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Shaping the national system of inter-industry knowledge exchange Vertical integration, licensing and repeated knowledge transfer in the German plastics industry☆

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Abstract

We will claim in this paper that it was in particular the above-average propensity to share innovative information with customers and competitors which caused the exceptional international competitiveness of the West German plastics industry including chemical firms, plastics fabricators and machine makers. The system of knowledge exchange of this national cluster was shaped in two main steps. In the first half of the 20th century, cartellization and mergers were first tolerated and then even supported by the German government. It was in this period when German chemical firms formed the vertically integrated I.G. Farben concern which provided an optimal organisational framework to explore the new technological path of plastics. After the breaking up of I.G. Farben the firms of the West German chemical firms had to find new ways to maintain inter-industry technological co-operation in the second half of the 20th century. It turned out that they became aware of both contractual and non-contractual solutions of bundling standard good and information which were often placed somewhere between "market" and "hierarchy". It seems to be no accident that all these different institutions did primarily encourage knowledge exchange between firms in geographical and cultural proximity. That is why the knowledge exchanging network of the plastics industry described in this paper has been in particular concentrated on German firms. Even so the question is still open whether this localisation is just a curiosity limited to a special industry cluster or part of a broader German system of knowledge exchange.

JEL classification: L 1; L 65; N 84; O 3

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1. The problem of knowledge exchange

Economic history is full of examples which suggest that technological creativity has been one of the most important sources of long-term economic growth (see, for example, Mokyr, 1990). However, like others gifts, this talent has not been equally distributed among people, firms or industries. What is more this kind of inequality often not even balances out on the level of states. Obviously some nations have done better than others in bringing forth particular industries dominating international markets by their comparatively superior capability to innovate. That is why, measured

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by economic standards, some countries have been forging ahead while others have been falling behind (see Abramovitz, 1986). Nevertheless, it would be wrong to conclude from these empirical observations that we have to accept such an uneven development in the future too. Instead politicians and managers of those nations lagging behind may be able to improve the technological creativity in their particular home market by changing the attributes of the legal, cultural and economic environment. To find out appropriate ways to do this recent studies analyse the respective merits and disadvantages of historical "national systems of innovation" (see Edquist, 1997; Freeman, 1995; Lundvall, 1992; Nelson, 1993; Porter, 1990).

The German system of innovation of the late 19th century, for example, is especially credited for its advanced education system, the variety of specialised research organisations sponsored by government and its industrial research laboratories. It is widely believed that the new products which emerged from these organisational innovations allowed German firms to overtake their British competitors in fields like steel, chemicals or electro technical products (see Keck, 1993). However, the diffusion of knowledge might be as important as the creation of knowledge to make a national system of innovation working effectively (see Lundvall, 1998). In this respect Lundvall (1988) emphasises the importance of inter-industry knowledge exchange between upstream and downstream firms. There are several channels through which innovative information can be transferred from one firm to another. Drejer (2000) focuses on the flow of information embodied in commodities. Mapping inter-industry interdependencies on the basis of input–output tables she gets the result that the chemical industry was and still is the major source of embodied technology in Germany. In this paper, we will concentrate on the channels of pure knowledge exchange between supplier and customer. New information can flow in both directions. Being informed about actual problems and future needs of their customers, upstream firms are better able to assess which kind of technological invention will also be economically successful. In this case, it is the downstream industry which determines the choice of R&D projects executed by the upstream producers. It is also possible that the latter shape the future direction of their customers' technological progress by independently developing a new product which can be profitably sold in downstream markets. Equipment manufacturers as well as commodity suppliers have incentives to create and transfer this kind of knowledge whenever they expect that the market success of such an innovation will also increase the demand for their own products which themselves are serving as inputs in the respective process of production (see VanderWerf, 1992). However, every exchange of goods bears the danger that the receiver of a particular good refuses the economic return. This is particularly true for transferring innovative knowledge since it is especially hard for the supplier to prove before court that an intangible piece of information has actually been delivered. We will elaborate this hypothesis using some techniques of game theory.

We will model knowledge exchange as a two-stage game with two players.[1] These are an upstream firm supplying commodities and a downstream firm processing these inputs to consumer goods. We further assume that the R&D department of the upstream firm additionally has the capability to develop ideas for product innovations which are supposed to be put up for sale at the market of the downstream firm. The transfer of this knowledge to the downstream firm can be carried out through product demonstrations and customer training. Since the downstream firm will be reluctant to pay for this kind of information before exactly knowing its contents the upstream firm is forced to reveal its knowledge first (see Carter, 1989). Then the downstream firm can decide either to take the knowledge transfer as a free lunch or to reward the upstream firm for creating and transferring the useful innovative information. Hence, the game of knowledge exchange has the extensive form shown in Fig. 1.

The upstream firm moving first has the choice between the two strategies "Do not transfer" and "Transfer". The strategy "Do not transfer" means that the upstream firm will not communicate any innovative information to the downstream firm. In this case, the upstream firm realises the zero payoff. The same is true for the downstream firm. Playing "Transfer" the upstream firm has costs which includes expenses both for R&D and for teaching the downstream firm how to manufacture the product innovation. The total payoff of the upstream firm depends on the reaction

[1] See Streb (1999). For a similar concept see also Greif (2000).

