CAN POLITICIANS SPEED UP LONG-TERM TECHNOLOGICAL CHANGE? SOME INSIGHTS FROM A COMPARISON OF THE GERMAN AND US-AMERICAN SYNTHETIC RUBBER PROGRAMS BEFORE, DURING AND AFTER WORLD WAR II.[1]

Jochen Streb
Heidelberg University

ABSTRACT

I investigated the effect of government demand on firms' innovation activities comparing the German and American synthetic rubber industries before, during and after World War II. I obtained three main results. 1. Because of the low price of natural rubber, price and sales guarantees were needed to motivate firms to produce the synthetic rubber BUNA S. 2. Facing fixed prices I.G. Farben improved their efficiency more than the American firms working under cost plus contracts. 3. The patent sharing agreement of the American synthetic rubber program caused firms to hold back advanced synthetic rubber inventions.

Can International Competitiveness be Achieved through National Technology Policy?

Present-day mass unemployment and low economic growth in many European economies have led to doubts about whether domestic industries can deal with increasing competition from producers in countries with lower wages. However, international comparative research shows that firms located in a country with comparatively high wages may be able to dominate international competition in the long term, as long as they are in a position to open new markets by applying innovative technologies.[2] This is due to the fact that the first mover has an array of economic advantages over his competitors who lag behind. At first, the innovator's already established brand name may have tied the consumers to his products. In addition, it is also possible that he can underbid the emerging competitors in a price war, even with comparatively high wages, since on account of his greater current and accumulated output he experiences cost reductions due to economies of scale and increases in efficiency subsequent to "Learning by doing." Finally, his greater experience leads to advantage with the new technologies in the area of research and development. While his competitors are still trying to perfect imitations of the "old" innovations, this first mover can already begin presenting "new" innovations to the market in the technological neighborhood of his earlier successes.

The high costs of research and development projects with unknown outcome imply considerable risks for a potential innovator, however. Therefore, even formerly innovative firms often stop investing in the search for innovations and limit themselves instead to the rather conservative strategy of improving their previously innovative and currently

established products and production processes in incremental steps and imitating successful products of their competitors. Yet in the long run this cautious behavior can lead to a loss in international competitiveness, since it allows backward competitors from low-wage countries to catch up technologically. National governments of high-wage countries try to react to this danger and re-accelerate the technological progress in domestic industries via an active technology policy. The following shall address the question of how a technology policy should be formulated to meet this aim.

The attempt to identify efficient technological measures with the aid of isolated cases leads to the well-known methodological problem called counterfactual hypothesis. This methodical problem can be avoided by comparing economic development in several case studies which are as similar as possible in their basic conditions but vary from each other in the variables to be examined. Therefore we have chosen a comparison of the economic development in the synthetic rubber production in Germany and the USA before, during and after World War II.

Points of Common: Government Demand, Technology and Quantitative Goal Attainment

In the first half of the 20th century the demand for natural rubber increased sharply, parallel to the growth of the new car industry. In the course of this development the access to the Southeast Asian rubber plantations became what seemed to be a pre-requests for the economic prosperity of the western industrialized countries and in an increasing measure for their military successes in modern mobile warfare. This explains why Adolf Hitler attached particular importance to setting up German synthetic rubber production in his secret memorandum of 1936 on the tasks of a four-year plan.[3] In the same year the German chemical trust I.G. Farben began constructing an industrial plant for the production of synthetic rubber in Schkopau (Buna I Plant), whose output reached a scale justifying the term industrial mass production in 1939 for the first time. Three more plants for synthetic rubber production were set up in the following years. The main synthetic rubber type produced was BUNA S, a copolymer made of 70% butadiene and 30% styrene.

The United States was by far the largest consumer of natural rubber in 1939 with a share of the world consumption at 53%. Natural rubber was also the most important American import good measured by value.[4] Nonetheless there was no government plan in the USA on the eve of World War II for setting up a domestic synthetic rubber industry in order to reduce what could have been seen from a military perspective as a dangerous dependence on natural rubber imports from Southeast Asia. Only the Japanese attack at Pearl Harbor on December 7, 1941 and the subsequent invasion of the Southeast Asian region moved the American government to begin the construction of a state-supported synthetic rubber production. The US rubber crisis appeared to be intensified by the circumstance that the synthetic rubber types developed by American firms, such as Duprene by Du Pont on the basis of chlorine and Butyl rubber by Standard Oil (New

Jersey) on the basis of isobutylene, were not appropriate for the production of car tires. However, thanks to the pre-war technological co-operation between Standard Oil (New Jersey) and I.G. Farben the patents and the technical know-how for producing the German synthetic rubber type BUNA S were available.[5] Finally, a total of 15 government-financed plants for BUNA S production were set up. These were operated by the four large American rubber fabricators: Firestone Tire Rubber Co., B.F. Goodrich Co., Goodyear Synthetic Rubber Corp. and U.S. Rubber Co. (three plants respectively) as well as by the Copolymer Corp., General Tire & Rubber Co. and National Synthetic Rubber Corp. (one plant respectively).

