aufbau der CEEFASKIN-Fertigung.

2. Players discount their future payoffs with the help of a discount factor a, a 0 (0,1). The discount factor is a measure for the “patience” of players. The higher a 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 “Technological transfer” and “Cooperation” as an equilibrium of the repeated game which is Pareto superior to the single shot Nash equilibrium “No technological transfer” and “No cooperation”.[10] We suppose that the chemical firm playing the game of technological cooperation with several plastics fabricators follows a simple trigger strategy each time:

1. In period 0 the chemical firm always plays strategy “Technological transfer.”
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, ..., 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 punishes 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 long-term cooperation. This aim will only be achieved if the trigger strategy implements combination “Technological transfer” and “Cooperation” 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 “No cooperation” in period t after playing “Cooperation” until period t-1. Because of this deviation the plastics fabricator will be excluded from any future technological transfer from period t+1 on. Then the plastics fabricator’s discounted long-term payoff equals

(3)

[10] For the general approach see FRIEDMAN (1971).

$$(1+\alpha+\ldots+\alpha^{t-1})[R_1-p_1\bar{x}]+\alpha^{t}[R_1-p_0\bar{x}]+(\alpha^{t+1}+\alpha^{t+2}\ldots)[R_0-p_0\bar{x}]$$

$$=\frac{1-\alpha^{t}}{1-\alpha}[R_1-p_1\bar{x}]+\alpha^{t}[R_1-p_0\bar{x}]+\frac{\alpha^{t+1}}{1-\alpha}[R_0-p_0\bar{x}]$$

The trigger strategy will only implement the cooperative solution as a subgame perfect Nash equilibrium if this sum is not bigger than the plastics fabricator's discounted long-term payoff when always playing "Cooperation,"

(4)

$$\frac{1-\alpha^{t}}{1-\alpha}[R_1-p_1\bar{x}]+\alpha^{t}[R_1-p_0\bar{x}]+\frac{\alpha^{t+1}}{1-\alpha}[R_0-p_0\bar{x}]\leq\frac{1}{1-\alpha}[R_1-p_1\bar{x}]$$

Transforming this inequality leads to

$$\alpha^{t+1}[R_0-p_0\bar{x}-R_1+p_0\bar{x}]\leq\alpha^{t}[R_1-p_1\bar{x}-R_1+p_0\bar{x}]$$

and finally to

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

From $\alpha<1$ follows

(5)

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

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 German chemical firm. What is more - given a certain difference of prices - the lower the discount factor α the higher the increase in revenues has to be to implement strategies “Technological transfer” and “Cooperation” as a subgame perfect Nash equilibrium through the trigger strategy. We have assumed that the chemical firm tries to play the game of technological cooperation with many plastics fabricators simultaneously. Let us suppose that the individual discount factors of these plastics fabricators a_i , with i = 1 ... I, are normally distributed over the interval (0,1). Then the number of plastics fabricators actually cooperating with the chemical firm will grow with increasing additional revenues caused by technological transfer.

Until now we have implicitly assumed that the differences (R_1-R_0) and (p_1-p_0) are constant in time. Allowing these quantities to change in time we are able to distinguish three different reasons for the ending of a former successful technological cooperation. All other things being equal players will end technological cooperation by turning to the single shot Nash equilibrium

1. if the additional revenues induced by the technological transfer have become too low to compensate the additional costs of the plastics fabricator; or
2. if the difference of prices has increased to an amount which cannot be compensated by the increases in revenues, or
3. if the prices for plastic materials of the German chemical firm have become equal to or lower than the respective prices of its international competitors.

In the first two cases the plastic fabricator will end the technological cooperation. In the third case the chemical firm may be unwilling to continue technological transfers. However, expectations 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 partly ending of technological cooperation within the network of the German plastics industry from the 1930s to the 1970s. This period covers first the National Socialist dictatorship and the post war reconstruction, second the so-called West German economic miracle, and third the decade of oil price shocks. We will show that the terms beginning, development and ending can be at least roughly assigned to these three subperiods. By choosing this time frame we also want to stress that the West German economic miracle can be understood as the continuation of an economic development already started in the 1930s. We will especially focus on the "Kunststoffrohstoffabteilung" (plastic materials department) of the German chemical firm BASF which was responsible for carrying out technological transfers from BASF to plastic fabricators and machine makers.

3.1 The beginning of technological cooperation

Completing trigger strategies it is usually assumed in repeated game models that players choose cooperative strategies in the first period 0 having by definition no own "history." However, we cannot just assume that automatically for chemical firms in the game of technological cooperation. A chemical firm will only take the risky first step to set up the capacities for developing and communicating product innovations[11] if it has a prior belief that the plastics fabricator is likely to cooperate after receiving the technological transfer. In our opinion in the early 1950s the German chemical firms had good reasons to suppose that technological cooperation with a downstream industry could be successfully carried out. Encouraging examples of 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 19th 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. 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 fabricators to cooperate.

First of all let us view the example of coal tar dyes.[12] The meteoric rise of the German chemical industry to a position dominating the world-wide market of coal tar dyes in the second half of the 19th century is usually explained by the excellent education of German chemists and the systematic use of industrial research laboratories. The fact is less noticed that the German producers of coal tar dyes also owed their success to the two new marketing strategies "customer consulting service" and "customer training" (BEER, 1959, pp. 91-94, STOKES, 1994, p. 20). The German chemical firms of the late 19th century had both technological and economic innovation capital.

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[11] The set up costs of these information producing capacities are independent of the number of times the game of technological cooperation will be played. See RADNER (1970) p. 457.

[12] 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 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.

