Was armament minister Albert Speer really responsible for the German "armament miracle" during World War II? New doubts arising from the annual audits of the German aircraft producers.

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Abstract

Armament minister Albert Speer is usually credited with causing the upswing in German armament production after 1941. Exploring the annual audit reports of the *Deutsche Revisions- und Treuhand AG* for six different firms, we question this view by showing that in the German aircraft industry the crucial political changes already occurred before World War II. The government decided in 1938 that aircraft producers had to concentrate on a few different types, and in 1937 cost-plus contracts were replaced with fixed price contracts. What followed was not a sudden production miracle but a continuous development which was fuelled by learning-by-doing and by the ongoing growth of the capital endowment.

Preliminary version. Please do not quote. Comments are welcome.

1 The German armament miracle

In December 1941 the Russian army stopped the German *Wehrmacht* near Moscow. That along with the United States' entry into World War II brought the National Socialists' strategy to fight so-called *Blitzkriege,* which could be waged with a comparatively low number of soldiers and arms, to a sudden end.[1] Now confronted with the prospect of a long-lasting war against the Unites States and Soviet Russia, the German military planners acknowledged that they had to increase their armament production considerably. This insight was frankly made public by the economic journal *Deutscher Volkswirt* (1942, p. 579): "*The winter campaign makes everybody aware of the fact that the German people are required to make an extreme military and economic effort. […] Using raw materials more economically, less workers will have to produce the same or even a larger amount of armament goods than are fabricated until now*" [translated by the authors].[2]

[Insert figure 1 here]

Apparently the German war economy was able to meet this demand. Figure 1 shows that the index of German armament production[3] originally prepared on behalf of Albert Speer's armament department more than tripled between early 1942 and July 1944. It might not be surprising that this considerable growth realized in a period of increasing Allies' air-raids on German firms and transportation networks led many observers to christen this development a miracle.[4] The index of German armament production, however, has its shortcomings. First of all, the Speer administration intentionally chose the first two months of 1942, in which armament production was comparatively low, as

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[1] See Kröner (1988). One might argue, however, that the heavy investment in armament production during 1940 and 1941 indicates that the National Socialists decided to prepare for a long-lasting war already at the beginning of World War II. For investment figures see, for example, Hopmann, 1996, S. 120.

[2] "*Der Winterfeldzug hat die Augen dafür geöffnet, dass vom deutschen Volk die äussersten militärischen und wirtschaftlichen Anstrengungen verlangt werden. […] gleichzeitig werden weniger Menschen unter sparsamerem Guterverbrauch der Wirtschaft dieselbe oder eine grossere kriegswichtige Produktion aufzubringen haben als vorher."*

[3] To construct this index the different armament goods like warships, tanks, artillery or ammunition were generally weighted by their prices of 1943. The development of aircraft production, however, was measured by the weight of the bombers and fighters. See Wagenführ, 1954, pp. 208-211.

[4] Overy (1994, p. 344), for example, speaks of the "so-called production miracle".

the base of the index to exaggerate its own achievements in the following years (Wagenführ, 1954, p. 211). The decision to calculate the index only for the period when Albert Speer was armament minister also hid the fact that the German armament production had already significantly grown between 1938 and 1940 (Wagenführ, 1954, p. 23). Another deficiency arises from the fact that after 1942 the index probably also included both armament goods that were produced in occupied countries[5] and older military equipment like aircrafts, that were just repaired after minor damages, which could be done with much less effort than producing new ones.[6] As a result, the index of armament production depicted in figure 1 might overstate the volume of really new weapons actually produced within the borders of Germany after 1941.

[Insert table 1 here]

There is no doubt, however, that German firms were able to increase their armament production between 1942 and 1944 considerably. Assuming that the firms' individual endowments with capital goods and blue-collar workers were rather constant in this period[7] historians generally put this growth down to a corresponding increase in labor productivity (Overy, 1994, pp. 344-345). Table 1 shows that while the number of employees in German armament production grew by 30 percent between January 1942 and July 1944, their output more than doubled in this period. This impressive rise is generally explained by rationalization measures enforced or even initiated by armament minister Albert Speer, who assumed office in February 1942 after his predecessor Fritz Todt was killed in an accident. Speer is especially credited with making the following political decisions that supposedly improved efficiency in armament production (Abelshauser, 1998, p. 156 f.; Overy, 1994, pp. 356-363; Weyres, 1975, pp. 47-49). First,

[5] The aircraft producer *Arado*, for example, obtained during the year 1942 several components and even completed aircrafts from firms located in Denmark, France and the Sudetenland. See audit report 1942, BArch R 8135/7085, p. 4. *ATG* received wings and steering from aircraft producers sited in Prague and Amsterdam. See audit report 1942/43, BArch R 8135/2168, p. 3. French firms produced the aircraft Ju 52 on behalf of *Junkers*. See audit report 1943, BArch R 8135/7560, p. 26.

[6] During the accounting year 1942/43, for example, the repair department of *Junkers* was booming. See audit report 1942/43, BArch R 8135/7560, p. 10.

[7] Precise estimates of both the total amount of investment and the number of blue-collar workers in the German armament industry before and during World War II don't exist.

the number of weapon types was reduced which might have allowed many firms to move to mass production and exploit economies of scale. Second, the frequency of minor design changes of a special type was also reduced so firms could save at least some of the costs arising from adapting their production equipment. Third, against the declared desire of the armed forces, finishing procedures like polishing or lacquering that add nothing to the strike power of a weapon were abolished, which reduced the working hours needed to produce one piece of an armament good. Fourth, firms were forced to share technological know-how in newly established committees in order to give less efficient firms the information considered necessary for imitating the technology of the superior firms. This might have also accelerated the diffusion of flow production techniques in German industry.

All these rationalization measures had in common that they enabled firms to decrease their production costs. Overy (1994, p. 357), however, raises serious doubts whether the firms would have realized these efficiency gains under the traditional regime of cost-plus contracts that seemed to dominate German procurement business until 1942. Firms that delivered weapons on the basis of a cost-plus contract generally got a payment that not only covered all their actual costs observed after the end of production, but also included a premium that was calculated as a given percentage of these costs.[8] That is why, under a cost-plus contract, an armament producer had no incentives to reduce costs; quite the reverse, he was motivated to increase them to get a higher premium. To make the rationalization measures listed above work it was therefore unavoidable to change to another type of procurement contract. In May 1942 the government ordered that cost-plus contracts had to be generally replaced with fixed-price contracts.[9] Under this new regime the procurement agency and the armament producer ex ante agreed on a fixed price of a weapon on the basis of their expectations about the future production cost. If the armament producer was able to fabricate the good at lower production costs than estimated, he was entitled to keep at least a part of this difference as an additional profit.

[8] For more details see Streb/Streb (1998).
[9] See *Anordnung über Einheits- und Gruppenpreise vom 19. Mai 1942*, Reichsanzeiger vol. 117.

As a result, firms now had the incentives to take the opportunities offered by Speer's rationalization program to decrease their costs.

The fact that it was under Speer's reign when all these reforms were enforced and the armament production boomed led many observers to the view that armament minister Albert Speer might have been one of the few competent political managers in the National Socialists' ruling classes. Kaldor (1946, p. 48) states: "*Speer's administration in the course of the following two-and-a-half years was the single great success which the German war economy can record, and the only that will retain a more than historical interest.*" This rather positive evaluation of Speer's capability is mainly based on the analysis of documents of the different state authorities and on macroeconomic data. Not much is known about the economic activities inside the individual firms. So the crucial empirical questions are still unanswered. Were the reforms of the Speer administration more than ineffective announcements? Did they cause a considerable increase in the armament producers' productivity? Could they therefore be interpreted as the main reason for the so-called armament miracle?