Table 1 Domestic consumption of rubber and production of BUNA S in Germany and the United States of America, 1937-1945

Year	Germany			United States of America		
	Production of the synthetic rubber BUNA S in metric tons[a]	Domestic consumption of natural and synthetic rubber in metric tons[b]	(II) in percent of (III)	Production of the synthetic rubber BUNA S in metric Tons[c]	Domestic consumption of natural and synthetic rubber in metric tons[d]	(V) in percent of (VI)
(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)
1937	2110					
1938	3994	101940	3.9			
1939	20576					
1940	37137	68004	54.6			
1941	65889	77280	85.3	231	1049010	0.0
1942	94166	97584	96.5	3781	659650	0.6
1943	110569	91008	121.5	185175	791532	23.4
1944	97493			680992	977256	69.7
1945				730914	1056686	69.2

a) cf. Dunbrook, R.F., "Historical Review," in *Synthetic Rubber*, ed. Stafford Whitby (New York: J. Wiley, 1954), 53.
b) cf. Laenderrat des Amerikanischen Besatzungsgebiets, *Statistisches Handbuch von Deutschland 1928-1944* (Muenchen: Ehrenwirt, 1949), 312.
c) cf. Dunbrook, "Historical Review," 52. One long ton equals 1.016 metric tons.
d) cf. Herbert, Vernon and Attilio Bisio, *Synthetic Rubber: A Project that had to Succeed* (Westport/CT: Greenwood Press, 1985), 127. One long ton equals 1.016 metric tons.

Table 1 shows that, by mere quantitative standards, both Germany and the United States were successful during World War II at compensating for the decline in their natural rubber imports through the production of BUNA S. Yet compared to their pre-war consumption levels, both countries were forced to reduce their rubber consumption when they entered the war on account of the initially insufficient production of BUNA S. This supply shortage caused by the decline in natural rubber imports was overcome in Germany after 1942 and in the USA after 1944. In Germany the BUNA S production surpassed the domestic consumption in 1943. In the United States the combined use of the three procurement sources - 1. synthetic rubber production, 2. natural rubber imports and 3. rubber recycling - allowed a new consumption record in 1945. However,

this finding should not mislead one into believing that BUNA S could easily replace natural rubber in every area of application equally well.

Differences: Increases in Efficiency and Advanced Synthetic Rubber Inventions

The development of the German and American production costs for a fixed amount of BUNA S is compared in columns III and IV of table 2, and shows that the American synthetic producers attained greater cost reductions than the German producers. The empirical data underlying this comparison not only contains the costs for labor, capital and energy inputs used in the synthetic rubber production plants, but also the costs for acquiring butadiene, styrene and other raw materials. That is why the observable difference in the development of production costs can be traced back to an array of causes. The possibilities include, for example, differences in the changes in wages and in the prices of the basic materials needed, or in economies of scale due to a greater output per production plant. However, it can be shown that the fall in American production costs was, for the most part, brought into the BUNA S factories by outside factors via technological changes in the upstream butadiene production.[6]

Table 2 Production costs per unit BUNA S in the German plant Schkopau (1939-1944) and on average of the 15 US-American plants (1943-1945, 1948/49)

Year[a]	Production costs per unit BUNA S					
	in Germany (Schkopau)		in USA			
	on the basis of butadiene out of acetylene[b]		on the basis of butadiene out of grain alcohol and oil (factual case)[c]		on basis of butadiene out of oil (counterfactual case)	
	Reichsmark per 100 kilograms	Index	cents per pound	Index	cents per pound	Index
(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)
t	216.22	100	35.50	100	14.22	100
t+1	164.23	76	30.70	86	14.61	103
t+2	159.65	74	23.10	65	14.34	101
t+3	167.57	77				
t+4	152.03	70				
t+5	137.57[d]	64	13.60	38	13.60	96
t+6			13.80	39	13.80	97

a) Starting point t is each time the year in which the respective national synthetic rubber production reached an industrial scale for the first time. For Germany t is 1939, for the United States t is 1943.

b) cf. Bayer-Archives Leverkusen, "Bestand: Ausschuesse und Kommissionen, Aktentitel: TEA-Buero," Signatur: 13/17, Mikrofiche 161, 12-13.

c) cf. Herbert, Vernon and Attilio Bisio, *Synthetic Rubber, a Project that had to Succeed* (Westport/CT: Greenwood Press, 1985), 130-131, Synthetic Rubber Recommendations of the U.S. President, transmitted to the Congress together with a Report on Maintenance of the Synthetic Rubber Industry in the United States and Disposal of Government-owned Synthetic Rubber Facilities (U.S. Govt. Print.Off., 1950), 44.

d) This number only refers to the first quarter of 1944.