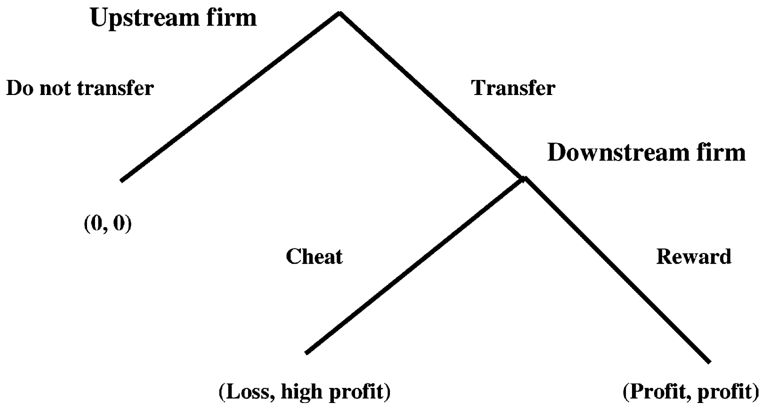

Fig. 1. The game of knowledge exchange.

of the downstream firm in stage 2. Being able to offer the product innovation to its customers exclusively the latter gets an unusual profit anyway. So the downstream firm might decide to play "Reward" which means that it compensate the upstream firm commensurately. Then both players would obtain a positive profit. However, the downstream firm will surely be tempted to refuse the upstream firm any economic return by playing "Cheat". In this case, the downstream firm will realise a higher profit while the upstream firm will have to face a loss.

To clarify the basic problems of trading information we now assume that both players meet only once. However, keep in mind that it is not realistic to interpret technological co-operation between firms as a single-shot game. In Section 3.2, we will give up this assumption and show that repeated strategic interaction might change the result of the game of knowledge exchange considerably. For the single-shot version of the game backwards induction leads to the unique Nash equilibrium in strategies "Do not transfer" and "Cheat". It is obvious that being in the decision-making process of the second stage the self-interested and profit maximising downstream firm will inevitably choose not to share its economic gains resulting from the preceding knowledge transfer. The anticipation of such a behaviour will effectively discourage the upstream firm to transfer its knowledge in the first stage. To put the matter in a nutshell, the knowledge transfer fails because of the fact that the promise of the downstream firm in the first stage to play "Reward" in the second stage is not credible since the upstream firm has no possibility to punish the downstream firm for deviating from this promise. However, since there also exists the strategy combination "Transfer" and "Reward", which would not only improve the situation of both players but as well increase the wealth of the national economy as a whole, this result is not satisfying. Hence, it seems reasonable for a society to try to establish additional rules of the game which change the outcome from the unwanted single-shot Nash equilibrium to this Pareto-superior solution. Because of historical, political and cultural differences some nations might be better than others in carrying out this task. In this case, country-specific institutions encouraging the knowledge exchange between firms should be added to the components of the respective national system of innovation.

We will claim in this paper that in 20th century Germany political and entrepreneurial decision-makers has been comparatively successful in promoting inter-industry knowledge transfer (see Lane and Bachmann, 1996). We will discuss this hypothesis in depth for the example of the German plastics industry which includes machine makers specialised in plastics fabricating machines, chemical firms producing plastic materials, and plastic fabricators. The selection of that example is especially justified by the fact that the exceptional international competitiveness of this national cluster, for example shown in Table 1, has been particularly caused by the stream of innovations primarily developed by the large chemical firms and

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 polymerised plastic materials	583	25.6	21.7
Machine and vehicle industry	7	17.8	16.8
Producers of rubber and plastics fabricating machines	72842	37.7[c]	35.1
Plastics fabricators	893	19.9	21.5

[a] See United Nations (2002).
[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.

then transferred to the small and medium-sized machine makers and plastics fabricators. For that reason we will try to identify the special institutions promoting this inter-industry information flow. Following Williamson‘s seminal distinction (see Williamson, 1975), we will be able to tell apart hierarchical and market solutions for the problem of knowledge exchange.

2. The hierarchical solution: vertical integration in the I.G. farben era

In the first half of the 20th century, cartellization and vertical integration were first tolerated and then even supported by the German political and juridical authorities.[2] An early milestone of this development was a decision of the German Supreme Court (Reichsgericht) in 1897 which confirmed that cartel agreements could in general be enforced under civil law. This judgement truly reflected the contemporary public opinion that cartels were a legitimate means to avoid the unwanted results of ruinous competition. Kleinwaechter (1883), for example, believed "that cartels aiming to organise chaos and to bring into line production with demand could be called to play the same role in the present time and the near future as the guilds did in the middle ages."[3] Taken by and large the first German cartel decree of 1923 still expressed the same view.[4] According to this law written cartel agreements were generally allowed. Though both executive and juridical authorities had the right to ban cartels misusing their power they hardly ever did. Consequently, it is not very surprising that this cartel decree officially pronouncing the legitimacy of such an alliance accelerated the diffusion of cartel agreements in Germany which doubled their number between 1923 and 1926 from 1500 to about 3000 (see Bremer, 1985, p. 120). The final act of the German cartellization was opened up in 1933 when the National Socialists entitled themselves to force private firms to enter into cartels.[5] So, in the early 1940s Gurland could conclude: "The economic situation is characterised by a very high degree of concentration. In no other country had cartels, the "horizontal" organisation of industry, achieved such progress as in Germany. In no other country was there such an intimate intertwining of production units both within the individual industries and across the boundaries of the individual trades. In no other country had the centralised organisation of both capital and commodity flow reached a similar level of completeness and tightness (Gurland, 1941, p. 230)." Table 2 sums up the increasing cartellization of the German economy between 1907 and 1935/1937.