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 the industrial research laboratories and filled with both commercial and technical staff. Customer consulting service was done by chemists who not only knew the special characteristics of new coal tar dyes but also had learned how to dye and print textiles.[13] Hence these chemists were able to understand the problems and the “language” of textile producers.[14] They explained in advance of sales how to use new coal tar dyes in production plants of textile producers and also provided technical help in cases of actual processing problems after sales. About 1900 the Coloristische Abteilungen developed the idea of customer training. They taught employees of textile firms to handle the latest techniques of dying and printing. Obviously this free one-year training was advantageous for textile firms. The chemical firms on their part won the loyalty of future customers. What is more they only informed the trainees about their own products thereby creating preferences. The Coloristische Abteilungen used customer consulting service and customer training both transferring technological knowledge to gain textile firms as long-term buyers. Half a century later German chemical firms recalled these marketing strategies when playing the game of technological cooperation with plastics fabricators.

We 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 fabricating machines hardly existed. 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.[15] But at this time economic circumstances have dramatically changed in comparison with those of the coal tar dyes boom before the First World War. Because of National Socialist autarky policy and the likely war markets for new plastic materials had to be primarily found within Germany. What is more the most important German chemical firms had formed I.G. Farben in the meantime,[16] so KURO had to open up new markets not only for BASF but for all I.G. Farben firms.

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[13] See ZOHLEN, OTTO. “Geschichte der AWETA 1865-1939.” BASF-ARCHIVES Q 001.

[14] To improve communication between chemists selling coal tar dyes and customers Coloristische Abteilungen also often employed native speakers abroad.

[15] See KUCKERTZ, HEINRICH. “Geschichte der AWETA 1896-1961.” BASF-ARCHIVE Q 001.

[16] 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,

However, after I.G. Farben had been broken up by the Allies KURO and most of its staff who had built up personal relationships with plastics fabricators remained in BASF. The accumulated innovation capital of KURO gave BASF a head start on its new German competitors in postwar Germany. Focusing on KURO of BASF in this paper we can continually view the development of technological cooperation in the German plastic industry from the 1930s to the period of German economic miracle.

Let us look at the period from 1938 to 1945. I.G. Farben not only included chemical firms but also machine makers like Eckert & Ziegler and plastics fabricators like Deutsche Celluloidfabrik Eilenburg, Rheinische Gummi- und Celluloidwerke Mannheim and Dynamit Nobel AG Troisdorf standing out due to its high 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 fabricating machines together with I.G. Farben machine makers and what is more to cause I.G. Farben plastics fabricators to test both new plastics fabricating machines and 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.

The two following examples are meant to represent product innovations developed by KURO in the period before 1945 (BASF, 1989, pp. 19, 24). Problems of Dynamit Nobel AG trying to fabricate new makes of polystyrene inspired KURO member H. Beck to invent the screw in-line injection moulding machine (patent 1943). This fabricating machine heats plastic materials more regularly and more precisely than conventional injection moulding machines[17] which allows the production of bigger plastic goods.[18] The screw in-line injection moulding machine was ready for market in the late 1950s and became an important export good of the German machine makers. So this product innovation as well represents the long-term technological progress in the German plastics industry overlapping political breaks. KURO also found a way to process the new plastic material isobutylene to plastic foils suitable for making buildings watertight thereby establishing a tradition. Product innovations for the construction industry turned into a special strength of the German plastics industry in the post war period.

Kalle & Co AG Wiesbaden Biebrich (Dreiverband 1904/06), Chemische Fabriken Uerdingen and Chemische Fabrik Griesheim. See STOKES (1988) pp. 11-13.

[17] The first injection moulding machine usable for large-scale production was innovated by Eckert & Ziegler in 1926.

[18] See GAETH, RUDOLF. “Entwicklungsgeschichte AWETA II im Jahre 1960.” BASF-ARCHIVE Q 001 (002).

We 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 fabricators in the immediate post war period. Positive past experiences created trust in the future willingness of plastics fabricators 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 (GROSSMANN, HART, 1986). However, we 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 fabricators at 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.

3.2 The development of technological cooperation

After defeating Germany in the Second World War the Allies firstly intended to prevent any future aggression of Germany through destroying all plants usable for producing military equipment. Point 3 of the "Plan for Reparations and Level of Post War German Economy"[19] from March 28th 1946 explicitly says: *"In order to eliminate Germany's war potential, the production of arms, ammunition and implements of war, as well as all types of aircraft and sea-going ships, is prohibited and will be prevented.*" What is more point 4 of this plan determined among other things that plants needed to produce synthetic rubber had also to be dismantled. The Allied Control Council actually forbad the production of synthetic rubber as well as butadiene and limited the capacities of styrene and chlorine, a raw material of polyvinylchloride, by Law Number 24 from March 3, 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 of synthetic rubber and plastic materials the obvious thing to do was to search for these alternatives in the latter field. The chemical products styrene and acetylene are necessary inputs for the production of the synthetic rubber

[19] Printed in RATCHFORD, ROSS (1947) pp. 225-230.