Butadiene was the actual bottleneck of the American synthetic rubber program. For this reason, producers fell back on butadiene based on grain alcohol which could be produced substantially more quickly, albeit four times more expensively than oil based butadiene. Only in the course of the progressive capacity development did the cheaper butadiene from oil, which had only contributed to the BUNA S production with a share of some 18% in 1943, replace grain alcohol based butadiene gradually. In 1948 and 1949 only oil based butadiene was used. This meant that the American BUNA S producers were able to achieve considerable cost savings that cannot be traced to their own efforts at increasing efficiency, but to the substitution of the more expensive grain alcohol based butadiene with the cheaper oil based butadiene. To distinguish these two determinants of the production cost development, it was hypothetically assumed that the butadiene production in the USA was completely based on oil from the beginning. Column VII in table 2 shows the striking result of this counterfactual hypothesis: without the cost reducing influence of the technological change in the butadiene production, the production costs for a unit of BUNA S in the first seven years of the American synthetic rubber production would have remained nearly constant. The German BUNA S production experienced no comparable dramatic process of technological substitution in the period under examination. Therefore, under the given conditions, the German production cost decrease of 36% in Schkopau could have been caused by mobilizing internal reserves of efficiency both in the manufacturing of BUNA S and in the upstream production of its chemical inputs.

Table 3 Production costs per unit BUNA S in Schkopau, first quarter of 1941 to first quarter of 1944[a]

Fourth of year	Production costs per 100 kilograms BUNA S		including expenses for					
			Butadiene		Styrene		Other inputs[b]	
	Reichs-mark	Index	Reichs-mark	Index	Reichs-mark	Index	Reichs-mark	Index
I. 1941	158.40	100	94.62	100	25.16	100	22.14	100
II.	159.79	101	95.43	101	25.38	101	21.60	98
III.	159.40	101	98.16	104	26.10	104	18.79	85
IV.	160.78	102	99.09	105	24.81	99	19.65	89
I. 1942	167.22	106	106.36	112	22.97	91	20.35	92
II.	165.97	105	106.04	112	21.92	87	20.34	92
III.	169.75	107	102.77	109	22.72	90	22.38	101
IV.	167.29	106	99.45	105	22.63	90	23.24	105
I. 1943	145.13	92	88.56	94	21.69	86	20.93	95
II.	156.51	99	92.00	97	22.84	91	21.71	98
III.	151.46	96	90.62	96	22.70	90	20.31	92
IV.	151.00	95	87.51	92	21.62	86	19.48	88
I. 1944	137.57	87	85.22	90	21.10	84	18.99	86

a) cf. Bayer-Archives Leverkusen "Bestand: Ausschuesse und Kommissionen, Aktentitel: TEA-Buero," Signatur: 13/17, Mikrofiche 161, 13.

b) The expenses for "other inputs" comprise wages, energy and repair costs, overheads, taxes as well as deprecation and interest payments.

As table 3 shows, the 13 % reduction in the production costs of a unit of BUNA S made between the first quarter in 1941 and the first quarter in 1944 at the BUNA I Plant in Schkopau can be traced back to lower costs for butadiene and styrene as well as to savings in factor costs, which in addition to labor and capital, especially takes the energy input into consideration. The reduced expenses for the chemical inputs butadiene and styrene can be explained in part by increases in efficiency in the upstream production levels, and in part by a thrifty use during the actual production of BUNA S.[7] Obviously the German BUNA S producers felt considerably stronger incentives than the American manufacturers to reduce their production costs via rationalization measures, via modification of the processes of production or via cautious handling of the chemical inputs.

The progress of Germany's advanced synthetic rubber research was revealed at the end of World War II when American experts investigated German production technologies. The Americans recognized early that they had the opportunity as an occupying power to use this knowledge, accumulated in Germany, as a modern form of reparations for their own military and economic purposes. In this process, the research projects of I.G. Farben were a preferred and repeated target of American inquiries. In the opinion expressed in 1956 by Carl S. Marvel, Professor of Chemistry at the University Illinois, who was personally involved in the investigations in Germany, the information collected led to a fundamentally new orientation of the American synthetic rubber research: "A very large proportion of the present research effort in the Government Synthetic Rubber Program is based on the leads that were obtained through these Technical Intelligence Reports."[8] New findings were obtained particularly in three fields:[9]

1. Cold rubber: During World War II the American BUNA S was polymerized in 12 hours at 50° Celsius. The American observer now found out that a procedure for "cold" polymerization had been conceived in the I.G. Farben laboratories. By combining an oxidizing agent and a reducing agent it was possible to produce synthetic rubber in 12 hours at 10° Celsius or in less than an hour at 40° Celsius. An increase in output and a lower energy consumption were among the resulting advantages.