It is sometimes argued that before the First World War the enforcement of the Sherman Antitrust Act

[2] See Feldenkirchen (1988). See also the relevant contributions in Pohl (1985).

[3] Kleinwaechter (1883, p. VI). In this work Kleinwaechter (1883, p. 143) also developed the influential idea that cartels are mostly "children of necessity" (Transl. Streb J.).

[4] See "Verordnung gegen Missbrauch wirtschaftlicher Marktstellungen (Kartellverordnung) vom 2. November (1923) pp. 1067f." Reichsgesetzblatt I (1923) 1067 f.

[5] See "Gesetz ueber Errichtung von Zwangskartellen vom 15. Juli 1933." Reichsgesetzblatt (1933) pp. 488 f.

Table 2
The cartellization of the German economy 1907–1935/1937[a]

West German industries	Share of cartellised firms' output in industry's total production (%)		
	1907	1925/1928	1935/1937
Mining	74	83	95
Iron and steel production	49	92	100
Non-ferrous metal production	10	31	80
Iron and steel processing	20	30	75
Non-ferrous metal processing	0	15	20
Mechanical engineering	2	15	25
Vehicle industry	7	11	15
Electrical industry	9	14	20
Precision engineering and optics	5	12	15
Chemical industry		70	75
Glass industry	36	66	100
Cement industry	48	90	100
Paper industry	89	70	85
Leather industry	5	5	10
Textile industry		10	15
Musical instruments and toys	9	18	15

[a] See Feldenkirchen (1985) p. 155.

which preferred amalgamations to cartels brought US-American firms to concentrate on merging instead of primarily cartellising like their British counterparts.[6] However, this conclusion does not explain the puzzling fact that the British firms facing a broader scope of action also restricted themselves mainly to one of these two options. It is the German example which shows that firms having the choice between the two organisational alternatives cartellising and integration can actually choose both. Apart from Germany's many cartels in the interwar period there also existed large mergers like the Vereinigte Stahlwerke AG in the iron and steel industry, the Schuckertwerke AG in the electrical industry or I.G. Farbenindustrie AG in the chemical industry (see Chandler, 1990, Part IV). What is more Kocka and Siegrist (1979, p. 82) hold the view that such mergers often arose from preceding cartels. This empirical development could be explained by the following reasoning. Above all participating in a cartel taught managers the advantages of exercising market power. However, they also had to learn that cartels were frequently destabilised by members trying to maximise their short-term profits by opportunistically breaking the agreements. So the idea to form a more reliable connection by integrating seemed to suggest itself.

For the ongoing argumentation of this paper Germany's outstanding cartel tradition has two important implications. First, as both cartels and mergers were often not limited to firms of the same industry they noticeably increased inter-industry knowledge exchange in the German economy in the first half of the 20th century. Second, the long-term co-operation within cartels and mergers created stable inter-industry networks which were frequently even strong enough to survive the antitrust legislation after the Second World War. In the following, we will discuss these two conclusions for the case of the plastics branch of I.G. Farbenindustrie AG founded in 1925. Since this large chemical trust was step-by-step arising from smaller and looser associations it is first of all a prime example for Kocka's and Siegrist's observation that in the first half of the 20th century it was nothing unusual that German firms' alliances were progressing from cartels to mergers. Finally, I.G. Farben comprised the chemical firms Bayerwerke Leverkusen, BASF Ludwigshafen and AGFA Berlin, this is the former "Dreibund" of 1904, Farbenwerke Hoechst Frankfurt/Main, Cassela Farbwerke Mainkur Frankfurt/Main and Kalle & Co. AG Wiesbaden Biebrich, that is the previous "Dreiverband"

[6] See, for example, Hannah (1974, p. 14).

of 1904, as well as Chemische Fabriken Uerdingen and Chemische Fabrik Griesheim (see Stokes, 1988, pp. 11–13).

Exploring the technological field of synthetic rubber these horizontally integrated firms also discovered ways to produce the new plastic materials polystyrene and polyvinylchloride on an industrial scale (see Plumpe, 1990, pp. 325–339). However, while synthetic rubber was demanded by the National Socialist Government preparing the Second World War (see Streb, 2002a,b), economic uses for these new plastic materials and even fabricating machines did seldom exist. That is why in 1938 the top managers of I.G. Farben decided not to wait until downstream firms would close this gap of knowledge but to set up the so-called plastic material department KURO ("Kunststoffrohstoffabteilung") at BASF Ludwigshafen assigned to develop the desired downstream innovations of its own accord.[7] Until the end of the Second World War this task was considerably facilitated by the fact that I.G. Farben was not only a horizontal amalgamation but vertically integrated too.[8] In particular, I.G. Farben included machine makers like Eckert & Ziegler in Cologne as well as plastics fabricators like Deutsche Celluloidfabrik in Eilenburg, Rheinische Gummi- und Celluloidfabrik and Schildkroete both in Mannheim, Rheinisches Spritzgußwerk in Cologne and last but not least Dynamit Nobel in Troisdorf which especially stood out due to its high innovativeness (see Ter Meer, 1953, p. 97). Obviously, most of these firms were located in the immediate geographical neighbourhood of the innovative focal points BASF in Ludwigshafen which is next to Mannheim and Bayerwerke in Leverkusen which is sited near Cologne and Troisdorf. Both vertical integration and localisation created optimal conditions for exchanging innovative knowledge (see Arrow, 1975; Maskell and Malmberg, 1999). The plastic material department KURO was able to develop plastics fabricating machines in co-operation with machine makers and what is more to cause plastics fabricators to test both new plastics fabricating machines and new plastic materials. Within I.G. Farben there was no danger that the supplier of some technological information was cheated by the recipient out of its economic return.