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

BUNA S. But styrene can as well be processed to the plastic material polystyrene; acetylene combines with hydrochloric acid to form vinylchloride which can be polymerized to the plastic material polyvinylchloride. Using their styrene and acetylene plants for production of plastic materials German chemical firms could protect them from dismantling. That which was lacking was a sufficient number of plastics fabricators demanding these products. That is why the chemical firms started supporting the building up of the German plastics fabricating industry.[21]

Let us again focus on the activities of KURO. After the breaking up of I.G. Farben KURO could not any longer cooperate with dependent downstream firms within the well-ordered organization of a concern. Henceforth KURO has had to play the game of technological cooperation with independent firms which had always the possibility to act in a non-cooperative way.[22] Therefore KURO had not only to open up markets for new plastic materials but also to gain plastics fabricators as long-term customers of BASF. First of all KURO members reestablished their contacts with already existing or potential plastics fabricators known from the I.G. Farben era. KURO granted those plastics fabricators initial aids by supplying free plastic materials and technological advices both by presenting new fabricating methods and by providing technical staff in cases of urgent processing problems. In the 1960s KURO refined its customer consulting service. Exploring downstream markets for plastic goods KURO started developing so-called “finished solutions”, i.e. complete strategies for plastics fabricators including information about how to produce an innovative plastic

[21] In the late 1940s, for instance, KURO encouraged some small plastics fabricators to erect 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 then.

[22] If the chemical firm took out a patent on a particular plastics fabricating process there could also be another way to promote the sales of the own products. In this case the chemical firm has the possibility to let the plastics fabricator choose between not paying a license fee when using plastic materials of this supplier or paying a license fee when processing products from competitors. That is what, for instance, 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. 23.7.1973.

good and where to sell it.[23] In addition KURO offered to optimize its customers' expensive moulds for free.[24] New plastic goods of long-term customers were tested no matter if the used plastic materials were bought from BASF or from other suppliers.[25] KURO also deployed the well-known customer training. Courses informing about new plastics fabricating methods were given. What is more KURO trained plastics engineers in a two-year program who were supposed to be exclusively employed by important customers of BASF (BASF, 1989, p. 52).

Members of the KURO staff pointed out that customer consulting service and customer training had considerably increased the loyalty of plastics fabricators to BASF in the post war period. They concluded that for this reason domestic and foreign competitors had not succeed in entering the market of BASF despite lower prices (KOLLEK, STANGE, 1985, pp. 284-285). In the 1960s, for example, BASF was able to sell the plastic material styrene acrylonitrile at a price being 5 % higher than the world market price.[26] However, the repeated game model of technological cooperation has shown that chemical firms can only maintain their customers' loyalty by permanently transferring technological knowledge which raises the revenues of plastics fabricators. Viewing the economic development in the 1970s will lead us to a similar result. So the marketing strategies customer consulting service and customer training will generate loyalty if and only if they communicate economically usable information which plastics fabricators cannot get as cheap 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 have to name the screw in-line injection moulding machine already mentioned above which was made ready for market by KURO in technological cooperation with machine maker Ankerwerke Nuremberg. This innovation helped the German plastics fabricators to get competitive advantages in world

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[23] In a first step, for instance, KURO developed a plastic good for the furniture industry. When a furniture fabricator was made interested in this invention, KURO introduced him to a plastics fabricator 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 1. Halbjahr 1964, AWETA II, pp. 46-48. KURO also checked new plastics fabricating machines 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 T 06, Informationsbriefe des Verkaufs Nr. 14. See also BASF-ARCHIVE F 9/159, Verkauf an Zentralbuero 6. Mai 1958, Preistellung fuer Monostyrol und Polystyrol.

markets since they had been informed about its usefulness by KURO early and in great detail. A second example for the innovativeness of KURO comes from the field of constructing. In the post war period the German construction industry had the highest consumption of plastic goods in this sector in the world for example leading in using 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 construction industry was the most important industrial customer of German plastics fabricators. In 1965 they sold 28.7 % of all plastic goods which were used as inputs in downstream industries to construction industry, 18.7 % to the machine makers, and 11.9 % to the electrical engineering industry (STATISTISCHES BUNDESAMT, 1972, pp. 60-71). Foamed polystyrene ("Styropor") innovated by KURO members Stastny and Gaeth in the early 1950s was also 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 makes of robust polystyrene for which KURO found uses in the construction of household and electrical appliances and in the car industry.

We have already mentioned briefly that it was the search for substitutes in a country being short of raw materials which gave the technological path chosen by German chemical industry its direction in the first half of the 20th century. This was still true in the period after the Second World War when shortage of raw materials more increased by the "dollar gap" of West Germany at least partly caused the fast growth of German plastics industry. Product innovations becoming successful export goods in a longer term were often "children of need" in the short term. It was for example not particular innovativeness but lack of alternatives which forced German construction industry to use plastic pipes instead of copper pipes, Styropor instead of cork.[27]

3.3 The ending of technological cooperation

In the 1970s KURO had to notice that plastics fabricators more and more often chose to switch to the strategy "No cooperation" in the repeated game of technological cooperation. Plastics fabricators kept trying to receive new technological information from KURO, but they refused the economic service in return buying

[27] Chipboards produced from wood scraps and urea-formaldehyde resins which were also innovated in the early 1950s helped the German furniture industry and machine makers specialised in chipboard fabricating machines to get a strong position in world market. See BASF-ARCHIVE T 06, Informationsbriefe des Verkaufs Nr. 4, p. 18.

plastic materials from suppliers with lower prices.[28] BASF reacted against this behavior as assumed for the trigger strategy in the repeated game model in section 2. Non-cooperative plastics fabricators were punished by being excluded from any future technological transfer. What is more KURO started selling new technological information instead of giving them away for free like before.[29] Establishing the plastics fabricator Delta Plastics BASF finally recalled vertical integration as an alternative to playing the 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 we will try to answer the question why in the 1970s many German plastics fabricators decided to end technological cooperation with German chemical firms after profiting from this inter-industry network for two decades. We know from analyzing the repeated game model in section 2 that plastics fabricators will be more likely to play a non-cooperative strategy first if the additional revenues caused by technological transfers decrease, or second if the additional costs resulting from not buying plastic materials from the supplier with the lowest prices increase. We will begin with having a closer look at the technological transfers.