To answer this questions we are exploring annual audits of German armament producers that are shelved in the Federal Archives in Berlin but have been widely ignored until now. We started our research project with a closer look at the aircraft industry whose development, we first thought, might be quite representative for what was going in other German war industries. This prior belief was supported by the facts, first, that the aircraft industry's average share in the armament production came to about 40 percent (Wagenführ, 1954, pp. 30, 69), and second, that the index of aircraft production represented by the broken line in figure 1 behaved very similarly to the index of all armament production. It turned out, however, that the development in the aircraft industry might not be that typical since it contradicts most of the well-known conjectures about the nature of the German armament miracle stated above.

We want to stress two points which will be discussed in detail in the following sections. First, the factor endowments of most of the aircraft producers were not constant, but

considerably expanded during the war. This holds for both capital and labor. Second, the increase in labor productivity after 1941 was more likely caused by learning-by doing effects than by the rationalization measures of the Speer administration. There was no structural break with respect to the procurement regime because in the aircraft industry fixed-price contracts were already used since 1937. These observations lead us to the conclusion that the reforms of the Speer administration had at best a minor influence on the armament miracle in the German aircraft industry. We will have to analyze other war industries in greater detail before we can answer the question whether this result is an industry-specific exception or true for most of the German armament producers.

2 The data

Our main data source is the firm-specific annual audit reports of the *Deutsche Revisions- und Treuhand AG*. Founded in 1922 as a state-owned limited company, the *Deutsche Revisions- und Treuhand* was instructed to audit all firms in which the German Reich had shares in or for which the state stood surety.[10] In 1924 this auditing company was transformed into a joint-stock company and became a subsidiary of the large state holding company *Vereinigte Industrieunternehmungen AG* (VIAG). After the Second World War the *Deutsche Revisions- und Treuhand AG* remained the preferred auditing company of the West German state. It was privatized step by step and finally merged with Price Waterhouse Germany in 1998.

The Federal Archives in Berlin Lichterfelde possess a collection[11] of the audit reports of the *Deutsche Revisions- und Treuhand AG* for firms that were engaged in the German armament production during World War II. Most of the available audit reports cover the period from 1939 to 1943. Since the auditors obviously needed at least one year to prepare their reports, most of the audits for the accounting years 1943/44 or 1944 were unfortunately missing and probably never finished. The typical audit report contains more than one hundred pages including not only a comprehensive analysis of the balance sheet

[10] See *Reichshaushaltsordnung vom 31. Dezember 1922*, § 48, §§ 110-117. The audit of the annual accounts of private-owned joint-stock companies by state-appointed auditors was not made compulsory until 1931.

[11] The shelf mark of this collection is Barch R 8135.

and the profit-and-loss-account but also detailed information about sales, prices, costs and the structure of the work force. Sometimes the reports even included a list of every single machine bought during the accounting year. In general, both the quantity and the quality of the information delivered increased between 1939 and 1942, which might reflect the National Socialists' desire to overcome the principal-agent problems of armament production by improving their knowledge about the production technology and the actual costs of the private firms.[12]

[Insert table 2 here]

In this paper, we mainly concentrate on the audit reports of six aircraft producers that all were engaged in the production of the bombers Ju 88 and Ju 87 originally designed by the company *Junkers Flugzeug- und Motorenwerke AG.*[13] Table 2 shows that these six firms considerably differed both in size and in their main business. The largest firm, *Junkers,* produced in its various plants all components of the aircraft Ju 88 including the engines.[14] To give the smaller firms the opportunity to exploit economies of scale, they were instructed to concentrate on one or a few components of the aircraft which they then exchanged among each other for final assembly.[15]

[Insert table 3 here]

Table 3 makes clear that the making of wings and fuselages were the production steps that consumed the most working hours of aircraft production. *Arado*, *Heinkel* and *Siebel* mainly produced wings while *ATG* provided fuselages, tail units and engines. *Weser* was chosen as the exclusive producer of the older bomber type Ju 87. To enable the other

[12] The National Socialists were well aware of the fact that the private firms tried to use asymmetric information to increase their profits at the expense of the state. See Streb (2003).

[13] Both the Dornierwerke in Friedrichshafen and the Norddeutsche Dornierwerke in Wismar were also shortly engaged in the production of Ju 88 bombers building 219 units (March 1940-Dezember 1940) and 467 units (January 1940-September 1941) respectively. See BA-MA RL 3/976, p. 48. Unfortunately, the Federal Archives' collection doesn't include any audit reports of the firm *Henschel* which was apparently also engaged in the Ju 88 production for some period of time.

[14] Junkers also produced the aircraft type Ju 52. See audit report 1939/40, BArch R 8135/2548, p. 57.

[15] The German state owned *Arado*, *Heinkel*, *Junkers* and *Weser* at least partly. See *Beteiligungsfirmen der Luftfahrtkontor GmbH*, BArch R 2/5550, p. 44 f.

firms to imitate its original design, *Junkers* shared information with them and also gave them technological support when needed.[16] Interestingly enough, the firms in our sample had already exchanged technological knowledge before Albert Speer ordered the newly founded inter-firms committees to do exactly this. In our sample, the aircraft producer *Heinkel* in Oranienburg stands out for two reasons. First, this firm had a much higher capital-labor ratio than the other producers. Second, after 1942, *Heinkel* drew most of its blue-collar workers from the nearby concentration camp.[17] We will come back to this points in the following sections.

3 Extensive growth

Table 4 shows that in the period covered by the available audit reports both the fixed assets and the work force of most firms in our sample increased with astonishing two-digit annual growth rates. The growth rates of the fixed assets might even be considerably underestimated since, on the one hand, the state granted generous depreciation privileges which allowed firms to transform profits into hidden reserves,[18] and, on the other hand, firms often increased their production capacities by leasing additional plants from other firms or the state[19] whose value did not show up in their balance sheets.

[Insert table 4 here]

Two firms deviated from the general trend. *ATG* was for some reason not able to use the favorable conditions of the German armament miracle to augment its own factor endowment. *Heinkel,* which had the highest capital-labor-ratio in 1939 increased in the following years only its work force. The development of the capital-labor ratio of the other firms was rather u-shaped with a minimum in 1939 (*Siebel, Weser*), 1940 (*Junkers*) or 1942 (*ATG*).

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[16] See audit report 1941/42, BArch R 8135-7559, p. 61.
[17] In March 1944 53 percent of the blue-collar workers of Heinkel were prisoners of the concentration camp Oranienburg. See audit report 1943/44, BArch R 8135-1916, p. 6.
[18] See *Endgültige Fassung der Richtlinie über Preisbildung und Finanzierung vom 12. Juni 1937*, BArch R 2/5475, p. 31.
[19] See audit report 1940 of Weser, BArch R 8135/5272, p. 2.

[Insert figure 2 here]

The German aircraft producers had built up excess capacities with respect to capital in the late 1930s. After World War II has started the firms recruited a lot of blue-collar workers in order to populate their newly built plants.[20] However, as the growth of the capital-labor ratio of most of the firms in our sample indicates, the growth of their fixed assets soon exceeded the growth of their work force again. This unbalanced development seemed to be caused by the shortage of labor that resulted from the increasing number of German male workers that were recruited by the army.[21] The fact that labor was probably the most important bottleneck of the German war industry explains why the armament producers were often not able to utilize their production capacity fully by running two or three shifts.[22] In the short run, firms instead increased the number of working hours per worker. At *Junkers*, for example, the workers' effective weekly working time grew from 53 hours in 1938/39, to 56 hours in 1939/40 and 58 hours in 1940/41.[23] It is well-known that the National Socialists tried to overcome the labor shortage in the German war industry, first, by fostering women's employment and re-allocating the German work force, and, then, by forcing foreign civilians, prisoners of war and concentration camp prisoners to work.[24] The audit reports of the *Deutsche Revisions- und Treuhand AG* gave us some idea if these measures worked out at the firm level. The example of *Arado* demonstrates that the aircraft producers were not able to use German women to replace their male workers lost to the army. In 1940, for example, 74 percent of all female blue-collar workers employed in *Arado*'s plant in Brandenburg-Neuendorf quit their job.[25] The audit report unfortunately mentioned no reason for this dramatic drop. We have to speculate whether the women were motivated to leave by bad working conditions or by the financial support given to soldiers' spouses by the government. On the whole, the share of female blue-

