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DEMYSTIFYING THE GERMAN “ARMAMENT MIRACLE” DURING  
WORLD WAR II. NEW INSIGHTS FROM THE ANNUAL AUDITS OF  
GERMAN AIRCRAFT PRODUCERS

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# **Demystifying the German “armament miracle” during World War II. New insights from the annual audits of German aircraft producers**

by

Lutz Budraß, Jonas Scherner, and Jochen Streb

## **Abstract**

Armament minister Albert Speer is usually credited with causing the boom in German armament production after 1941. 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. We question the received view by showing that in the German aircraft industry the crucial changes that triggered the upswing in aircraft production 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 that cost-plus contracts were replaced with fixed price contracts. What followed was not a sudden production miracle but a continuous development which was fuelled first by learning-by-doing and then by the ongoing growth of the capital and labor endowment.

**Keywords:** German armament miracle, World War II, Albert Speer, Aircraft industry, Learning-by-doing, Fixed-price contract, Labor productivity

**JEL Codes:** H57, L64, N44

## 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.<sup>1</sup> Now confronted with the prospect of a long-lasting war against the United States and Soviet Russia, the German military planners acknowledged that they had to increase their armament production considerably. This insight was, for example, 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, fewer workers will have to produce the same or an even larger amount of armament goods than are fabricated until now*" [translated by the authors].<sup>2</sup>

[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<sup>3</sup> 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 Allied air-raids on German firms and transportation networks, led many observers to christen this development a miracle.<sup>4</sup> 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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<sup>1</sup> See Kröner (1988). One might argue, however, that the heavy investment in armament production during 1940 and 1941 indicates that the National Socialists already decided to prepare for a long-lasting war at the beginning of World War II. For investment figures see, for example, Hopmann, 1996, p. 120.

<sup>2</sup> "*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 Güterverbrauch der Wirtschaft dieselbe oder eine größere kriegswichtige Produktion aufzubringen haben als vorher.*"

<sup>3</sup> 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.

<sup>4</sup> 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 important detail that German armament production had already grown significantly between 1938 and 1940 (Wagenführ, 1954, p. 23).<sup>5</sup>

[Insert figure 2 here]

Another deficiency arises from the fact that the index also included armament goods that were produced in occupied countries.<sup>6</sup> Figure 2, for example, shows that in occupied Poland (*Generalgouvernement*) armament production for the German armed forces nearly quadrupled between February 1942 and May 1944.<sup>7</sup> It would therefore be misleading to interpret the armament index as a consistent measure for the growth of German weapons production within the borders of 1937. An additional shortcoming resulted from the fact that the index also counted the increasing number of older military equipment like aircraft that were just repaired after minor damage, which could be done with much less effort than producing new ones.<sup>8</sup> As a result, the index of armament production depicted in figure 1 might considerably over-state the volume of new weapons produced within the traditional borders of Germany after 1941.

[Insert table 1 here]

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<sup>5</sup> For more details about the role of statistics in German armament planning under Speer's reign see Tooze, 2001, pp. 253 f.

<sup>6</sup> This fact is explicitly stated in *Anmerkungen zum Text des Lageberichts 1943/44*, BArch R 3/1965, Blatt 67. See also *Lagebericht 1943/44*, R 3/1965, Bl. 82.

<sup>7</sup> Poland was of course not the only and not the most important location of armament production for the German armed forces. The aircraft producer *Arado*, for example, obtained during the year 1942 several components and even completed aircraft 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. Our main data source is the firm-specific annual audit reports of the *Deutsche Revisions- und Treuhand AG* shelved in the Federal archives in Berlin. We will discuss this source at length below.

<sup>8</sup> 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.

There is still no doubt, however, that German firms were able to increase their armament production between 1942 and 1944. At least implicitly assuming that the firms' individual endowments with capital goods and blue-collar workers were rather constant in this period,<sup>9</sup> historians generally explain the increase in armament production by a corresponding increase in labor productivity (Overy, 1994, pp. 344-345). This explanation is often justified by table 1, originally published by Wagenführ after World War II. Based on rather rough estimates table 1 shows that German armament production tripled between January 1942 and July 1944 while the employees producing armament goods within the German borders grew by only 30 percent in the same period. One might conclude from these data that the productivity of this work force more than doubled in two and a half years. However, Wagenführ himself (1954, p. 125) acknowledges that this growth rate of labor productivity might be too high because of the increasing armament production in occupied countries. Yet, the results of table 1 are generally accepted and 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 (Abelshauser, 1998, p. 156 f.; Overy, 1994, pp. 356-363; Weyres, 1975, pp. 47-49). First, 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 decreased, 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 destructive 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 inter-firm committees in order to give less efficient firms the information considered necessary for imitating the technology of the

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<sup>9</sup> 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 do not exist.

superior firms. This might have especially 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 about 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.<sup>10</sup> 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 necessary to change to another type of procurement contract. In May 1942, the government ordered that cost-plus contracts in general had to be replaced with fixed-price contracts.<sup>11</sup> Under this new procurement 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. As a result, firms now had the incentive to take the opportunities offered by Speer's rationalization program to decrease their costs.