Until now we have discussed technological transfers in the German plastics industry by naming product innovations developed by KURO. In a more macroeconomic approach we will now turn our attention to long-term growth of total factor productivity in the plastics fabricating 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. Technological progress usually does not fall like manna from heaven but results from R&D efforts. We have seen it was the big chemical firms and not the small or medium-sized plastics fabricators which did most of R&D in the German plastics industry in the post war period. Technological transfers from chemical firms to plastics fabricators

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[28] After successfully developing a polyethylene bottle for milk in technological cooperation with KURO, plastics fabricators, for instance, 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.

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

were then carried out either by communication or by delivering improved inputs. Sometimes both channels acted in combination. This again shows the example of the screw in-line injection moulding machine. In a first step KURO informed machine makers and plastics fabricators about how to produce and how to use this innovation. In a second step plastics fabricators substituted in-line screw injection moulding machines for their obsolete fabricating machines by buying them from machine makers.

Hence there are grounds for believing that the development of total factor productivity of German plastics fabricators was mostly determined by R&D successes and failures of upstream chemical firms. Under this assumption total factor productivity of the plastics fabricating industry can be used to answer the question at least roughly whether or not technological cooperation in this inter-industry network resulted in considerable increases in revenues of plastics fabricators. We have calculated total factor productivity on basis of a Cobb-Douglas production function which is homogeneous of degree 1 in the inputs labor and capital.[30]

(6)

$$P_t = O_t - aL_t - (1-a)(U_t + C_t)$$

Variables marked by the subscript t denote growth rates in year t. *P* stands for total factor productivity, *O* for gross real value added, *L* for total amount of hours worked, *C* for capital stock, *U* for capacity utilization, and *a* for wage share of factor incomes. Figure 1 in the appendix shows the annual growth rates of total factor productivity both for the German plastics fabricating industry and for the German manufacturing industry as a whole in the period from 1950 to 1980. We want to stress three results:

1. Except for the years 1963, 1975 and 1979 the annual growth rates of total factor productivity of plastics fabricators were always higher than those of manufacturing industry. This might indicate an above-average technological progress in plastics fabricating industry.
2. However, annual growth rates converged in time. In the first decade the average annual growth rate of total factor productivity of plastics fabricators amounted to over 350 % of the one of manufacturing industry. In the following this number was declining to 230 % in the second decade and to mere 160 % in the last decade.

[30] For calculation method see SOLOW (1957) and NELSON (1964). For data see KRENGEL et al (1973 and 1975) and GOERZIG et al (1986).

3. What is more the average annual growth rate of total factor productivity of plastics fabricators was also decreasing in its value from 5 % (1951-1960) via 2.1 % (1961-1970) to 1.3 % (1971-1980). German plastics fabricators were not able to repeat the considerable increases in productivity of the first two decades in the 1970s.

It seems highly likely that these results mean that the stream of product innovations communicated from the chemical firms to the plastics fabricators became much thinner in the 1970s.[31] This result may not be surprising since many important markets for plastic goods (packaging and containers, building materials, electronic equipment, household goods, toys) had been already developed thirty years after the discovery of standard plastic materials. There is also the fact that consumers started rejecting plastic goods in new uses and what is more preferring "natural" goods in apparent established markets of plastic goods due to both an increase in per capita income and an awakening care for environmental problems in the 1970s.[32]

Figure 2 in the appendix shows the development of growth rates of total factor productivity in the German and the US-American plastics fabricating industries for the period from 1951 to 1976. The US-American data are taken from KENDRICK and GROSSMAN (1980, p.151). Two reasons prevent direct comparison of German and US-American numbers. First KENDRICK and GROSSMAN used a slightly different method for calculating total factor productivity.[33] Second underlying Major Group 30 of Standard Industrial Classification includes not only plastics fabricators but also rubber fabricators. Nevertheless, we should at least be able to identify the main differences between the two industries. The fact stands out that the annual growth rates of total factor productivity of US-American plastics fabricators had negative values in the majority in the 1950s while the German numbers of this period were exceptionally high. We understand these comparatively higher growth rates of total factor productivity in the German plastics fabricating industry partly as a catching-up process partly as a developing lead in special fields like plastic goods used by construction industry.

[31] An indicator for the decreasing innovativeness of the 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.

[32] 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 KT,Fachreferat Polyvinylchloride, p. 27.

[33] KENDRICK and GROSSMAN used among other things a weighted arithmetic average of labor 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.

During the 1960s and the early 1970s the average annual growth rates of total factor productivity of the German and the US-American plastics fabricating industries were almost equal. This observation seems to indicate that in this period technological cooperation with the German chemical firms did not any longer help German plastics fabricators to get competitive advantages over their US-American competitors. This assumption is also supported by the fact that US-American chemical firms themselves started cooperating with plastics fabricators by building up departments similar to KURO in the early 1960s.[34] A speech of David H. Dawson of Du Pont from May 2nd 1961 excellently illustrates that: *"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 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."*[35] Successful marketing strategies can also be imitated.[36]

Let us summarize. The economic incentives for German plastics fabricators to choose a cooperative strategy in the repeated game of technological cooperation considerably declined in the 1970s. The threat of German chemical firms to exclude a plastics fabricator from future technological transfers lost a good deal of its terror since product innovations developed by German chemical firms obviously became rarer and less often led to additional revenues of plastics fabricators in a amount known from the past. What is more foreign chemical firms also provided new technological information for plastics fabricators now.