2. Oil-extended rubber: In Germany methods were developed during World War II to extend BUNA S by adding mineral oil. This approach increased the amount of available synthetic rubber and lowered its price per unit.

3. Synthetic natural rubber: A disadvantage of BUNA S was that it could not be used for producing airplane and truck tires that were exposed to heavy loads. I.G. Farben scientists expressed the view to an American research team that this requirement would only be met by a still-undiscovered synthetic rubber type whose molecular structure corresponded to that of natural rubber (a compound of isoprene). In fact, the following decade demonstrated that it was actually possible to produce synthetic poly-isoprene whose characteristics largely matched those of natural rubber.

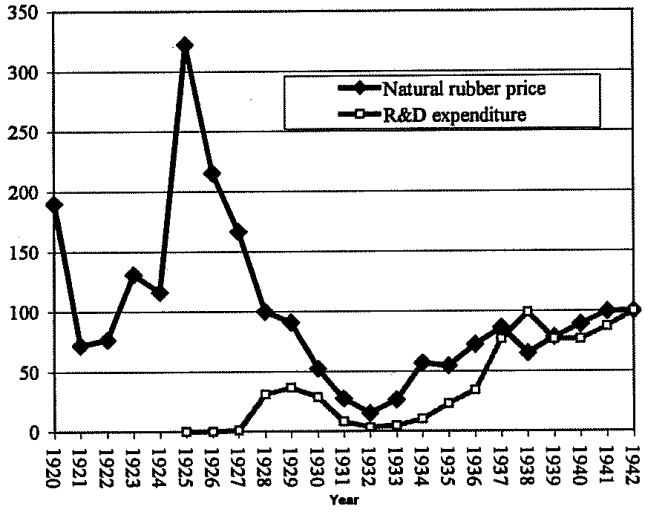
In all three cases the American companies succeeded in picking up the suggestions from Germany, improving them and making them ready for the market. This quick transformation of German know-how into market goods justifies the conclusion that the German lead in the area of advanced synthetic rubber research described above cannot

be explained by a lack of technological competence of the American companies. We will show that it may have had more to do with the governmental patent policy during World War II.

Market Risk and Government Command: the Selection of BUNAS

In the first half of the 20th century potential synthetic rubber producers found orientation for their evaluation of the future profitability of synthetic rubber primarily on the price of the substitute produced on Southeast Asian plantations. The higher the present and anticipated future price for natural rubber, the more willing a firm was to take the risk of investing in the development of synthetic rubber. This simple connection is demonstrated in figure 1 for the period between 1920 to 1942. It sketches the development of the New York market price for natural rubber as well as those research expenses I.G. Farben paid out in the framework of the synthetic rubber program.

Figure 1 Natural rubber price (1942=100)[a] and expenditure for synthetic rubber research of I.G. Farben (1942=100)[b]



a) New York market price for plantation ribbed smoked rubber, cents a pound, cf. Plumpe, Gottfried. *Die I.G. Farbenindustrie AG, Wirtschaft, Technik und Politik 1904-1945* (Berlin: Duncker & Humblot, 1990), 341, 349, Howard, Frank A. *Buna Rubber, the Birth of an Industry* (New York: D. van Nostrand, 1947), 8.

b) cf. Morris, Peter J.T. *The Development of Acetylene Chemistry and Synthetic Rubber by I.G. Farben Aktiengesellschaft 1926-1945* (Unpublished PhD Oxford, 1982. Available in BASF-Archives Ludwigshafen), 158.

The fall in the price of natural rubber after the end of World War I compelled the British to introduce the so-called Stevenson plan in their Southeast Asian colonies on November 1, 1922, which limited the amount of rubber exported for the purpose of stabilizing prices. Obviously, this measure went too far, since, together with the sharp increase in demand, it catapulted the price up to a record high of 72.5 cents per pound, whereby chemical companies acquired the view for the first time that it was possible to develop a synthetic rubber that could be competitive in terms of quality and price.