The following example is meant to elucidate the advantages of inter-industry knowledge exchange in the I.G. Farben era. In the early 1940s, Dynamit Nobel reported to the plastic material department of BASF that its workers had difficulties to fabricate the latest makes of polystyrene using the conventional injection moulding machines innovated by Eckert & Ziegler in 1926. Hereupon the KURO staff strove to solve this technological problem. Finally, it was actually KURO member H. Beck who succeed in doing this by inventing the screw in-line injection moulding machine in 1943. This fabricating machine heats plastic materials more regularly and more precisely than its predecessors thereby allowing the production of bigger plastic goods like the covering of refrigerators.[9] After the Second World War this invention helped not only the West German machine makers but also the West German plastics fabricators to get competitive advantages in world markets since they had been informed about its usefulness by KURO early and in great detail.

This example shows that vertical integration may indeed improve the flow of information between chemical firms and plastics fabricators and what is more might induce a more efficient R&D investment level in both industries (see Grossman and Hart, 1986). However, after the breaking up of I.G. Farben by the Allies the hierarchical solution for the problem of inter-industry knowledge exchange was not feasible any longer. Because of that German chemical firms were forced to create new institutions for transferring information between now independent firms. In the following we will concentrate on the development in Western Germany in the 1950s and 1960s.

3. The market solution: bundling standard good and information in the post-war period

As the post-war period was not only characterised by a strict antitrust legislation but also by the turning away from autarky the West German plastics

[7] See Kuckertz, Heinrich. "Geschichte der AWETA." BASF-Archive Q 001.

[8] See Office of Military Government for Germany (1986). See also Reichelt (1956).

[9] See Gaeth, Rudolf. "Entwicklungsgeschichte AWETA II im Jahre 1960" BASF-Archive Q 001 (002).

producers had to face two main problems not existing in the preceding I.G. Farben era. First, there was the unattractive possibility that the newly independent plastics fabricators would decide to choose activities running counter to the plastics producers' objectives. In particular, the latter were now able to refuse technological co-operation with the upstream firms. Second, there was the danger that foreign plastics producers trying to gain shares in the reopened West German market would succeed in displacing traditional local suppliers. Generally, in oligopolistic price competition a firm with comparatively high production costs will be pushed out of the market by more efficient suppliers who will set their prices just below the inefficient firm's marginal costs (see Tirole, 1988). In the 1950s, the West German plastics producers were especially threatened by this possibility since they deployed an inferior technology producing plastic materials from coal instead of oil like their US-American competitors (see Stokes, 1994). After making up for this shortcoming by imitating the superior technology of the American firms the West German plastics producers had to realise that in the meanwhile Italian and Dutch firms began to profit from large domestic deposits of natural gas serving as a comparatively cheap raw material for plastic materials (see Aftalion, 1991). It was not possible to remove this kind of locational disadvantage.

However, we take the view that in the post-war period the West German plastics producers were capable to avoid price competition with cheaper foreign suppliers through product differentiation. In general, product differentiation means that each firm produces an otherwise homogenous good in a special quality which noticeably 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 gaining the ability to alter profitably prices away from marginal costs (see Shaked and Sutton, 1982). Generally, the characteristics defining the quality level of a special product are inextricably linked with that product. On the other hand, it is possible to imagine that a firm does increase the quality of its standard product by bundling[10] it with an independent second good. This is what the West German plastics producers did when offering the plastics fabricators standard plastic materials combined with information about innovative plastics applications.

The creation of this kind of knowledge mainly took place in special plastic material departments of the German chemical firms for which the KURO of BASF already mentioned above was the encouraging archetype. Since the imitation of this organisational novelty of the German chemical industry also needed time, the foreign competitors were not able to supply similar knowledge in the short run. Therefore, the West German plastics producers had a temporary monopoly for this customer service gradually fading away in the 1960s when foreign firms themselves started building up similar departments. A speech of David H. Dawson of the US-American chemical firm Du Pont from May 2nd 1961 excellently illustrates the reasons for this catching-up process: "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 (cited after Backman, 1965, p. 44)." In the long run the particular institutions of a national system of knowledge exchange can be imitated by other nations too.

However, because of the comparatively high transaction costs of an isolated market exchange of knowledge it is very difficult to use an information monopoly for rent extracting. We have already mentioned that plastics fabricators are likely to refuse the economic return after receiving the innovative knowledge since third persons are hardly able to judge whether information transfer have been correctly carried out or not. Bundling information and plastic material makes

[10] For a general discussion of the "bundling" strategy, see Adams and Yellen (1976).

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. What is more if customers prefer this combination to the sole plastic material, product differentiation by bundling allows the supplier to put through a higher price than its competitors. Hence, by bundling standard good and information the West German plastics producers killed two birds with one stone avoiding problems arising from the locational disadvantages of the domestic production and from the high transaction costs of exchanging information.

We do not hesitate to conclude that all this was considerably facilitated by the German cartel tradition. Chemical firms recalling successful technological co-operation within I.G. Farben were more likely to dare to communicate technological knowledge to current independent plastics fabricators than competitors without this experience. Positive past experiences seemed to create trust in the future willingness of plastics fabricators to co-operate.