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[34] In 1960 Du Pont opened a sales department in Geneva which was responsible for the technological consulting of the European customers. See BASF-ARCHIVE Q 006 Ordner 1, Anwendungstechnische Mitteilungen aus Werk und Praxis Band III, AWETA II, KURO-LARO-SPEZIAL, Jahrgang 1960, Dezember-Heft. The Goodrich Chemical Comp. established a similar department in the Hague the same year. See FREUDENBERG-ARCHIVE 3/01250, Bericht ueber den Besuch bei der Firma B.F. Goodrich Chemical Comp., Cleveland am 28.3.1960.

[35] Cited after BACKMAN (1965) p.44.

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

Let us finally view the development of prices for plastic materials. The price competition in the field of standard plastic materials increased in the 1970s since more and more new suppliers entered world market such that overcapacities inevitably occurred.[37] The group of new suppliers included among others Japan and the oil producing countries at the level of national economies and the petroleum raffinating industry integrating forwards into plastics producing and plastics fabricating at the level of firms. Plastics producers in Belgium, Italy and the Netherlands especially became competitors of German chemical firms. An important thing here is that firms in Italy and the Netherlands profited from a particular locational factor. Large deposits of natural gas which can be used as a cheap raw material for production of plastic materials were discovered in both countries in the late 1950s (AFTALION, 1991). During and after the collapse of the Bretton Woods regime of fixed exchange rates the German Mark was considerably revaluated, for example with regard to the US-Dollar by 120 % between 1968 and 1980 (DEUTSCHE BUNDESBANK, 1995, p. 10). This development brought both advantages and disadvantages for the German chemical industry. On the one hand the repeated revaluations of German Mark enabled German plastics producers to buy necessary inputs produced from oil and usually priced at US-Dollars at comparatively lower prices than their foreign competitors. On the other hand it became more difficult for the German chemical industry to export plastic materials and easier for foreign suppliers to undercut its prices in Germany. How were the prices of plastic materials actually developing against this economic background?

A detailed comparison of international prices for the standard plastic materials polyvinylchloride, polystyrene, and polyethylene is hardly possible on basis of available data.[38] What is more German chemical firms affirm that a unique price for a certain plastic material does not even exist at the level of the firm itself since prices were differently set dependent on the particular customer and the amount of plastic materials ordered.[39] Nevertheless let us look at the published data about the development of German producer prices and wholesale prices in Italy and the USA converted in German Mark per kilogram for the plastic materials polyvinylchloride (figure 3) and polyethylene[40] (figure 4) for the period from 1968 to 1980. It turns out that

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[37] See BASF-ARCHIVE Q 002/5 1972-, Taetigkeitsbericht der AWETA KT 1972, Fachreferat Polyvinylchloride, p. 20.

[38] Statistical surveys of the international chemical industry edited by OECD did for example not include any data about prices of plastic materials in the 1970s.

[39] See for example BASF-ARCHIVE F 9/159, Preise der Lupolen-Marken vom 25.8.1958.

[40] In 1968 BASF noted 50 polyethylene producing competitors on the whole, among them 13 US-American and 7 Italian firms. See BASF-ARCHIVE Q 006 Ordner V, Anwendungstechnische Mitteilungen aus Werk und Praxis

German price competitiveness regarding both polyvinylchloride and polyethylene considerably got worse compared with the wholesale prices in the USA, especially in the time before the first oil price shock in 1974. We get a different result in regard to Italy. German and Italian prices for polyvinylchloride were almost developing parallel with slight advantages for Italy. In contrast to this prices for polyethylene were clearly changing to the disadvantage of Italy. Further price comparisons for polystyrene and with respect to Belgium or the Netherlands would be desirable but are not possible on basis of current available data. However, the international development of the indices of Revealed Comparative Advantage regarding the national plastics producers between 1970/72 and 1981/83 confirms the observations of figures 3 and 4 and seems to close some further gaps of our knowledge. Belgium and the Netherlands considerably improved their competitiveness in the world plastic material market in the 1970s, the United States held its position, Germany and Italy fell behind (UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION, 1986, p. 206).

The following conclusion may be drawn from the analysis of section 3.3. Playing strategy “Cooperation” in the repeated game of technological cooperation lost its attraction for German plastic fabricators in the 1970s since product innovations developed by German chemical firms did not any longer increase their productivity and revenues in the same amount as in the two decades before while differences between prices of German and foreign standard plastic materials did at best not considerably change in favor of the German suppliers. These observations explain why KURO had to notice in the 1970s that plastic fabricators more and more often behaved non-cooperative. There may be a third reason. German plastics fabricators themselves faced an intensifying competition for the rather stagnating demand for plastic goods. It is conceivable that this increased competition caused plastic fabricators to become more “impatient” and to strive for maximizing short-term profits primarily, i.e. their discount factors were not constant but decreased. All other things being equal decreasing discount factors themselves would increase the number of plastics fabricators playing “No cooperation” in the 1970s.

All that does not imply that German chemical firms completely stopped playing the game of technological cooperation in the fields of plastics in the 1970s. But they turned their attention to more advanced plastic

Band III, AWETA II und Schaumstoff-Abteilung, Jahrgang 1968, Maerz-Heft.

materials and to new partners.[41] This again illustrates KURO which successfully developed the plastic gas tank for the car industry.[42]

4 Conclusion

Starting point of section 1 was the hypothesis that a national industry needs both technological and economic innovation capital to succeed in Schumpeterian competition in world markets for a long term. Technological innovation capital is built up by early entering a new technological path often motivated by potential demand of governments. It enables a national industry to invent products on the respective frontier of knowledge. Economic innovation capital means the capability to transform technologically producable goods in successful product innovations. A national industry can improve this capability by forming networks with downstream or upstream industries. Technological transfers within these inter-industry networks can lead to clusters of different national industries all being highly competitive in international markets. Such a cluster was the German plastics industry in the decades after the Second World War including machine makers specialized in plastics fabricating machines, chemical firms producing plastic materials, and plastics fabricators. In the following we focused on technological transfers within the network of the German plastics industry.