So in 1926 the board of directors of the newly founded I.G. Farbenindustrie AG decided to resume synthetic rubber research, which Bayer had given up after World War I on account of the low price for natural rubber. The American chemical firm Du Pont had already made this decision the year before. In fact, the synthetic rubber inventions were not a long time in coming. In 1929 I.G. Farben developed BUNA S on the basis of butadiene and styrene and then BUNA N as a copolymer from butadiene and acrylonitrile in 1930. Du Pont followed in 1931 with Duprene. Finally in 1937 the American Standard Oil Development Company succeeded in vulcanizing a synthetic rubber from butadiene and isobutylene on the basis of the technological information received from I.G. Farben. Unfortunately, as the fruit of the synthetic rubber program was still ripening, its profitability was already being questioned, since the market price of natural rubber fell to 3.4 cents per pound in 1932 as a result of the Great Depression. Synthetic rubber did not appear to be able to compete with natural rubber under market principles.

In Germany the situation changed again after the National Socialists seized power. In light of the National Socialist drive for autarchy I.G. Farben judged the future profitability of their synthetic rubber inventions more and more on the growing probability that government price and sales guarantees would be granted for synthetic rubber. So I.G. Farben again increased their research expenditures in this area despite continuing low natural rubber prices, when the Reichswehr announced its interest in synthetic rubber for tire production in 1933.[10] Nonetheless I.G. Farben at first steadfastly resisted the increasing pressure from the National Socialists to resume industrial production of synthetic rubber. How can this hesitance be explained? Obviously in light of the development of the price of natural rubber the chemical firm had to reckon with the fact that the costly construction of synthetic rubber production capacities could prove to be an extremely poor investment if government demand was dropped. This argument could have also been made for the production of synthetic fuel, which, however, did not hinder I.G. Farben from making an agreement with the Reich on December 14, 1933 for building an industrial synthetic gasoline production plant.[11] The restraint of I.G. Farben is therefore probably to be attributed to the fear of falling behind the competition through an early commitment to one particular type of synthetic rubber. This "Lock-in"[12] into a particular production and research program can be a considerable competitive disadvantage if, in the course of things, one of the alternatives not invested in or even a new invention proves to be a superior product, and an adjustment in production can not be made in the short run or only at high costs. This possibility explains why I.G. Farben

delayed the start of the synthetic rubber production and carefully tested all available alternatives first.

The hopes of I.G. Farben were first focused on the synthetic rubber Duprene from Du Pont, which was more cost-effective to produce on the basis of chlorine then their own BUNA variants. However, due to its lack of strength, Duprene was not suitable for tire production. After that BUNA N was favored. In 1935 tests showed that according to the state of knowledge at that time working vehicle tires could not be produced exclusively from BUNA, but only out of a combination of BUNA and natural rubber. Since at this time it was not possible to join BUNA N with natural rubber, this alternative was also ruled out as a basic material for producing tires. What militated against the remaining alternative BUNA S was that there was still no solution for the problem that this comparably hard synthetic rubber could not be processed on the conventional machines for producing tires. Under these circumstances it probably seemed advisable to the decision makers at I.G. Farben to do without the industrial production of synthetic rubber at first and search instead for another superior synthetic rubber by means of further R&D projects. Nevertheless, they decided to yield to the pressure of the state by committing themselves to the production of BUNA S.[13]

In contrast to I.G. Farben the American companies were not willing to invest their own funds in building production capacities for BUNA S. Therefore not only government price and sales guarantees, but also government financing of the production plants were needed to motivate private firms to open production of BUNA S.

American Cost-plus Versus German Fixed-price Contracts

I showed that the cost reductions in the German plant Schkopau can primarily be traced back to internal increases in efficiency, while the cost reductions in the American companies were caused primarily by exogenous technological change in the butadiene production. In the following I will investigate whether this empirical finding can be explained by difference in the way government procurement of synthetic rubber was organized.

Traditionally there are two standard types of procurement contract available to the government: the fixed-price and the cost-plus contract. For the fixed-price contract, the purchasing price is fixed prior to production at the conclusion of the agreement and thus independent of the ex-post observable production costs. Therefore during the price negotiations, the synthetic rubber producer has the possibility to enforce comparatively high prices by falsely stating production costs which are higher than his true costs that are only known to him alone. This form of adverse selection can be avoided by using a cost-plus contract by which the purchase price is set at delivery on the basis of the ex-post observable production costs. Since in this case the companies are refunded all costs incurred, the cost-plus contract doesn't offer any incentives to reduce the production costs after the completion of the agreement.