Whoever refers to the concept of trust has to face the problem that in social sciences there is nothing like a general agreement about the underlying sources of trust (see Lyons and Mehta, 1997). Economists, on the one hand, like to think that the decision to trust somebody is only based on a rational evaluation of the economic conditions of the actual market situation (see James, 2002; Sobel, 2002). This means in the context of the game of knowledge exchange that a supplier of information will only trust his customer, who is supposed to be self-interested, when he knows that the economic incentives are such that for the latter it pays more to co-operate than to cheat. In the following, we will use this argument to explain the functioning of repeated knowledge transfer. Sociologists, on the other hand, assume that trust between social actors evolves out of common beliefs and shared experiences and what is more can be fostered by suitable social institutions like a highly specified contract law or strong trade associations.[11] In the post-war period, trust resulting from shared experiences obviously played some role. It was already in the year 1974, for example, when the chemical firm Bayer, trying to revitalise the knowledge exchange with the plastics fabricator Freudenberg, still referred to the satisfying technological co-operation in the 1930s.[12] However, the question remains if loyalty and goodwill of receivers of knowledge will continue to exist when changing economic conditions increase the incentives for dishonest behaviour. We will discuss this point in Section 3.2.

The knowledge transfer between independent firms could be effectively carried out either by deploying contractual license agreements or by just using the reputation effects of repeated interactions. First, we will discuss the case of license agreements by analysing post-war marketing strategies of Bayer.

3.1. Licensing: a contractual type of bundling standard good and information

In the early 1950s, the chemical firm Bayer being one of the three main successors of I.G. Farben succeeded in developing the new plastic material polyurethane whose type Vulkollan was supposed to serve primarily as a basis for fabricating foam materials like insulating layers or upholstery. However, unlike other plastic materials Vulkollan cannot be produced by the chemical firm itself but has to be compounded by plastics fabricators. That is why Bayer intending to deliver the chemical components of Vulkollan was forced to reveal the innovative technological process to the downstream plastics fabricators. To prevent that after being completely informed the plastics fabricators would "cheat" by buying the necessary inputs from cheaper suppliers this knowledge exchange was carried out by using a formal license agreement. The heart of this written contract was a discriminating royalty tariff eventually giving Bayer the opportunity to realise higher prices than its competitors.[13] For this the actual amount of the royalty did depend on the origin of the used inputs. When the used components would be bought from Bayer there was no royalty payment at all, but when they were purchased from other chemical firms the licensee had to pay a fee based on the actual

[11] See Arrighetti et al. (1997), Lane and Bachmann, 1996.

[12] Bericht ueber Besuch bei Bayer AG Leverkusen am 6 Februar 1974 von Dr. Hans Erich Freudenberg, 8 February 1974, Freudenberg-Archive 2/02561. Freudenberg itself was not a formal member of I.G. Farben but intensively exchanged information with both the nearby BASF in Ludwigshafen and the contemporary centre of synthetic rubber research Bayer in Leverkusen. See Streb (2001).

[13] See the model of the German Vulkollan license agreement of the year 1954, Bayer-Archive, Kautschuk-Vulkollan Allg., 151/3.

prices of Bayer. A manager of British Dunlop summarised this kind of agreement: "Bayer will grant non-exclusive licenses to Dunlop under its Vulkollan patents and will give full existing technical knowledge and also knowledge obtained during the term of the agreement without payment or royalty, providing Dunlop purchases the raw materials from Bayer. It was explained that Dunlop may not be in a position to import some or all of these materials. In this case, Bayer would ask for a 10% royalty of the raw material purchased elsewhere, based on the Bayer prices."[14] Consequently, Bayer was able to appropriate the economic return for innovating Vulkollan either by selling its own products at comparatively high prices or by getting an extraordinary royalty. Bundling standard good and information in this way seems to solve the problem of knowledge exchange neatly.

To make sure that downstream plastics fabricators will actually accept such a license agreement the chemical firm has to restrict the number of licensees to an amount which is small enough to allow every recipient of the innovative information to improve its economic situation at the expense of the uninformed. Following Manskell and Malmberg (1999), it may be supposed that in this case the chemical firm will concentrate on firms which are located in its geographical neighbourhood or what is more which are already part of its traditional user–producer network. Fig. 2 might confirm this view.

Fig. 2 shows that in the early 1950s West German plastics fabricators were involved in more than half of all Vulkollan license agreements either just initiated or already concluded. European firms outside West Germany made up another third. Hence, the direct knowledge transfer to distant plastics fabricators from overseas was rather small. This empirical observation may encourage us to assume that the greater the geographical or cultural distance between a knowledge producing and a knowledge needing firm the lesser the chance that they will actually exchange information.[15]