[20] See Budrass, 1998, p. 674.
[21] The sum total of Germans drafted grew from 5.6 millions in 1940 via 7.4 millions in 1941, 9.4 millions in 1942 and 11.2 millions in 1943 to 12.4 millions in 1944 (Wagenführ, 1954, pp. 35, 45).
[22] This observation was stressed by Kaldor, 1946, p. 35.
[23] See audit report 1939/40, BArch R 8135/2548, p. 15; audit report 1940/41, BArch R 8135/7558, p. 11. See also Budrass, 1998, p. 675.
[24] See Overy, 1994, pp. 291-303
[25] See audit report 1940, BArch R 8135/7084, p. 9.

collar workers in the total work force of *Arado* decreased from 19.9 percent in 1939 via 15.6 percent in 1940 to 15.1 percent in 1941.[26]

The audit reports also contain some remarks that imply that the aircraft producers weren't very satisfied with the performance of those German workers who were forced by the state to leave their traditional occupation and hometown in order to work in armament production. *ATG*, for example, told the auditor that this type of worker needed extensive training before he could be deployed fruitfully.[27] The fact that, for example, *Arado* declared that in 1942 1,100 workers had to be fired for lack of aptitude,[28] leads us to the conjecture that the "forced" German workers especially tried hard to prove their incompetence to be released. As a result, the aircraft producers more and more relied on foreign workers whose productivity was apparently much higher than the propaganda made the people believe. Even a document of the Reich's aviation department found in the military archives in Freiburg stated that the productivity of female Russians and Czech skilled worker came up to 90 to 100 percent of the productivity of the German workers.[29]

[Insert table 5 here]

Table 5 shows the development of the work force of *Heinkel* in Oranienburg which is best documented by the audit reports we reviewed. Between January 1940 and March 1941 *Heinkel* could still increase its work force by about 30 percent by hiring mainly male German workers. After this period, however, the number of both male and female German workers was steadily decreasing. Between summer 1941 and summer 1942 it was the employment of foreign civilian workers under which female Russians played a prominent role which enabled *Heinkel* not only to replace its lost German workers but also to expand its work force again by 40 percent. In summer 1942 the firm decided to

[26] See audit report 1940, BArch R 8135/7084, p. 17; audit report 1941, BArch R 8135/7085, p. 7.
[27] See audit report 1939/40, BArch R 8135/2167, p. 25.
[28] See audit report 1942, BArch R 8135?7085, p. 6.
[29] See BArch MA RL 3/976, p. 24. This document also claims that French and Belgians reached 80 to 95 percent, Russians 60 to 80 percent, Italians 70 percent, and Dutch, Danes and workers from the Balkans 50 to 70 percent of the productivity of a German worker.

improve its capacity utilization by running more than one shift. The additional workers needed for this plan were taken from the nearby concentration camp.[30] In the following months *Heinkel* more and more depended on the labor of concentration camp prisoners whose share in the sum total of all blue-collar workers fast grew from 11 percent in September 1942 via 35 percent in March 1943 to 53 percent in March 1944. The development of *Heinkel*'s work force until summer 1942 might be quite representative for which was going on in the German aircraft industry as a whole. Instead, *Heinkel*'s transformation into a firm that mainly exploited concentration camp prisoners was rather exceptional. The other aircraft producers more relied on foreign civilian workers. At *Junkers*, for example, the share of concentration camp prisoners and prisoners of war in the sum total of all employees was only about 2 percent in September 1943 whereas foreign civilian workers came to more than a third of all employees.[31]

The data presented in this section reveal that the increase in German aircraft production during World War II can at least partly explained by the growth of the firms' factor endowment. In this respect, the growth of production was not a miracle at all.

4 Productivity growth

Figure 3 shows that, with the exception of *Heinkel,* the aircraft producers' labor productivity calculated as sales per blue-collar worker considerably rose during the period under consideration.[32] Since sales were measured by actual prices which rather decreased over time the real efficiency gains might be even underestimated. In 1940, *Heinkel* was the firm with the highest labor productivity followed by *Siebel*, *Junkers*, *ATG* and finally *Weser*. This hierarchy changed in the following two years. In 1942, *Junkers* had taken over the lead while *Heinkel* had even fallen behind *Siebel* and *ATG*.

[Insert figure 3 here]

[30] See Budrass, 1998, p. 778 f.
[31] See audit report 1942/43, BArch R 8135/7560, p. 17.
[32] Since we don't have data about the number of blue-collar workers of *Arado*, we aren't able to calculate this firm's labor productivity.

At first glance, the fact that *Heinkel* was the only firm in our sample that had both a falling capital-labor-ratio and a decreasing labor productivity might suggest that the latter was caused by the former. A detailed comparison of figure 2 and 3 makes clear that the firms' changes in labor productivity cannot be satisfactorily explained by the changes in their capital-labor ratios. *ATG,* for example, who had the lowest and rather decreasing capital-labor ratio was able to improve its labor productivity steadily and nearly reached the respective number of *Junkers* in 1943.[33] We will see in the next sub sections that the quite continuously growing labor productivity of *Junkers*, *ATG, Siebel* and *Weser* was most likely caused by learning-by-doing. The question remains why *Heinkel* wasn't able to increase its efficiency too. In our opinion, it was the comparatively discontinuous development of its production program which prevented *Heinkel* from raising its labor productivity by learning-by-doing. Originally, *Heinkel* had produced the bomber He 111 in Oranienburg. In 1940 the firm was instructed to concentrate on the production of wings for the Ju 88 instead.[34] This change in the production program involved a substantial re-organization of the production process. Workers who were used to assemble a whole airplane had now to learn how to fabricate a special component of another design. Old machines became useless and had to be replaced with new ones the workers were unfamiliar with. Since we do not know *Heinkel*'s sales per blue-collar worker in the year 1939, we are unable to say whether or not the firm was able to adapt without a decrease in labor productivity. What we do know is that *Heinkel* paid for the next sudden about-turn of its production program with a considerable loss of efficiency. In the accounting year 1942/43 *Heinkel* gave up its production of Ju 88 wings and started to fabricate the new bomber type He 177.[35] This time the necessary adaptation process was made even more difficult by the fact that simultaneously a large number of concentration camp prisoners newly arrived at the firm who had to be trained and made further adjustments of the firm's organization of production necessary. Hence it is not surprising that labor productivity dropped by about 25 percent in this year. It took another

[33] The steep rise of *ATG*'s labor productivity in the accounting year 1942/43 was probably caused by a restriction of the own production program that resulted from the decision to move the production of engines to *Opel* in R*ü*sselsheim and of tail units to *Würtembergische Metallwarenfabrik* in Geisslingen. See audit report 1942/43, BArch R 8135/2168, p. 3.
[34] See audit report 1940, BArch R 8135/7498, p. 5.
[35] See audit report 1942/43, BArch R 8135/7500, p. 15.

two years until Heinkel was suddenly ordered to stop also the production of the bomber He 177 and to concentrate instead on the final assembly of the fighter Fw 190 which was needed to repel the Allied bombers.[36] The other aircraft producers of our sample were given much more time to learn how to produce a special component or aircraft efficiently. From the audit reports we know that they were engaged in the production of the bombers Ju 88 and Ju 87 at least the following time spans: *Arado* from October 1939 until the second half of 1942, *ATG* from January 1940 until June 1943, *Junkers* from February 1939 until September 1943, *Siebel* from January 1940 until December 1943, and *Weser* from 1938 until December 1942.[37]

4.1 Learning curves

The idea of learning curves was introduced into economics by Alchian in 1963. Analyzing the data of 22 different aircraft types produced by the American industry during World War II Alchian finds out that the direct amount of labor required to produce a unit of a special aircraft type regularly declines when the total output of this type is expanded. This relationship can be graphically expressed by the so-called learning curve.[38] The basic explanation for the negative slope of this function is that workers learn as they work. In this respect, learning-by-doing means that the more often a worker repeats a special task the more efficient he or she will become. This effect might arise in all kinds of industries but the increase in labor productivity is expected to be especially high when workers are given rather complex tasks like it has been the case in the aircraft industry during World War II. Another general characteristic of the learning curve is that the decrease in working time required to produce a special good will be less with each successive unit of output. This implies that aircraft producers realize substantial efficiency gains above all in the early stage of a production run whereas the learning effects might totally cease when the number of accumulated units reaches a certain threshold.