In section 2 we developed a repeated game model of technological cooperation in order to explain under which economic circumstances plastics fabricators will buy plastic materials from a supplier offering its products at higher prices than its competitors. It turned out that a chemical firm can gain plastics fabricators as long-term customers despite its higher prices if it also supplies technological information which lead to additional revenues of plastics fabricators being higher than their additional costs.

In section 3 we viewed the historical development of technological cooperation in the German plastics industry from the 1930s to the 1970s. We especially concentrated on the so-called “Kunststoffrohstoffabteilung” (KURO), a special department of the chemical firm BASF, which was established to carry out technological transfers from BASF to other industries. The opening up of the new technological path of plastics was a byproduct of producing the synthetic rubber BUNA S by I.G. Farben.

[41] The idea to concentrate on advanced plastic materials was already expressed by KURO in 1968. See BASF-ARCHIVE Q 002/4 1967-1971, Taetigkeitsbericht 1968 AWETA II, Fachreferat Polyvinylchloride.

[42] Daimler-Benz, Porsche and VW received the technological information about this invention for free in the early 1970s. However, KURO and BMW agreed in 1974 that the latter would carry some part of the costs of developing the plastic gas tank for its cars. See BASF-ARCHIVE Q 002/5 1972-, Taetigkeitsbericht der AWETA KT 1974, Marktentwicklung Maschinenbau und Elektrotechnik, p. 63. See also BASF-ARCHIVE Q 002/4 1967-1971. Taetigkeitsbericht der AWETA II fuer das Arbeitsjahr 1967, Technikum fuer Kunststoffverarbeitung, p. 73.

After the Second World War German chemical firms supported the building up of the German plastics fabricating industry with the help of the marketing strategies customer consulting service and customer training which had been learned and for the first time successfully deployed during the coal tar dyes boom. Technological cooperation in the decades of the German economic miracle resulting in famous product innovations like the screw in-line injection moulding machine or foamed polystyrene drove the German plastics industry to a leading position in world markets. However, in the 1970s many German plastics fabricators switched to play a non-cooperative strategy in the repeated game of technological cooperation when starting buying their inputs from foreign suppliers at lower prices. Then we calculated growth rates of total factor productivity in the German plastics fabricating industry for the period from 1950 to 1980. It turned out that increases in productivity of German plastics fabricators in the 1970s were neither as high as in the two decades before nor higher than those of their US-American competitors. This result seems to prove that in the 1970s product innovations developed by German chemical firms did not increase revenues of plastics fabricators as often as in the past. What is more foreign chemical firms had also started offering new technological information in the meantime. All that considerably decreased incentives for German plastics fabricators to cooperate with German chemical firms.

The concepts of inter-industry technological cooperation in particular and non-imitable innovation capital in general can help to explain why certain national industries are dominating international markets for a long time. We can also learn from this concepts what national industries should do and should avoid if they want to win international Schumpeterian competition.

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Freudenberg Firmen- und Familienarchiv (FREUDENBERG-ARCHIVE), Weinheim, Germany.

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Appendix

Table 1 Domestic and Foreign Prices for Plastic Materials[1]

Year	Polyvinylchloride			Polyethylene		
	German Producer Prices	US-American Wholesale Prices	Italian Wholesale Prices	German Producer Prices	US-American Wholesale Prices	Italian Wholesale Prices
	1968=100	1968=100	1968=100	1968=100	1968=100	1968=100
1968	100	100	100	100	100	100
1969	104.5	97.7	104.3	96.5	96.4	100
1970	105.5	91.0	101.7	94.3	89.8	100
1971	103.8	83.5	97.4	91.8	70.1	100
1972	102.4	63.2	95.5	86.6	53.3	103.7
1973	108.0	54.1	93.1	85.9	50.3	111.1
1974	148.7	91.0	147.4	116.4	74.9	148.1
1975	141.6	106.0	131.0	112.5	90.4	146.3
1976	146.6	103.0	143.1	116.7	101.8	169.4
1977	144.6	102.3	131.9	110.5	95.2	147.2
1978	132.0	90.2	117.2	106.2	80.2	129.6
1979	157.2	94.0	148.3	128.9	79.6	184.3
1980	160.6	107.5	151.7	142.6	103.6	217.6

1 STATISTISCHES BUNDESAMT, editor. “Preise und Preisindizes fuer industrielle Produkte, Index der Erzeugerpreise.” *Fachserie M Preise, Loehne, Wirtschaftsrechnung Reihe 3*, Wiesbaden. STATISTISCHES BUNDESAMT, editor. “Preise und Preisindizes im Ausland.” *Statistik des Auslands Reihe 5*, Wiesbaden. The US-American and Italian prices are converted in German Mark per kilogram on basis of the average exchange rate of the respective year. For the exchange rates see DEUTSCHE BUNDESBANK, editor, 1995. “Devisenkursstatistik Februar 1995.” *Statistisches Beiheft zum Monatsbericht* 5. Frankfurt/Main. Notice that a US-American pound equals 0.4536 kilogram.