The fact that it was apparently 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) stated immediately after the war: "*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.*" Until today the rather positive evaluation of

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<sup>10</sup> For more details see Streb/Streb (1998).

<sup>11</sup> See *Anordnung über Einheits- und Gruppenpreise vom 19. Mai 1942*, Reichsanzeiger vol. 117.

Speer's capability is mainly based on the analysis of documents of the different state authorities, on macroeconomic data, and, last but not least, on Speer's autobiography in which he successfully built up his own myth.<sup>12</sup> However, not much is known about the economic activities inside the individual firms. So crucial empirical questions are still unanswered: Were the reforms of the Speer administration more than ineffective announcements? Did they really cause a considerable increase in the armament producers' productivity after a surprisingly short period of time? Could they therefore be interpreted as the main reason for the so-called armament miracle?

To answer these 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, the aircraft industry's average share in the armament production came to about 40 percent (Wagenführ, 1954, pp. 30, 69). Second, the index of aircraft production represented by the broken line in figure 1 behaved very similarly to the index of total 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 results 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, increases in labor productivity especially occurred before 1942 and were more likely caused by learning-by doing effects than by rationalization measures. In particular, there was no structural break with respect to the procurement regime during the war 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

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<sup>12</sup> See, especially, Speer, 1969, pp. 219-228.



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.

From an organizational point of view the governmental administrators of the German aircraft industry were able to keep a comparatively high degree of independence of Speer up to the year 1944. The aviation department (*Reichsluftfahrtministerium*) under Hermann Göring had planned and executed air armament since 1933. Competing with army and navy ordnance offices for raw materials and workers thereafter, the autonomy of the aviation department was confirmed when Speer took over the armament department in February 1942. Especially Field Marshal Erhard Milch, who led the ordnance office of the aviation department after November 1941 and had also been a promising candidate for the position of the armament minister, successfully repelled any attempts to reduce his responsibility for air armament (Eichholtz, 1985, p.60). The wider framework of Milch's armament strategies, however, was set by Speer. Moreover, in March 1944, aircraft production finally also came under the direct control of Speer's armament department.

## **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.<sup>13</sup> 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.

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<sup>13</sup> 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. See Guinnane, 2003, p. 248.

The Federal Archives in Berlin Lichterfelde possess a collection<sup>14</sup> 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. The typical audit report contains not only a comprehensive analysis of the balance sheet 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.<sup>15</sup>

[Insert table 2 here]

In this paper, we mainly concentrate on the seven German aircraft producers listed in table 2. For six of these firms audit reports of the *Deutsche Revisions- und Treuhand AG* were available and covered most of the war time.<sup>16</sup> For the *Henschel Flugzeug-Werke AG* we added data from company files which partly survived in the archives of *Zahnradfabrik Friedrichshafen (ZF)* at Calden near Kassel. Most of these firms produced the double-engine Ju 88 bomber, originally designed by the company *Junkers Flugzeug- und Motorenwerke AG*.

[Insert figure 3 here]

The so-called Ju 88-program, which was established by Göring in mid-1938 and was aimed at exploiting economies of scale and raising the technological standards of aircraft production, presented a major innovation in German procurement organization. The largest firm, *Junkers*, produced in its various plants all components of the aircraft Ju 88

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<sup>14</sup> The shelf mark of this collection is BArch R 8135.

<sup>15</sup> 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 Scherner (2004) and Streb (2003).

<sup>16</sup> See *Audit reports of the Deutsche Revisions- und Treuhand AG* in the appendix.

including the engines,<sup>17</sup> while *ATG*, *Arado*, *Heinkel-Oranienburg*, *Henschel* and *Siebel*, among others,<sup>18</sup> concentrated on some components and tasks like wings, fuselages, engine suspension, tail units, and final assembly.<sup>19</sup> In order to give *Junkers* the opportunity to boost its output of Ju 88, *Weser* took over the production of the single-engine Ju 87 bomber which had been *Junkers*' main product until then. *Junkers* was vested with the right to act as a state agency. It organized the flow of raw materials and labor to the firms of the different divisions and also had the right to direct their specific production decisions. To enable the other firms to imitate its design and production methods, *Junkers* shared information and also gave them technological support when needed.<sup>20</sup> Interestingly enough, the firms in our sample had already exchanged technological knowledge<sup>21</sup> before Albert Speer ordered the newly founded inter-firms committees to do exactly this. There is some evidence, indeed, that Speer's reform based on positive experiences with the Ju 88-program.<sup>22</sup>

The Ju 88-program constituted one of the largest German armament projects. The firms which took part in the original plan of 1938 employed more than half of the workforce engaged in German airframe production. Even in 1943, when the focal point of air armament began to shift to fighters, the participants in the Ju 88-program still employed a third of it (Budraß, 1998, p. 834). Between September 1938, when series production started at *Junkers*, and September 1944, when it was cancelled, some 14,000 Ju 88 bombers were built.