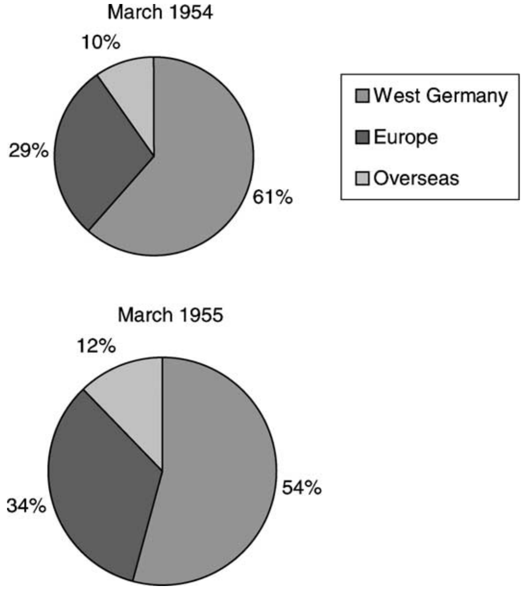

Fig. 2. Bayer's Vulkollan license agreements with plastics fabricators in West Germany, Europe and overseas, initiated or concluded, March 1954 and March 1955. See "Vulkollan-Vertraege Deutschland, 18. Maerz 1954", "Vulkollan-Vertraege Ausland, 18. Maerz 1954", "Vulkollan-Vertraege Inland, 18. Maerz 1955" and "Vulkollan-Vertraege Inland, 18. Maerz 1955", Bayer-Archive "autschuk-Vulkollan Allg." For data see Vulkollan-Vertraege 151/3.

That would help to explain why the development of highly innovative clusters like the West German plastics industry is often restricted to a special region or nation. Though Fig. 2 has not to be explained by distance alone. It was also the comparatively low prices of plastic materials in the United States of America that made the managers of Bayer believe that there was no chance to gain American plastics fabricators as customers for polyurethane components from Germany: "In America too there is only sense in producing Vulkollan where great quantities are concerned. Because of that exporting the respective raw materials which are in addition more expensive than in the United States is out of question."[16] That is why Bayer dealing with American Vulkollan producers did not try to establish the discriminating royalty tariff known from West Germany and Europe

[14] See the letter from E.A. Murphy (?) to Dr. Konrad of the synthetic rubber and plastic material department of Bayer, 25 April 1953, Bayer-Archive, Kautschuk-Vulkollan Allg., 151/3.

[15] This hypothesis seems particularly true for the exchange of tacit knowledge which requires an eyeball-to-eyeball contact between the one who knows and the one who wants to learn. See Polanyi (1966).

[16] Letter from O. Bayer to Dr. Konrad et al., 30 August 1951. Bayer-Archive, Erich Konrad—Lizenzvertraege fuer Vulkollan in den USA 1951–1954, 314/19 (transl. Streb J.).

but just tried to sell its technological know-how for cash.[17]

Bundling standard good and information by employing a discriminating royalty tariff was not an unusual exception limited to the case of Vulkollan. It was again Bayer, for example, trying to sell technological information about an innovative polyethylene foam who still used this contractual solution of the problem of knowledge exchange in the 1970s.[18] In general, license agreements seem to be an adequate method to bundle standard good and information whenever the new knowledge in question can be patented. Otherwise, the knowledge producing firm might use a non-contractual type of bundling standard good and information. We will show this by returning to the activities of the plastic material department KURO of BASF.

3.2. Repeated knowledge transfer: a non-contractual type of bundling standard good and information

To explain under which circumstances a repeated knowledge transfer between an upstream firm and a downstream firm can be interpreted as a non-contractual type of bundling standard good and information it is helpful to reconsider the game of knowledge exchange depicted in Fig. 1. For this we have first of all to specify the downstream firm's strategy "Reward". We now assume that "Reward" means that the downstream firm purchases its inputs from the upstream firm at a price which not only covers the costs of producing the standard good but also enables the upstream firm to appropriate the economic return for creating and transferring innovative knowledge. Therefore, this price is usually higher than the one demanded by other suppliers competing by offering just the plain standard good. Consequently, getting "Reward" in the repeated game of knowledge exchange would lead to similar benefits for the upstream firm than pushing through the discriminating royalty tariff in the license agreements discussed above.

Backwards induction has shown that the single-shot version of the game of knowledge exchange has an unique Nash equilibrium in strategies "Do not transfer" and "Cheat". Fortunately, in reality inter-industry knowledge exchange is rather a repeated game than a single-shot game.[19] 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 upstream firm surely wants to use this capacities for producing not only one but a permanent stream of product innovations being useful for downstream firms. If the upstream firm succeeds in doing this it can punish a downstream firm playing "Cheat" once by excluding it from further information transfer. In this case, the latter will fall behind informed competitors.

It can actually be shown that under certain conditions it is possible for the upstream firm to implement combination "Transfer" and "Reward" as an equilibrium of the repeated game which is Pareto superior to the single-shot Nash equilibrium "Do not transfer" and "Cheat" by following a simple trigger strategy:[20]

1. In period 0 the upstream firm always plays strategy "Transfer".
2. In period t the upstream firm will play strategy "Transfer" if and only if the downstream firm played strategy "Reward" in all past periods 0, $\ldots, t-1$.
3. If the downstream firm will choose strategy "Cheat" in any period t the upstream firm will play strategy "Do not transfer" in every future period starting from period $t+1$. In this way, the upstream firm punishes the non-co-operative downstream firm through returning to the single-shot Nash equilibrium.

As a result, this trigger strategy implements combination "Transfer" and "Reward" as a subgame perfect Nash equilibrium of the repeated game of knowledge exchange whenever the increase in the downstream firm's profits resulting from the knowledge transfer is higher than its additional costs when buying its inputs from the upstream firm which demands

[17] See, for example, the Vulkollan contract with B.F. Goodrich, Bayer-Archive "Erich Konrad—Lizenzvertraege fuer Vulkollan in den USA 1951–1954," 314/19.

[18] See "Lizenzvertrag zwischen Bayer AG und Carl Freudenberg ueber Herstellung von vernetztem Polyaethylen-Schaumstoff, 16/23 July 1973." Freudenberg-Archive 3/04802.