First of all, the 1937 agreement between the German Reich and the I.G. Farbenindustrie AG was the legal basis for the production and sale of BUNA S in Germany.[14] According to Paragraph 8 of this agreement the construction of the production capacities for 24,000 annual metric tons of synthetic rubber was financed approximately half from I.G. Farben's own funds and the other half through a loan from the Reich. Sales of synthetic rubber were supposed to be made directly to the rubber fabricating industry. However, at the completion of the contract, there was still no solution to the problem that the conventional tire manufacturing machines could not process BUNA S due to its toughness. On account of this technological uncertainty, the contractual partners made an agreement in Paragraph 9 that the Reich would take over the whole annual production of BUNA S if the private tire producers were not willing to buy this synthetic rubber. Independent of whether I.G. Farben sold its BUNA production to private companies or to the state, the Reich guaranteed a cost-effective price in Paragraph 10. If the price in trade with the rubber fabricators fell below this guaranteed minimum price, then the difference would be refunded by the Reich. Vice versa I.G. Farben had to pay the additional yield to the Reich. Each respective guaranteed minimum price was supposed to be fixed semi-annually on the basis of book-keeping results of the Schkopau production plant and then adjusted to the changed production costs if necessary. In this respect, the agreement reached between the Reich and I.G. Farben created a cost-plus contract. In order to give the operators of the BUNA production plant an incentive for reducing costs anyway, this cost-plus contract was modified through a bonus that changed the cost-plus contract to a simple incentive contract.[15] I.G. Farben should get 10% of all cost savings related to in-house measures as additional profit.

After I.G. Farben had developed the method of thermal degradation which made BUNA S suitable for tire production, the sales of this type of synthetic rubber seemed to be guaranteed within a German rubber market that was protected both by foreign exchange controls and import duties on natural rubber. Therefore, it was logical for I.G. Farben to relinquish government price and sales guarantees in all subsequent agreements on the construction of additional industrial capacities. This does not mean now that the chemical firm as a monopolist could freely set the price of synthetic rubber, though. It was instead the Commissioner for Price Regulation ("Reichskommissar für Preisbildung") who determined the price of innovative goods like BUNA S. The Commissioner was also responsible for enforcing price reductions on goods that were necessary for war.[16] Hence I.G. Farben actually delivered their synthetic rubber to private demand at fixed prices decreed by the government. Since it had to be reckoned with that the Commissioner for Price Regulation would call in further price reductions, the economic incentives for reducing costs set by fixed prices were augmented.

In the United States the synthetic rubber production was regulated by means of agreements of lease and plant operating agreements.[17] The private companies obligated themselves in the agreements of lease to set up the planned synthetic rubber plants as quickly as possible and to equip them with the necessary machines. By completely financing the building up of this capacity it was the government Defense Plant Corpora-

tion which acquired the property of the new production plant. It was leased to the rubber fabricators for the symbolic sum of one dollar per year. The "Plant Operating Agreements" dealt with the actual synthetic rubber production and were arranged as cost-plus. Private companies produced BUNA S that was commissioned by and at the risk of the government's Rubber Reserve Company. The Rubber Reserve Company maintained a bank account for every plant operator for the purpose of covering a rather broad range of production costs. Through this the synthetic rubber fabricators had the possibility to immediately and completely finance all production costs incurred directly from state funds.

If we believe contemporary observers, then there was intense competition between the various American synthetic rubber plants, which looked to demonstrate their relative superiority via a rapid increase in the amount they produced. Herbert and Bisio (1985) or Morris (1989) attributed this behavior to "wartime patriotism." However, I hold the view that the ongoing economic uncertainty of the American synthetic rubber producers can also be interpreted as a prime cause of the efforts at increasing production. In light of the negative assessment of future profitability of the synthetic rubber, the synthetic rubber producers had to reckon with the possibility that after the post-war re-establishment of the trade with Southeast Asian rubber plantations the extent of the American synthetic rubber capacities would at least be drastically reduced. Therefore it must have seemed to be crucial to both white-collar and blue-collar workers at a synthetic rubber plant for their longer-term job security to distinguish themselves from other factories. The best way of doing this in an atmosphere of fear induced by the wartime shortage of rubber was to produce greater quantities of high quality BUNA S than competitors using similar production facilities.

By way of summary, government demand motivated the synthetic rubber manufacturers in the USA primarily to increases in production by the means of cost-plus contracts, whereas in Germany it motivated them to reduce costs by setting economic conditions which simulated fixed-price contracts.

American Exchange of Information versus German Protection by Patent

While research and development outcome stagnated in the United States after BUNA S was successfully imitated, in Germany the technological knowledge for advanced synthetic rubber inventions was created. How can this difference in R&D efficiency be explained?

As long as I.G. Farben satisfied the National Socialists' demand for synthetic rubber they had not to fear that outsiders would be allowed to develop their own synthetic rubber production in the German national economy directed by the National Socialists. Therefore they could trust that innovation profits could be completely acquired in an extent determined by the Commissioner for Price Regulation. This lack of competitive pressure can considerably reduce the innovativeness of a monopolist. However, I.G. Farben had long planning periods and obviously counted on a return after the war to a more

open economy, in which their synthetic rubber would have to compete with natural rubber from abroad. In this case it would actually make sense to prepare synthetic rubber inventions within the protected conditions of the national socialist war economy that were at least equal to the competition's products in terms of price and quality.