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[36] See audit report 1943/44, BArch R 8135/1916, p. 5.
[37] See BArch MA RL 3/976, p. 48; *Arado*'s audit report 1942, BArch R 8135/7085, p. 5; *ATG*'s audit report 1942/43, BArch R 8135/2168, p. 3; *Junkers*' audit report 1942/43, BArch R 8135/7650, p. 10; *Siebel*'s audit report 1943, BArch R 8135/7938, p. 6; *Weser*'s audit reports 1938 and 1942, BArch R 8125/5271, p. 2, and BArch R 8135/8133, p.4.
[38] See Hartley, 1965, p. 123.

Given non-increasing wages the learning curve obviously translates via falling labor costs into decreasing production costs per unit. This is not the only way, however, in which learning-by-doing can reduce the overall costs of an aircraft producer (Sturmey, 1964, pp. 961-963). When workers get used to a special production process they also learn to avoid wrongly cutting or shaping which saves material. The prices of components bought from others firms decrease because these suppliers realize learning effects too. Since experienced workers are able to produce a higher number of units in a certain period of time than green hands, learning-by-doing also cuts overhead costs per unit whenever those overhead costs were fixed in the respective time span.

The National Socialist military planners were already well aware of the existence of learning curves in the aircraft industry. That is why the aviation department carefully kept track of the decreasing direct labor input, actually drew its own learning curves for both different aircraft types and different aircraft producers, and finally used the information delivered by these charts to predict the future development of the labor productivity in the aircraft industry.[39]

[Insert figure 4 here]

The available data allow us to construct a curve that shows the development of the working hours the three firms *ATG*, *Junkers* and *Siebel* needed on average to produce one unit of the Ju 88 bomber in the period from August 1939 to August 1941. Notice that the vertical axis presents the logarithm of the working hours. Overall, the average working hours spectacularly dropped from 100,000 in October 1939 to 15,317 in August 1941. This finding supports the assumption stated above that learning effects are especially high in the early stage of a production run. Two details of figure 4 are noteworthy too. The decrease in labor productivity in spring 1940 was caused by the appearance of the two new producers *ATG* and *Siebel* which started their Ju 88 production later and were therefore less efficient than *Junkers* at this point in time. The decrease in labor

[39] See, for example, BArch MA RL 3/931, pp. 13, 34-36.

productivity in spring 1941 resulted from the adaptation costs that occurred because of the change to the new design Ju 88 A 4. This design modification, however, interrupted the learning process only for a few month, as the firms returned to their long-term learning curve in June 1941.

[Insert table 6 here]

Table 6 demonstrates for the example of *Junkers* that learning effects translated into falling production costs. In the two-year period between 1940/41 and 1942/43 the total costs to produce one unit of the Ju 88 bomber fell by 33 percent, the direct material costs by 29 percent and the labor costs by 60 percent. The decrease in labor costs might be even larger than the decrease in working hours since wages were also decreasing during World War II because of the growing share of foreign civilian workers, prisoners of war and concentration camp prisoners who were paid lower wages than the German workers.[40] Table 6 also shows that the increase in labor productivity depicted in figure 4 didn't stop after 1941. At the end of the accounting year 1942/43 *Junkers* only needed about 7,000 working hours to build an aircraft which production had required 100,000 working hours four years ago.[41]

The precise timing of the Ju 88 program gives us some idea why the concurrence of the supposed German armament miracle and Albert Speer's reign might have been just coincidental. It was in May 1938 when the aviation department finally decided that the Ju 88 bomber would become one of the major weapons of the German air force.[42] The firms which were chosen to participate in this program were instructed to end their established production and adapt their plants to the new design instead. The actual production of the Ju 88 bombers started in 1939. The firms used the following two years to move down their learning curves and to realize the substantial increases in labor productivity that occurred in the early stage of a production run. Around the end of 1941 the production processes were finally run in and the Ju 88 producers were ready to take off. In February

[40] See, for example, Heinkel's audit report 1942/43, BArch R 8135/7500, p. 49.
[41] See audit report 1942/43, BArch R 8135/7560, p. 76.
[42] See Budrass, 1998, p. 548 f.

1942 Albert Speer became armament minister. This was exactly the right time to be credited with the considerable increase in the Ju 88 production in the following two and a half years. In our opinion, however, this growth was not a sudden miracle made possible by Speer but the continuation of a development started in 1938 and fuelled by the ongoing learning effects shown by table 6 and the growth of the firms' capital endowment discussed in section 2.[43]

4.2 Who learned?

We assumed above that the increase in labor productivity portrayed by the learning curve generally results from the blue-workers' capability to improve their efficiency when regularly repeating a given task. An implicit precondition of the assumption that it is the individual worker, who learns, is that he stays long enough in the firm to do so. The available data imply that this precondition wasn't realized in the German aircraft industry. Table 7 shows for *Junkers* and *Arado* that during World War II the fluctuation of the work force was extremely high. Junkers, for example, lost every accounting year between a fifth and a third of the employees recruited before. Since this firm nevertheless tried to increase its work force, the number of newly recruited and mostly very inexperienced employees came to about 40 percent in every accounting year we have data for. This observation suggests that a lot of employees only worked a few month in the plants of the German aircraft producers[44] and had, as a consequence, not the time to increase their labor productivity by learning-by-doing considerably. If it wasn't the individual worker who improved its efficiency by learning-by-doing the question arises how the existence of learning curves in the German aircraft industry can be explained then.

[Insert table 7 here]

Reviewing the B-17 production in Boeing's Plant No. 2 in Seattle, Washington, during World War II, Mishina (1999, p. 163) also observed that this plant "*attained its peak*

[43] Milward (1965) points out that the German armament miracle was not only caused by rationalization but also by a considerable growth of the firms' factor endowments.
[44] See Budrass, 1998, p. 461.

production as well as peak efficiency predominantly with green hands and not with the men who were brought into the plant by the massive hiring program of 1941. The heroic female workers – known generally as Rosie the Riveter – had had a factory job only for a year or two when Plant No. 2 recorded its best performance. Unless labor skill is easily transferable, these facts undermine the learning-by-doing hypothesis that regard direct workers as the principal embodiment of experiential learning." Mishina (1999, p. 164) states that it was first and foremost the management of the firm who learned during the production run how to improve the workers' productivity by improving the production system. These improvements included the implementation of just-in-time production to clear the shop-floor of stocks that weren't necessary for the current production, the breakdown of the assembly process into finer subassemblies which increased the division of labor, and the reduction of rework thanks to greater interchangeability of components.