[19] For a survey of repeated game theory see, for example, Pearce (1992).

[20] For the general approach see Friedman (1971). See also Streb (1999).

comparatively high prices. We will show that this condition held for the inter-industry knowledge exchange in the West German plastics industry in the post-war period.

After the Second World War, the Allied Control Council forbade the production of synthetic rubber (see 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.[21] 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. That is why the chemical firms started supporting the building up of the West German plastics fabricating industry.[22]

Let us focus on the activities of KURO of BASF. In the immediate post-war years, KURO members re-established their contacts with already existing or potential plastics fabricators known from the I.G. Farben era. KURO granted those plastics fabricators initial aid by supplying plastic materials and technological advises for free. In the 1960s, KURO refined this kind of "customer consulting". 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 good and where to sell it. 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 bought its plastic materials from BASF.[23] In addition KURO offered to optimise its customers' expensive moulds for free.[24] Eventually, 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 used the marketing strategy "customer training".[26] In special courses, employees of plastics fabricators were taught to handle the latest techniques of processing plastic materials. Obviously this was advantageous for the plastics fabricators. The chemical firm BASF on its part hoped to win the loyalty of future customers. What is more KURO only informed the trainees about BASF's own makes thereby creating customers' preferences for these products. Furthermore KURO trained plastics engineers in a 2-year program who were supposed to be exclusively employed by important customers of BASF (see BASF, 1989, p. 52).

Members of the KURO staff pointed out that "customer consulting" 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 (see Kollek and Stange, 1985, p. 284). 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.[27] However, the analysis of the repeated game of knowledge exchange suggests that chemical firms with comparatively high prices can only maintain their customers' loyalty by permanently transferring knowledge which actually raises the profits of plastics fabricators. So, the marketing strategies "customer consulting" 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 post-war period. Examples especially came from the field of constructing.

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

[22] In the late 1940s, for instance, KURO of BASF 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). Then polyethylene became especially useful for the packaging industry.

[23] 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 Q 002/4 1967–1971, Taetigkeitsbericht der AWETA K fuer das Arbeitsjahr 1970, Technischer Kundendienst Spritzguß und Hohlkoerperblasen, p. 71.

[27] 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.

In the post-war period, the German construction industry had the world-wide highest consumption of plastic goods in this sector for example leading in using plastic pipes for water supply (see Freeman, 1963, p. 47). KURO went in front of this development. Foamed polystyrene ("Styropor"), for instance, invented by KURO members Stastny and Gaeth in the early 1950s, was used as an insulating material in the construction industry (see Hoelscher, 1972, p. 49).

In the 1970s, KURO had to notice that plastics fabricators more and more often chose to switch to the strategy "Cheat" in the repeated game of knowledge exchange. Plastics fabricators kept trying to receive new technological information from KURO but refused the economic service in return buying plastic materials from suppliers with lower prices.[28] BASF reacted against this behaviour as assumed for the trigger strategy: non-co-operative plastics fabricators were punished by being excluded from any further technological transfer. KURO also started using a contractual type of bundling standard good and information by 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 dealing with independent firms.[30] Why did this change happen?

We know from analysing the repeated game model that plastics fabricators will be more likely to play "Cheat" if the profits caused by knowledge transfer decrease. That is why we have to look for empirical facts indicating a declining economic value of the communicated product innovations. Therefore, we will now turn our attention in a more macroeconomic approach to long-term growth of total factor productivity in the plastics fabricating industry as a whole. As we have seen most of the R&D in the West German plastics industry in the post-war period was done by the big chemical firms and not by the small or medium-sized plastics fabricators. Hence, there are reasons to believe that the development of total factor productivity of German plastics fabricators was to a great part determined by R&D 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 co-operation in this inter-industry network resulted in sufficient increases in revenues of plastics fabricators.[31]

Fig. 3 shows the annual differences between the growth rates of total factor productivity in the West German plastics fabricating industry and in the West German manufacturing industry from 1951 to 1980. We want to stress two results:

1. Except for the years 1963, 1975 and 1979 the annual growth rates of total factor productivity of the plastics fabricators were always higher than those of the 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.

What is more the average annual growth rate of total factor productivity of the plastics fabricators was also decreasing in its absolute value from 5% (1951–1960) via 2.1% (1961–1970) to 1.3% (1971–1980). West German plastics fabricators were not able to repeat the ample 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. This result may not be surprising since many important markets for

[28] After successfully developing a polyethylene bottle for milk in technological co-operation with KURO, the plastics fabricator, 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.

[30] See BASF (1989, pp. 93–96); Kollek, Stange (1985, pp. 297–300).

[31] 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.