Table 2 **Annual Growth Rates of Total Factor Productivity, in percentage**

Year	Annual Growth Rate of Total Factor Productivity in percent [1]			Year	Annual Growth Rate of Total Factor Productivity in percent [1]		
	German Plastics Fabricators [2]	German Manufacturing Industry [3]	US Plastics Fabricators [4]		German Plastics Fabricators [2]	German Manufacturing Industry [3]	US Plastics Fabricators [4]
1951	14.1	3.4	15.1	1966	1.2	-0.1	0.9
1952	2.6	0.9	-2.8	1967	2.9	0.8	0.3
1953	5.2	0.8	-4.9	1968	3.2	1.3	4.2
1954	2.6	2.3	-3.6	1969	3.2	1.9	5.1
1955	4.8	2.4	-0.7	1970	0.3	0.1	-8.2
1956	2.0	0.6	-1.3	1971	2.7	0.2	6.8
1957	7.8	1.4	-2.4	1972	3.7	1.3	3.5
1958	4.6	0.4	3.8	1973	3.5	1.5	4.3
1959	8.4	2.1	13.5	1974	1.2	0.2	-9.3
1960	6.7	2.5	0.2	1975	0.1	0.4	-1.8
1961	3.5	0.8	4.3	1976	3.4	2.0	7.4
1962	6.0	0.9	6.0	1977	2.4	0.9	
1963	0.6	0.9	7.4	1978	1.6	0.5	
1964	6.1	2.0	2.6	1979	0.6	1.5	
1965	2.1	0.6	0.3	1980	0.4	0.0	

1 The German numbers are calculated on basis of data from GOERZIG, BERND, JOACHIM SCHINTKE and PETER BAUMANN, 1986. “Produktionsvolumen und -potential, Produktionsfaktoren des Bergbaus und des Verarbeitenden Gewerbes in der Bundesrepublik Deutschland - begruendet von Rolf Krengel.” *Statistische Kennziffern* 28 1970-1985. Berlin. KRENGEL, ROLF, EGON BAUMGART, ARTHUR BONESS, RAINER PISCHNER and KAETHE DROEGE, 1973. “Produktionsvolumen und -potential, Produktionsfaktoren der Industrie im Gebiet der Bundesrepublik Deutschland einschliesslich Berlin (West).” *Statistische Kennziffern* 13 1950-1960. Berlin. KRENGEL, ROLF, EGON BAUMGART, ARTHUR BONESS, RAINER PISCHNER and KAETHE DROEGE, 1975. “Produktionsvolumen und -potential, Produktions-faktoren der Industrie im Gebiet der Bundesrepublik Deutschland einschliesslich Saarland und Berlin (West).” *Statistische Kennziffern* 16 Neuberechnung 1960-1970. Berlin. The numbers for the US Plastics fabricators are from KENDRICK, JOHN W. and ELLIOT S. GROSSMAN, 1980. “Productivity in the United States. Trends and Cycles.” Baltimore, London, who use a slightly different calculating method.

2 The wage share of the German plastics fabricators is fixed on a = 0.408.

3 The wage share of the German manufacturing industry is fixed on a = 0.360.

4 This industry also includes the US rubber fabricators.

Figure 1 Annual growth rates of total factor productivity in the German plastics fabricating industry (GPF) and the German manufacturing industry (GMI), 1951-1980, in percentage

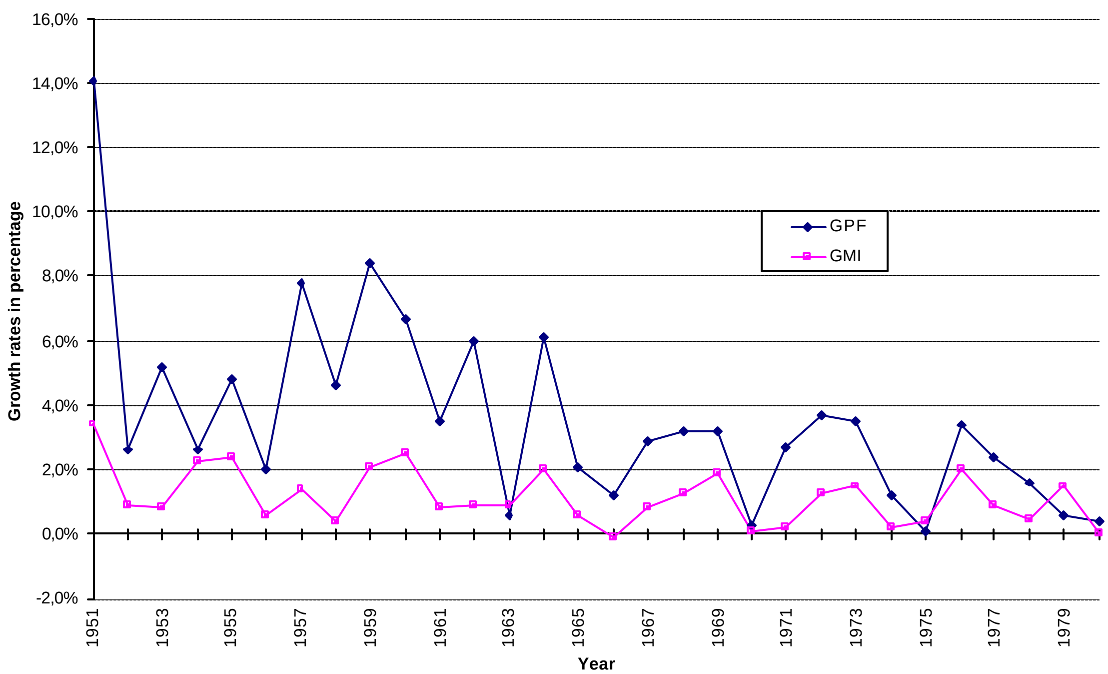

Figure 2 **Annual growth rates of total factor productivity in the German plastics fabricating industry (GPF) and the US-American plastics fabricating industry (USPF), 1951-1976, in percentage**