We found some evidence in the audit reports that in the German aircraft industry it was also primarily the production system that embodied the learning effects and not the individual workers themselves. The auditor of *Junkers*, for example, pointed out that in the accounting year 1941/42 the firm's savings in labor costs were above all caused by technical rationalization measures, by the refining of the production methods and the introduction of assembly lines.[45] In *Siebel*'s plants the average number of workers needed to do final assembly of one unit of the Ju 88 bomber dropped from 9 to 2,2 between 1941 and 1943. This increase in labor productivity was again explained by the introduction of assembly lines. The audit report also mentioned, however, that the more frequent use of interchangeable components might have improved efficiency too.[46] These examples support our conjecture that in the German aircraft industry too it was the manager and not the worker who learned. In the last sub section we will discuss how the managers were actually motivated to use their experiences to improve the production system.

[45] See audit report 1941/42, BArch R 8135/7559, p. 95.
[46] See audit report 1943, BArch R 8135/7938, p. 10.

4.3 Incentives to learn

Under a regime of cost-plus contracts the managers of the German aircraft producers wouldn't have been especially eager to realize cost reductions by improving the production system since lower production costs would have inevitably translated into lower profits. Actually, this problem was explicitly addressed by the German procurement agencies which in late 1936 especially complained about the fact that aircraft producers which were given a cost-plus contract did nothing to increase labor productivity but rather tried to increase their labor costs in order to raise their profits which were until then calculated on the basis of the actual production costs. Since it seemed to be impossible for an outside observer to tell the necessary costs from the superfluous ones the only way to use the profit-maximizing behavior of the aircraft producers for the purpose of the state would have been to pay them prices which were independent from the actual costs.[47] These considerations led the German aviation department to the decision to change to fixed-price contracts in spring 1937.[48]

From this date on, the unit price of the bombers or fighters of a certain batch was already fixed in the moment when the procurement agency ordered a firm to produce them. The calculation of the size of this price primarily based on the actual costs of earlier production runs but also took into account expectations about the future development of the firm's learning curve. When the aircraft producer was able to fabricate the aircraft at lower production costs than estimated in the ex ante price agreement he was entitled to keep this difference as an additional premium as long as his profit per sales didn't exceed a certain rate that was originally laid down at 10 percent.[49] The procurement agency, on the other hand, was allowed to check the firm's book-keeping in order to calculate the price of a future batch on the basis of up-dated information about the firm's productivity.

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[47] See *LC an den Chef des Verwaltungsamtes Herrn Generalmajor Volkmann, Berlin, den 12. Dezember 1936*, and especially *Anlage 1: Gebrüder Behner Maschinenfabrik, Leipzig-Plagwitz, den 20. Juli 1936 an Herrn Oberst Mooyer, Bevollmächtigter des Reichsluftfahrtministeriums für das Luftfahrtindustriepersonal*, BArch MA RL 3/169.

[48] See *LD 1 an LC II, Berlin, den 10. März 1937*, BArch MA RL 3/169.

[49] The managers had incentives to raise profits even when the firm was state-owned since the size of their wages depended on the size of profits. See *Bezugsprüfung von Heinkel/Oranienburg 1942/43,* BArch R 8135/7500, p. 1.

[Insert figure 5 here]

Figure 5 demonstrates by the example of *Siebel*'s wing set production in 1942 that the procurement agency was usually not able to update its estimations about a firm's labor costs as fast as the firm actually moved down its learning curve. This is especially true for the batches 23 to 26 of the wing set production. While the procurement agency was apparently believing that the learning effects of this production process were already fully exploited, *Siebel* was still able to decrease its labor costs by about 25 percent.

[Insert figure 6 here]

The fact that the prices set by the procurement agency responded to the firms' cost reductions only after a certain time lag typically created a wave-like development of the aircraft producers' profits as it is depicted in figure 6 that shows the profits per unit of *Junker*'s Ju 88 A-4 production during the two accounting years 1940/41 and 1941/42. During this two-year period *Junkers* had to face only three price cuts which occurred at the beginning of the batches 42, 48 and 54 respectively. Each of these price adjustments which were calculated on the basis of the latest available production costs decreased *Junkers*' profits considerably. Since each of the new prices was fixed for six batches *Junkers* was then given both the time and the incentives to decrease its costs by exploiting the learning effects arising during the production run. As a result, *Junkers*' profits were generally the higher the longer a certain price was kept constant. It is conceivable, however, that on the eve of a new price adjustment *Junkers* consciously held back some improvements to shift already possible efficiency gains into the period which followed the anticipated price reduction. Such a behavior would explain why *Junkers* was able to match the large price cut of batch 54 with an appropriate cost reduction.

[Insert table 8 here]

Table 8 reveals that, while both sales and operating profits were generally increasing during the whole period covered by our data, five of the six aircraft producers of our

sample realized their highest operating profits per sales volume already in the year 1939. The rather downwards trend of the profit rates during World War II can be explained by two reasons. First, as we have already seen in figure 4, the learning effects of the Ju 88 production were especially high in the years 1939 and 1940. Second, after 1939, the state was not longer willing to tolerate outstanding profits of the aircraft producers and therefore often reduced the fixed prices after checking the book-keeping results. In 1940, for example, *Arado*'s operating profits per sales volume were decreased from 13,5 percent to 9 percent by later price adjustments.[50] The expectation that the state was going to cut profits ex post certainly lowered the firms' willingness to reduce costs. Since they were still allowed to keep a part of the additional profits that resulted from learning-by-doing it seems reasonable to assume that the incentives implemented by the fixed-price contracts didn't totally cease.

It is noteworthy that in the German aircraft industry fixed-price contracts were only used for aircraft producers' series production whereas the development of prototypes or repair work were still paid on the basis of cost-plus contracts. This duality of the procurement regime gave the aircraft producers the possibility to increase their profits by cheating. The trick was to assign overhead costs which actually occurred during series production to, for example, the development of a new prototype. This shifting of overhead costs led to increasing profits in two ways. In series production which was paid by fixed prices the profits rose because of decreasing costs. In the case of the newly developed prototype, where the payment not only covered all costs but also included a premium calculated as a given percentage of these costs, the profits rose because of increasing costs. Unfortunately, the audit reports didn't reveal such an obvious mischief of the firms. We have clearly shown, however, that the Speer administration cannot be credited with the introduction of fixed-price contracts into the German aircraft industry.

[50] See audit report 1940, BArch R 8135/7084, p. 15. These numbers only apply to *Arado*'s sales at fixed prices. Table 8 shows all sales.

5 Conclusions

It is widely believed that it was the Speer administration which caused the sudden upswing of the German armament production after 1941 by introducing several rationalization measures and, probably most important, by replacing cost-plus contracts with fixed-price contracts. The example of the six aircraft producers engaged in the production of the Ju 88 and Ju 87 bombers suggests instead, that in the aircraft industry, which accounts for about 40 percent of German armament production, the crucial political changes occurred not in 1942 but already before World War II started. In spring 1937 the aviation department chose to rely on fixed-priced contracts in order to give the aircraft producers the right incentives to reduce costs. In summer 1938 it decided that the aircraft producers had to concentrate on a few different types or components so they could run larger production series. What followed was not a sudden production miracle but a rather continuous development. Moving down the learning curve the managers of the aircraft producers learned how to deploy the workers more efficiently. The resulting increases in labor productivity combined with a ongoing growth of the capital endowment explain why the aircraft producers were able to raise their monthly production continually until summer 1944. We will have to analyze other war industries in greater detail before we can answer the question whether this result is an industry-specific exception or true for most of the German armament producers.