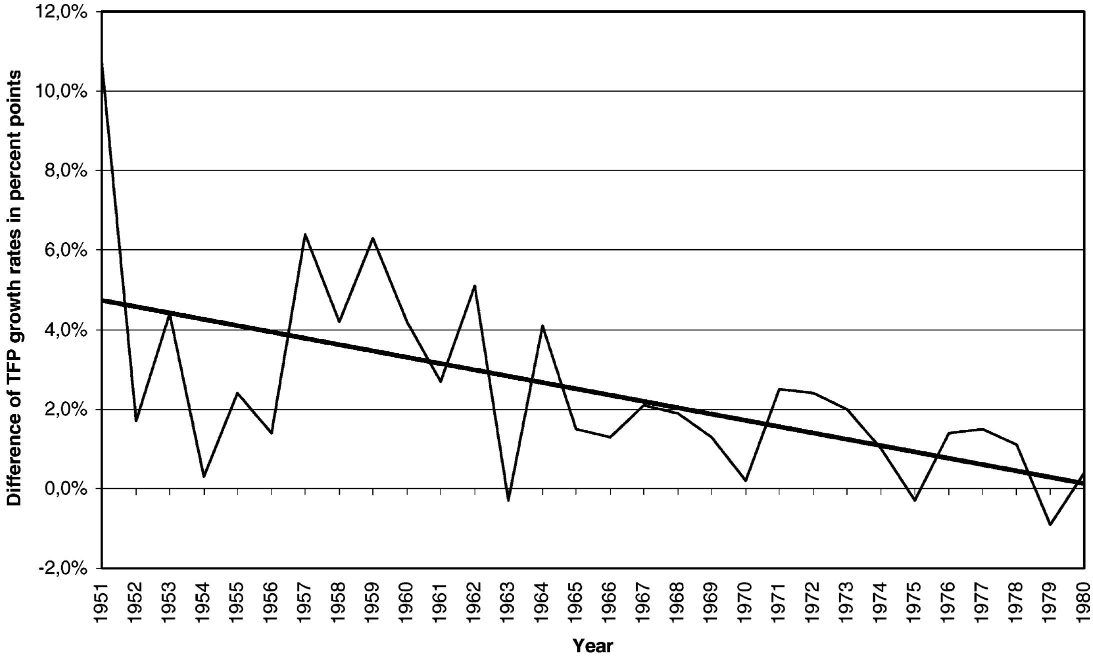

Fig. 3. The difference between the growth rates of total factor productivity of the West German plastics fabricators and the West German manufacturing industry, 1951–1980 (in percentage points). For data see Krengel et al. (1973), Krengel et al. (1975) and Goerzig et al. (1986).

plastic goods[32] had been already fully developed 30 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 consciousness for environmental problems in the 1970s.[33] All that does not imply that West German chemical firms completely stopped bundling standard good and information by repeated knowledge transfer. But they turned their attention to more advanced plastic materials and to new customers. This again illustrates KURO of BASF which successfully developed a plastic gas tank for the car industry. Daimler-Benz, Porsche and Volkswagen received the information about this innovation for free. 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.[34]

The failure of the repeated knowledge exchange in the German plastics industry in the 1970s indicates that trust based on shared experiences might not be sufficient to preserve inter-industry co-operation under unfavourable economic conditions. Hence, our findings seem to support the view that in economic relationships socially-oriented trust is less important than the kind of trust which is based on rational calculation of self-interested actors.[35]

[32] There are, for example, the markets for packaging and containers, building materials, electronic equipment, household goods and toys.

[33] 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.

[34] 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.

[35] See Lyons and Mehta (1997, p. 256).

4. Is there something like a German system of knowledge exchange?

We have claimed in this paper that it was in particular the above-average propensity to share innovative information with customers and competitors which caused the exceptional international competitiveness of the West German plastics industry including chemical firms, plastics fabricators and machine makers. The system of knowledge exchange of this national cluster was shaped in two main steps. In the first half of the 20th century, cartellization and mergers were first tolerated and then even supported by the German governments. It was in this period when German chemical firms formed the vertically integrated I.G. Farben concern which provided an optimal organisational framework to explore the new technological path of plastics. Chemical firms were able to develop plastics fabricating machines together with machine makers and what is more to cause dependent plastics fabricators to test both new machines and new plastic materials. The comparatively low transaction costs of transferring knowledge within I.G. Farben facilitated outstanding innovations like pioneering applications of the new plastic materials polyvinylchloride and polystyrene or the screw in-line injection moulding machine. After the breaking up of I.G. Farben the firms of the West German chemical firms had to find new ways to maintain inter-industry technological co-operation in the second half of the 20th century. It turned out that they became aware of both contractual and non-contractual solutions of bundling standard good and information. We especially analysed the merits and shortcomings of license agreements and repeated knowledge transfer.

It seems to be no accident that all these different institutions did primarily encourage knowledge exchange between firms in geographical and cultural proximity. That is why the knowledge exchanging network of the plastics industry described in this paper has been in particular concentrated on German firms. Even so the question is still open whether this localisation is just a curiosity limited to a special industry cluster or part of a broader German system of knowledge exchange.[36] First evidence for the latter is the fact that because of the plastics industry's role as a general technology source for the entire economic system of Germany[37] its knowledge exchanging network has expanded into a broad range of industries like textiles, machinery or motor vehicles.[38] So, it may be not too surprising that Harabi analysing data of the "Mannheim Innovation Panel" collected in 1994 comes to the conclusion that "the phenomenon of vertical relations between innovating, specially R&D performing, firms and customers is therefore widespread in German industry (see Harabi, 1997, p. 12)." What is more "this phenomenon seems to be more important in Germany than in France or Switzerland"[39] where similar empirical investigations have been carried out. For getting deeper results further research work comparing both different industries and different countries is needed which is hopefully stimulated by this paper.

[36] Most of inter-industry knowledge exchange may be even limited to a special region. See Delhaes-Guenther (2000).

[37] See Drejer (2000, pp. 384, 386).

[38] See, for example, the institutions the plastics fabricator Freudenberg used to organise technological co-operation with downstream clothing and car industries in Streb (2001).

[39] See Harabi (1997, p. 14).

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