An agreement was made in the American synthetic rubber program that each private company should transfer their respective patents for rubber production to the Rubber Reserve Company which would in turn make them available to all producers participating in the government's program. Neither the original patent owner nor the Rubber Reserve Company obtained a financial compensation for this. In addition, a technical committee was set up with the synthetic rubber producers in which new technological information was to be exchanged. The additional research contracts made with the companies did not contain any financial premium on accomplishment. Under these circumstances no firm could hope to get an advantage over the competition through the development of an invention, since they could neither acquire an exclusive patent right nor keep their know-how confidential. Incentives of this sort would make it more advisable to do without the search for pioneering inventions and to strive for only small technological improvements instead and to use the government's funds for improving their own ability to innovate in the future. That is what American synthetic rubber producers in fact did.[18]

The minor technological improvements in the American synthetic rubber manufacture primarily concerned the optimization of the BUNA S formula and the process of polymerization. The application of these innovations was tied to the specific qualifications of particular employees and therefore as tacit knowledge could not be repeated in other companies without at least the practical instruction of these experts. Therefore, these small improvements made it possible for a synthetic rubber factory to distinguish itself with higher output and product quality from other plants.

For the successful development of innovations as well as for quick imitation of new products from competitors a research department was necessary that was occupied by staff who were highly qualified and above all familiar with the object of research and who had the necessary laboratory equipment and measuring instruments that corresponded to the state of the art technology. The American synthetic rubber manufacturers therefore used the government research subsidies to equip their research departments in the non-competitive phase of World War II thereby preparing for the period of strong competition that would, as expected, arise after the synthetic rubber production was privatized. After the return to exclusive patent rights in the summer of 1955 the American companies actually revealed their potential to innovate which had only been hold back until then.

Table 4 Economic Incentives of the government synthetic rubber programs

Economic incentives	In Germany	In the United States
Economic incentives for starting production	HIGH price and sales guarantees	VERY HIGH price and sales guarantees, government financing of the production plants
Economic incentives for reducing production costs	HIGH de facto fixed-price contract	LOW cost-plus contract
Economic incentives for developing advanced synthetic rubber types	MEDIUM temporary national monopoly	LOW agreements of exchanging patents and information

Summary

To better understand the economic incentives of government demand for innovations, the respective technological and economic developments were compared with each other in the German and American synthetic rubber industry before, during and after World War II. The results are summarized in table 4.

In light of the low market price of natural rubber the view held in Germany as well as in the USA was that the BUNA S synthetic rubber suitable for tire production could not compete with natural rubber. Therefore government price and sales guarantees for synthetic rubber were introduced in both countries. Moreover, in the USA government financing of the production plants was needed to move private companies to begin manufacturing BUNA S.

The different ways the government procurement contracts were arranged explains why the German synthetic rubber fabricators reduced their production costs through increases in efficiency considerably more than the American producers whose cost savings can be attributed primarily to a technological change in the upstream butadiene production. A profit increase in Germany was possible under the actual conditions of a fixed price contract primarily through cost reductions. In the USA increased profits were possible in the framework of cost-plus contracts through production increases.

The agreements on exchanging patents and technological information valid during the American synthetic rubber program led the American synthetic manufacturers to hold back all research projects whose state of knowledge did exceed the pre-war level until the privatization of the synthetic rubber industry would make it possible to realize gains from innovations again. On the other hand, monopoly and patent right protection offered the German I.G. Farben sufficient incentives for developing the technological foundation for secondary synthetic rubber inventions.

This historical comparison shows that politicians aiming to speed up long-term technological change by government demand have to take into consideration that apparently small details of the institutional setting can change the outcome of an innovation process dramatically.

Notes

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2. cf. Dollar, David and Edward N. Wolff, *Competitiveness, Convergence and International Specialization* (Cambridge: MIT Press, 1993), Freeman, Chris and Luc Soete, *The Economics of Industrial Innovation* (3rd ed., London: Pinter, 1997), Landes, David S., *Der entfesselte Prometheus: Technologischer Wandel und industrielle Entwicklung in Westeuropa von 1750 bis zur Gegenwart* (Köln: Kiepenheuer & Witsch, 1973), Nelson, Richard R., *National Innovation Systems: A Comparative Study* (Oxford: University Press, 1993), Porter, Michael, *The Competitive Advantage of Nations* (London: Macmillan, 1990).

3. "Denkschrift Hitlers ueber Aufgaben eines Vierjahresplans, 1936." Published in *Vierteljahrsheft fuer Zeitgeschichte* 3 (1955): 208.