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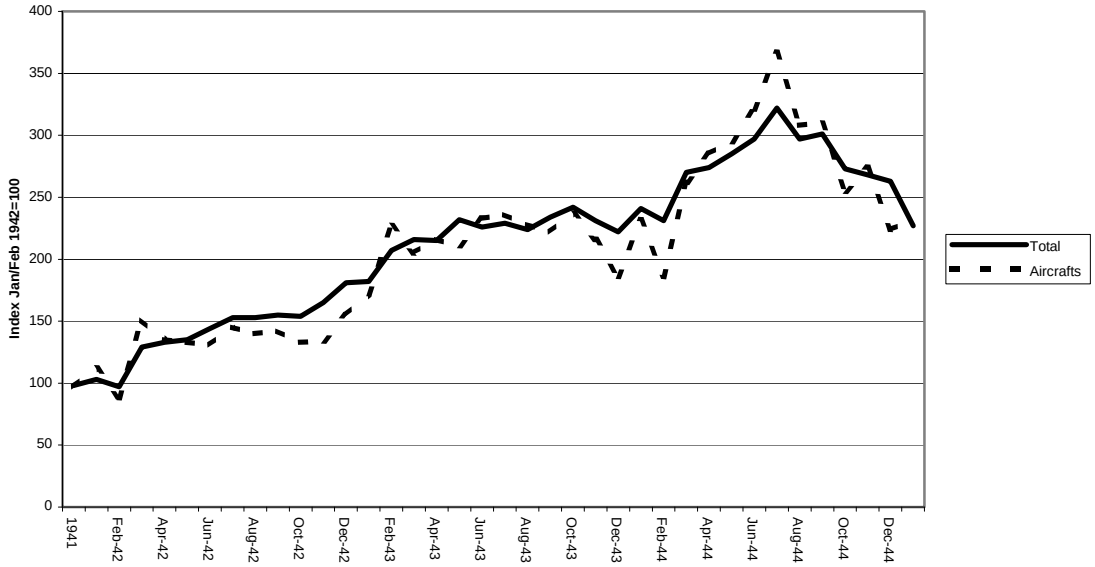
Appendix

Figure 1 German Armament Production 1941-1945[a]



a Wagenführ, R., 1954. *Die deutsche Industrie im Kriege 1939-1945*. Berlin: 178, 180.

Figure 2 Capital-Labor-Ratio 1937-1943

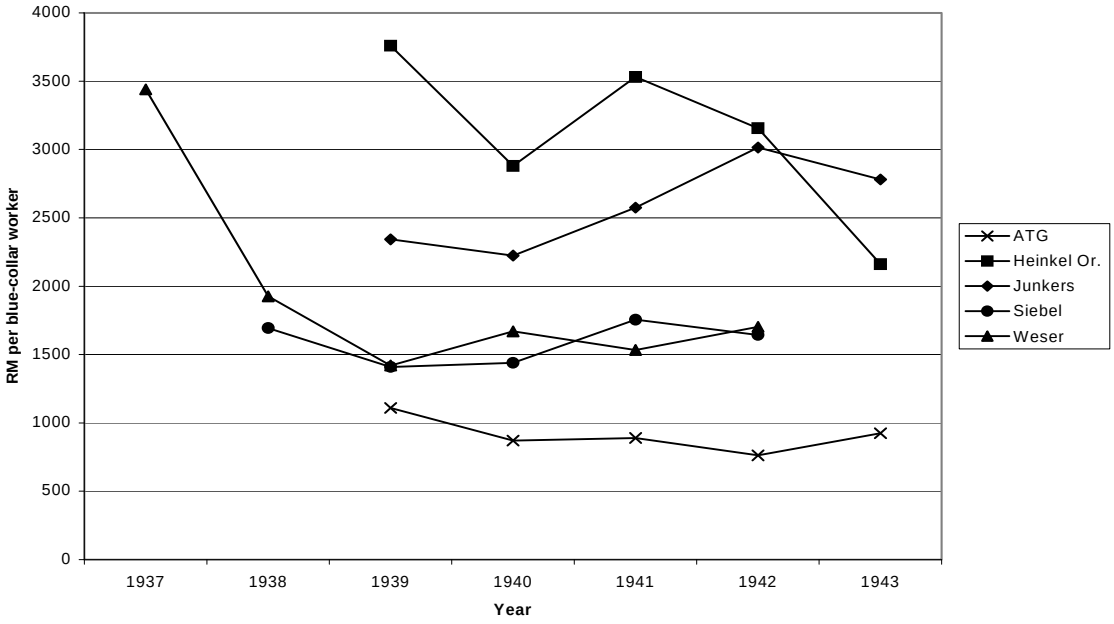


Figure 3 Sales per Blue-collar Worker

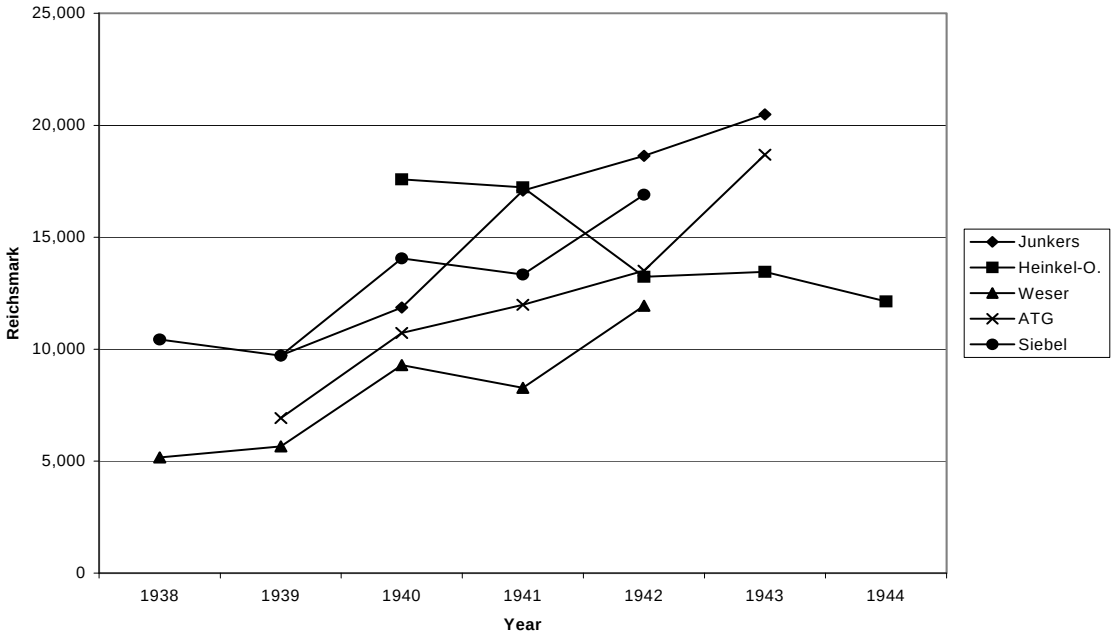
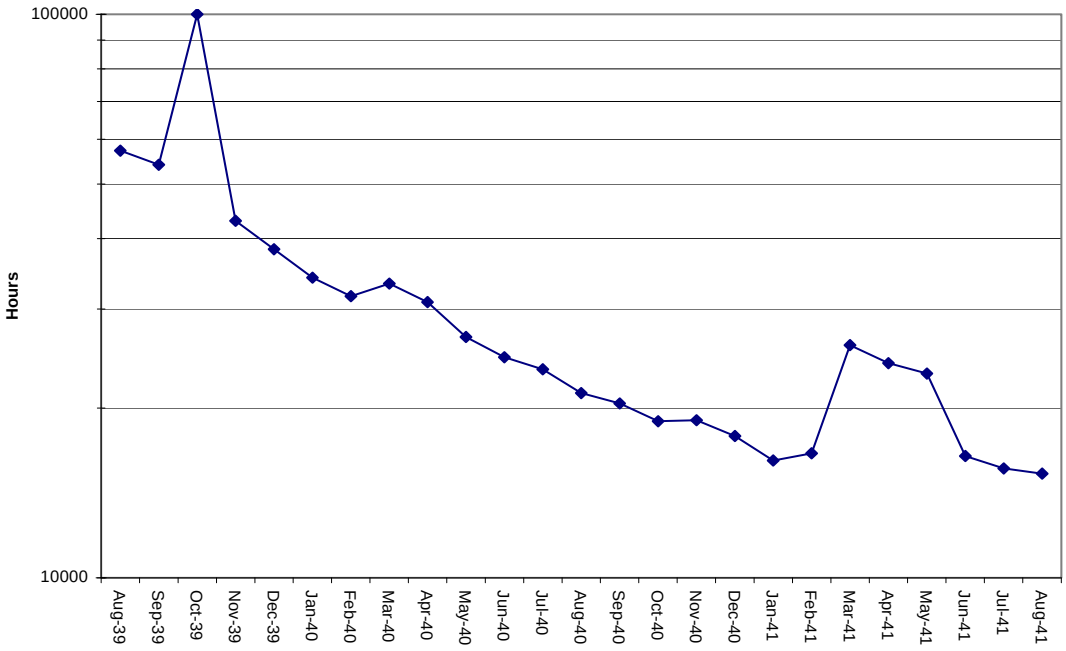
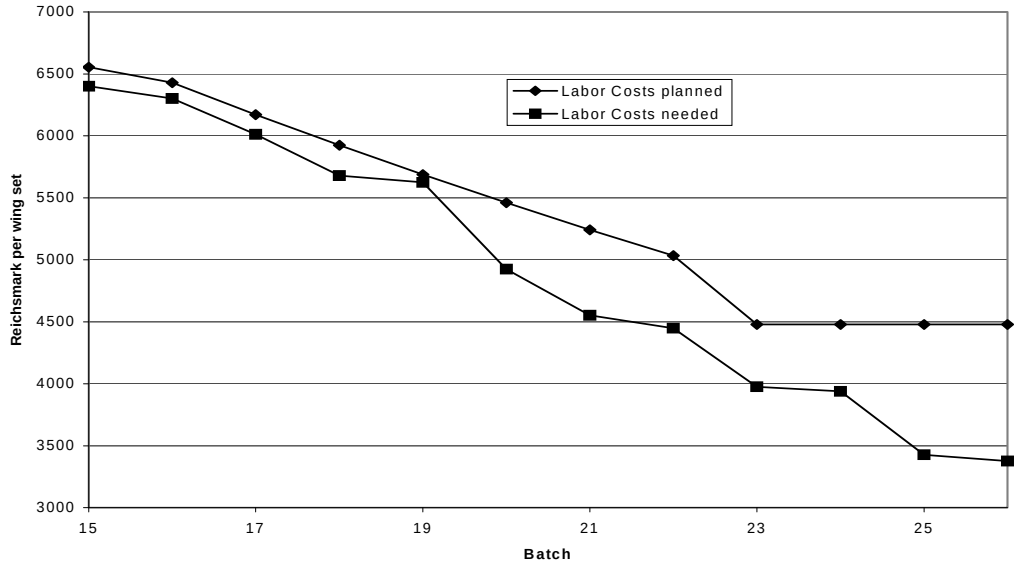