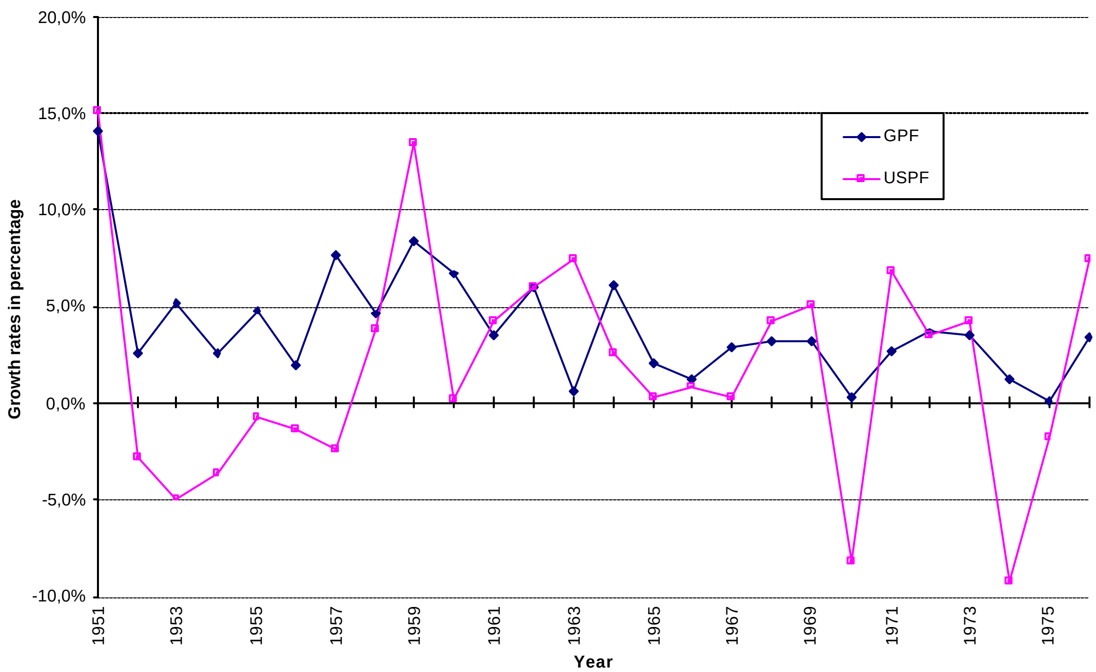

Figure 3 **German domestic producer prices and wholesale prices in Italy and the USA for polyvinylchloride, in German Mark per kilogram, 1968-1980, 1968=100**

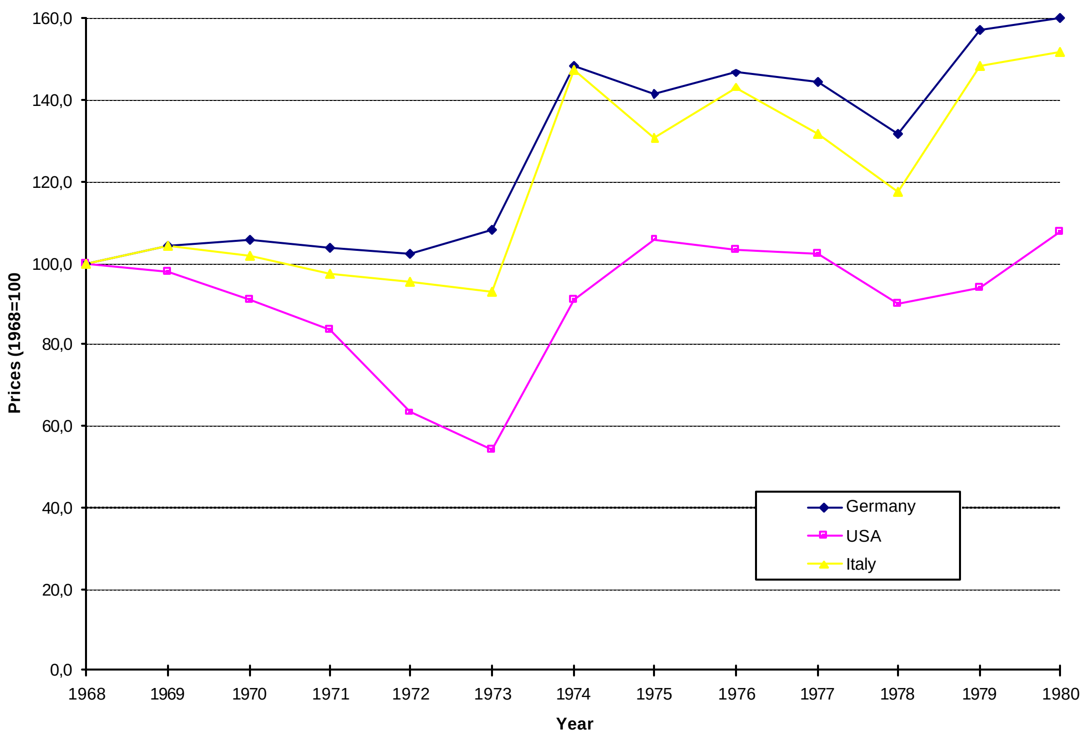

Figure 4 **German domestic producer prices and wholesale prices in Italy and the USA for polyethylene, in German Mark per kilogram, 1968-1980, 1968=100**