4. cf. Synthetic Rubber Recommendations of the U.S. President, transmitted to the Congress together with a Report on Maintenance of the Synthetic Rubber Industry in the United States and Disposal of Government-owned Synthetic Rubber Facilities (U.S. Govt. Print.Off., 1950), Appendix A, Herbert, Vernon and Attilio Bisio, *Synthetic Rubber: A Project that had to Succeed* (Westport/CT: Greenwood Press, 1985), IX.

5. In the United States BUNA S was labeled GR-S (Government Rubber-Styrene Type).

6. In Germany the prices and wages had already been frozen in 1936 on the existing level. cf. "Verordnung ueber einen allgemeinen Preisstopp vom 26.11.1936," Reichsgesetzblatt I, 1936, 955 f. A corresponding regulation was made in the USA in April 1942 through the "General Maximum Price Regulation," cf. Mills, Geofrey and Hugh Rockoff, "Compliance with Price Controls in the United States and the United Kingdom during World War II," *Journal of Economic History* 47 (1987): 197-213. However, constant prices do not imply that the qualities of the respective inputs remained constant in time, too. Another question still unanswered is as to what extent the deployment of concentration camp prisoners and other slave workers decreased production costs of German firms during World War II. cf. Spoerer, Mark, *Zwangsarbeit unter dem Hakenkreuz* (Muenchen: Deutsche Verlags-Anstalt, 2001), 183-190.

7. Due to a more efficient use of butadiene in the BUNA S production between the first quarter of 1941 and the fourth quarter in 1943 the expenses for butadiene fell with 8% stronger than the upstream production costs of a unit of butadiene which was reduced by only 3% in the same time frame. cf. Bayer-Archives "Bestand: Ausschuesse und Kommissionen, Aktentitel: TEA-Buero," Signatur: 13/17, Mikrofiche 161, 12-13.

8. Cited in Gimbel, John, *Science, Technology and Reparations. Exploitation and Plunder in Postwar Germany* (Stanford: University Press, 1990), 150.

9. cf. DeBell, John M., William C. Goggin and Walter E. Gloor, *German Plastics Practice,* published with permission of the Department of Commerce (Springfield/Mass: De Bell and Richardson, 1946), 438-440, Weidlein, E.R., "Synthetic Rubber Research in Germany," *Chemical and Engineering News* 24 (1946): 771-774.

10. cf. Plumpe, Gottfried, *Die I.G. Farbenindustrie AG: Wirtschaft, Technik und Politik 1904-1945* (Berlin: Duncker & Humblot, 1990), 357. See also Bundesarchiv Berlin "Schreiben der I.G. Stickstoffabteilung an das Heereswaffenamt vom 15.8.1933", R 8128/ A 1153.

11. cf. "Leuna-Agreement between the German Reich and the Ammonia Plant Merseburg GmbH on Dezember 14, 1933," BASF-Archiv Akte PIER 83.

12. cf. Arthur, W. Brian, "Competing Technologies, Increasing Returns, and Lock-in by Historical Events," *Economic Journal* 99 (1989): 116-131.

13. cf. Fritz ter Meer, in September 1935, cited in Plumpe, *I.G. Farbenindustrie,* 365.

14. cf. Hoechst Archives TEA Files 1446-1457.

15. On the arrangement of incentive contracts in the National Socialist arms economy cf. Streb, Jochen and Sabine Streb, "Optimale Beschaffungsvertraege bei asymmetrischer Informationsverteilung: Zur Erklaerung des nationalsozialistischen "Ruestungswunders" während des Zweiten Weltkriegs," *Zeitschrift für Wirtschafts- und Sozialwissenschaften* 118 (1998): 275-294.

16. In fact, due to the pressure from the Commissioner for Price Regulation the price of a kilogram of BUNA S was reduced from 4 RM in 1937 to 3 RM in 1938 and 1939 to 2.30 RM after 1940.

17. cf. Appendix XXIII "Agreement of Lease" and Appendix XXVII "Typical Copolymer Plant Operating Agreement," in The Government's Rubber Projects, Vol. 2. *A History of the U.S. Government's Natural and Synthetic Rubber Programs 1941-1955.* These appendices were only added to the original manuscript and are kept in National Archives Washington/DC, Entry 26 Administrative Histories of the RFC's Wartime Programs, Location 570, 65:33:7 / Box 16.

18. For details cf. Solo, Robert A., "Synthetic Rubber: A Case Study in Technological Development under Government Direction," *Study of the Subcommittee on Patents, Trademarks, and Copyrights of the Committee on the Judiciary United States Senate. Eight-fifth Congress, Second Session* (Study No. 8 Washington, 1959).

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