Figure 4 Average working hours per unit Ju 88 (ATG, Junkers, Siebel)[a]



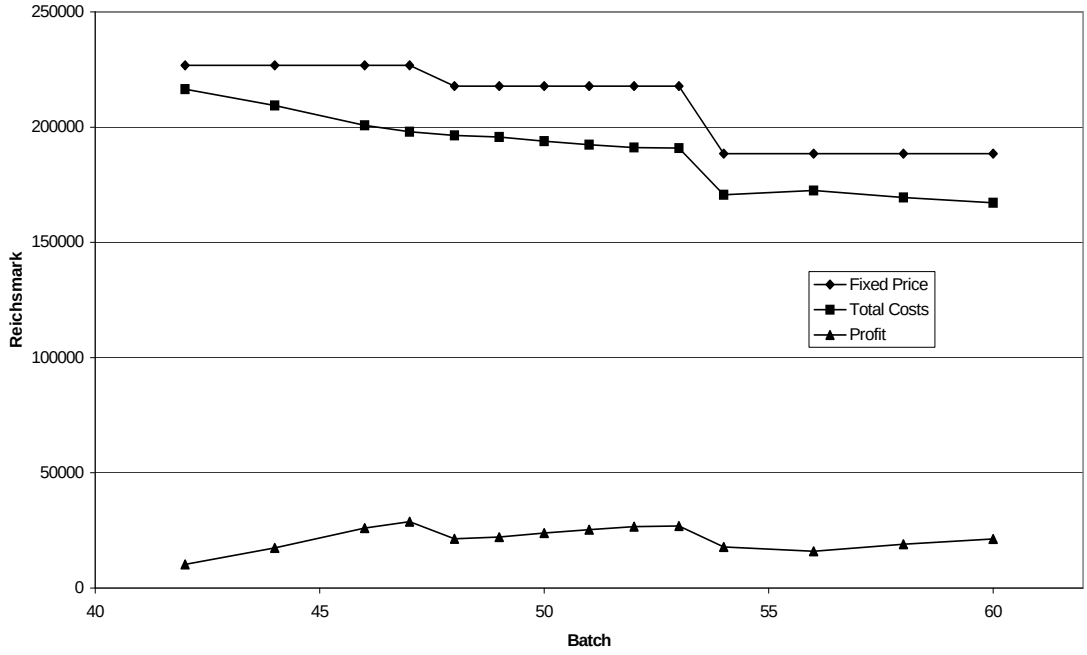
a Barch MA RL 3/976, p. 48, BArch MA RL 3/931, pp. 34-36.

Figure 5 Labor costs per Ju 88 wing set, planned in advance and actually needed, Siebel 1942[a]



a See audit report 1942, BArch R 8135/2518, p. 18.

Figure 6 Profit per unit of Junker's Ju 88 A-4 production, 1940/41 to 1941/42[a]



a See audit report 1940/41, BArch R 8135/7558, p. 56; audit report 1941/42, BArch R 8135/7559, p. 94.

Table 1 Labor Productivity in the German Armament Production 1941-1944 (New Year 1941/42 = 100)[a]

Time	Armament Production	Employees	Labor Productivity
New Year 41/42	100	100	100
New Year 42/43	177	113	157
New Year 43/44	225	119	189
June/July 44	300	130	234
November 44	260	132	197

a Wagenführ, R, 1954. *Die deutsche Industrie im Kriege 1939-1945*. Berlin: 125.

Table 2 Selected German Aircraft Producers

Firm	Fixed Assets in 1939, million RM	Blue-collar Workers in 1939	Main Business
Junkers Flugzeug- und Motorenwerke, Dessau	110.6 (Sep 39)	47,200	Production of the bomber Ju 88 and of aircraft engines
Arado Flugzeugwerke, Potsdam	54.0 (Dez 31)		Production of Ju 88 wings, final assembly of Ju 88
Heinkel-Werke, Oranienburg	21.5 (Dez 31)	5,719	Production of Ju 88 wings, final assembly of Ju 88
Weser Flugzeugbau, Bremen	16.2 (Dez 31)	11,428	Production of the bomber Ju 87
ATG Allgemeine Transportanlagen-Gesellschaft, Leipzig	6.5 (Jun 31)	5,820	Production of Ju 88 fuselages, tail units and engines, final assembly of Ju 88
Siebel Flugzeugwerke, Halle	5.9 (Dez 31)	3,048	Production of Ju 88 wings, final assembly of Ju 88

Table 3 Allocation of working hours over the different stages of production of military aircrafts with several engines[a]

Various Things	3.8%
Final Assembly	4.7%
Equipping	6.7%
Engines	6.7%
Wings	27.2%
Steering	2.6%
Tail Unit	11.2%
Landing Gear	7.6%
Fuselage	29.3%

a BArch MA RL 3/931, p. 15.

Table 4 Extensive growth of the selected German Aircraft Producers

Firm	Annual growth rate	
	Fixed assets	**Blue-collar workers**
Junkers, Dessau	23 % (39-43)	18 % (39-43)
Arado, Potsdam	18 % ((39-42)	
Heinkel, Oranienburg	4 % (39-43)	20 % (39-43)
Weser, Bremen	21 % (39-42)	14 % (39-42)
ATG, Leipzig	- 3 % (39-43)	2 % (39-43)
Siebel, Halle	23 % (39-43)	18 % (39-42)

Table 6 Decreasing Production Costs at Junkers[a]

Accounting year: Type	Production costs RM	Labor costs RM	Material costs RM
1939/40: Ju 88	523,385		
	210,648		
1940/41: Ju 88 A 5	196,825	14,998	141,996
	187,324	13,497	136,431
1940/41: Ju 88 A 4	216,523	21,481	143,479
	198,019	12,467	142,246
1941/42: Ju 88 A 4	170,605	12,211	128,160
	167,129	10,803	126,446
1941/42: Ju 88 A 4 trop.	173,143	12,114	129,680
	159,484	7,876	125,897
1941/42: Ju 88 D 1 trop.	156,807	8,580	122,844
	154,670	7,686	122,422
1942/43: Ju 88 A-4 trop.	141,246	6,876	107,966
	139,274	6,475	107,155
1942/43: Ju 88 D-1 trop.	137,204	6,592	104,515
	131,145	5,750	101,500

a For each accounting year both the highest and the lowest production costs of a special design are reported. For more details see audit report 1939/40, BArch R 8135/2548 , p. 70; audit report 1940/41, BArch R 8135/7558, p. 56; audit report 1941/42, BArch R 8135/7559, p. 94; audit report 1942/43, BArch R 8135/7560, p. 76.

Table 5 Development of the Work Force of Heinkel-Oranienburg[a]

Groups	Jan. 1940	Dec. 1940	March 1941	March 1942		June 1942		Sept. 1942		Dec. 1942		March 1943		July 1943		March 1944
				♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	
Germans				6074	999	5508	954	4917	856	4402	715	3714	696	3690	649	3656
Russians				-	-	54	578	228	801	471	811	196	949	149	785	
Other foreigners				1391	53	2203	289	1705	247	1460	196	1422	206	1011	191	1386
Prisoners of war		130?	206	830	-	663	-	556	-	511	-	509	-	468	-	424
Concentration camp prisoners				-	-	-	-	1144	-	2226	-	4107	-	5676	-	6240
Sum total ♂	4868	5734	6265	8295		8428		8550		9070		9948		10994		10768
Sum total ♀	851	1043	1136		1052		1821		1906		1722		1851		1585	938
Sum total	5719	6777	7401	9347		10249		10456		10792		11799		12579		11706

a Audit report 1940, BArch R 8135/7498, appendix p.62; audit report 1941, BArch R 8135/7499, appendix p. 37; audit report 1942, BArch R 8135/7499, appendix p. 71; audit report 1943, BArch R 8135/7500, p. 50; audit report 1944, BArch 8135/1916, p. 6.

Table 7 Employees recruited and dismissed, in percent of all employees at the end of the accounting year[a]

Firm	Employees	1939	1940	1941	1942
Junkers	recruited	38 %	45 %	43 %	40 %
	dismissed	19 %	20 %	33 %	37 %
Arado	recruited		35 %	35 %	34 %
	dismissed		26 %	18 %	32 %

a For Arado see audit report 1940, BArch R 8135/7084, p. 8; audit report 1941, BArch R 8135/7085, p. 7 f.; audit report 1942, BArch R 8135/7085, p. 6. For Junkers see audit report 1940/41, BArch R 8135/75558, p. 22; audit report 1941/42, BArch R 8135/7559, p. 141.

Table 8 Sales Volumes and Operating Profits of the Selected German Aircraft Producers, 1937-1944

Firm	Period	Sales Volume, in million RM	Operating profit	
			in million RM	in % of the sales volume
Junkers	1937/38	345,6	24,0	6,9
	1938/39	408,4	36,2	8,9
	1939/40	664,2	44,1	6,6
	1940/41	1146,5	67,0	5,8
	1941/42	1321,3	109,7	8,3
	1942/43	1712,8	117,8	6,9
Arado	1939	146,8	17,0	11,6
	1940	204,3	16,6	8,1
	1941	208,1	16,0	7,7
	1942	266,0	22,0	8,3
Heinkel-Oranien.	1939	91,9	11,1	12,1
	1940	116,9	10,5	9,0
	1. Quarter 1941	31,2	3,2	10,3
	1941/42	114,5	7,9	6,9
	1942/43	134,8	10,2	7,6
	1943/44	145,7	11,8	8,1
Weser	1937	29,6	0,6	2,0
	1938	36,9	3,9	10,6
	1939	56,3	6,8	12,1
	1940	112,5	10,0	8,9
	1941	114,6	10,4	9,1
	1942	189,3	11,1	5,9
ATG	1938/39	40,4	4,0	9,9
	1939/40	74,1	5,4	7,3
	1940/41	88,7	9,8	11,0
	1941/42	96,3	6,8	7,1
	1942/43	122,2	8,4	6,9
Siebel	1938	28,7	1,6	5,6
	1939	33,4	4,5	13,5
	1940	65,9	8,2	12,4
	1941	74,5	6,6	8,9
	1942	107,6	10,0	9,3
	1943	135,0	8,8	6,5

Abstract Armament minister Albert Speer is usually cre...Â Historical Articles [Unofficial]. Demystifying the German Armament Miracle During World War II: Demystifying the German Armament Miracle During World War II: Economy.Â " This paper uses the annual audit reports of the Deutsche Revisions- und Treuhand AG for seven firms which together represented about 50 % of the German aircraft producers...." and i quote from the text, line 1 page 5: There is still no doubt, however, that German firms were able to increase their armament production between 1942 and 1944. So the article torpedoes itself. The study openly states it is severely flawed in the Abstract. Two years into the war, in September 1941, German arms seemed to be carrying all before them. Western Europe had been decisively conquered, and there were few signs of any serious resistance to German rule.Â Imbued with an unquestioning faith in Hitler and his will to win, Speer restructured and rationalised the arms production system, building on reforms already begun by Todt. His methods helped increase dramatically the number of planes and tanks manufactured in German plants, and boosted the supply of ammunition to the troops.Â The Germans were forced to retreat. The missing German tanks had not been destroyed; they had been pulled out by Hitler to deal with a rapidly deteriorating situation in Italy. Albert Speer (born March 19, 1905) is the Reich Minister of Armaments and War Production, as well as the chief architect of Adolf Hitler. Speer is the head of the reformist faction within the National Socialist German Workers' Party, and believes that the party must reform itself and the country, in order to adapt to the modern age and survive. Speer joined the Nazi Party in 1931 and quickly became a member of Adolf Hitler's inner circle. Speer oversaw the construction of many new structures during... Demystifying the German â€œarmament miracleâ€ during World War II. New insights from the annual audits of German aircraft producers. by Lutz BudraÃŸ, Jonas Scherner, and Jochen Streb.Â 1 The German armament miracle In December 1941 the Russian army stopped the German Wehrmacht near Moscow. That along with the United Statesâ€™ entry into World War II brought the National Socialistsâ€™ strategy to fight so-called Blitzkriege, which could be waged with a comparatively low number of soldiers and arms, to a sudden end.1 Now confronted with the prospect of a long-lasting war against the United States and Soviet Russia, the German military planners acknowledged that they. New doubts arising from the annual audits of the German aircraft producers. Jonas Scherner University of Mannheim Jochen Streb University of Hohenheim Abstract Armament minister Albert Speer is usually credited with causing the upswing in German armament production after 1941. Exploring the annual audit reports of the Deutsche Revisions- und Treuhand AG for six different firms, we question this view by showing that in the German aircraft industry the crucial political changes already occurred before World War II.Â 1 The German armament miracle In December 1941 the Russian army stopped the German Wehrmacht near Moscow.