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<sup>17</sup> *Junkers* also produced the aircraft type Ju 52. See audit report 1939/40, BArch R 8135/2548, p. 57.

<sup>18</sup> 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.

<sup>19</sup> The German state owned *Arado*, *Heinkel*, *Junkers*, and *Weser* at least partly. See *Beteiligungsfirmer der Luftfahrtkontor GmbH*, BArch R 2/5550, p. 44 f.

<sup>20</sup> See audit report 1941/42, BArch R 8135-7559, p. 61.

<sup>21</sup> Due to the ambiguous role of *Junkers*, however, the Ju-88 program initially caused sharp resistance from the companies concerned. See Budraß, 1998, p. 552.

<sup>22</sup> See *Aus der geheimen Aktennotiz von Karl Albrecht, Geschäftsführer der Wirtschaftsgruppe Feinmechanik und Optik, über die Sitzung der Reichsgruppe Industrie am 27. März 1940 zum Verhältnis zwischen der Reichsgruppe Industrie und dem Reichsminister für Bewaffnung und Munition*, in Eichholtz/Schumann, 1969, pp. 245 f.

### 3 Extensive growth

In this section we analyze the development of both the work force and the fixed assets of our firm sample during war time. With respect to the latter the figures officially revealed in the audit reports might considerably underestimate the actual development of firms' capital stock for two reasons. On the one hand, the state granted generous special depreciation allowances that were by no means justified by wear and tear but were intended to enable firms to transform profits into hidden reserves.<sup>23</sup> On the other hand, firms often increased their production capacities not by investment in new plants but by leasing already existing plants from other firms or the state,<sup>24</sup> whose value then did not show up in their balance sheets. To estimate the amount of the capital stock that was actually employed by the German aircraft producers we therefore adjusted the officially published figures by the following procedure. We added back all special depreciation allowances ( $SD_t$ ) of a particular accounting year ( $t$ ) to the officially published fixed assets ( $FA_t$ ) and then used the "regular" depreciation rates  $r_i$ ,  $i=t, \dots, t+n$ , (regular depreciations in year  $i$ /officially published fixed assets in year  $i$ ) to depreciate them step by step in the actual and following years.<sup>25</sup> When data were available we also included the value of the leased plants ( $P_t$ ) in our estimation of the capital stock in year  $t$ . In the following year the value of the leased plants was either depreciated at the same rate like the rest of the production capacity or, when the audit reports contain this information, replaced by its up-dated value ( $P_{t+1}$ ). As a result, the adjusted fixed assets (AFA) for the years  $t$  and  $t+1$ , for example, are defined as:

$$AFA_t = FA_t + (1 - r_t)SD_t + P_t$$

$$AFA_{t+1} = FA_{t+1} + (1 - r_{t+1})(1 - r_t)SD_t + (1 - r_{t+1})SD_{t+1} + (1 - r_{t+1})P_t$$

or

$$AFA_{t+1} = FA_{t+1} + (1 - r_{t+1})(1 - r_t)SD_t + (1 - r_{t+1})SD_{t+1} + P_{t+1}$$

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<sup>23</sup> See *Endgültige Fassung der Richtlinie über Preisbildung und Finanzierung vom 12. Juni 1937*, BArch R 2/5475, p. 31. For the particular write down of capital in 1938 see BArch R 2 Anh./37, pp. 31 f. See also Budraß, 1998, pp. 492 f.

<sup>24</sup> See audit report 1940 of *Weser*, BArch R 8135/5272, p. 2. See also Hopmann, 1996, pp. 123, 195 f.

<sup>25</sup> In its book-keeping *Henschel* explicitly distinguished between "real" fixed assets actually employed and "official" fixed assets decreased by special depreciation allowances.

Table 3 shows that in the period covered by the available audit reports both the adjusted fixed assets and the work force of most firms in our sample increased with astonishing annual growth rates. The highest growth rates were realized in the pre-1941 period when on average adjusted fixed assets increased by 18.3 % and blue-collar workers by 24.5 % per year. However, even in the post-1941 period, extensive growth of the aircraft producers was remarkably large.

[Insert table 3 here]

Two firms deviated from the general trend. *ATG* was for some reason not able to use the favorable conditions of the German war economy to augment its own factor endowment to the same extent as the other firms of the Ju 88-program. *Heinkel*, which had the highest capital-labor-ratio in 1939, increased in the following years only its work force. In contrast to *Heinkel*, the capital-labor ratio of the other firms was either growing (*Arado*, *ATG*, *Henschel*, *Junkers*), or only slightly falling (*Siebel*, *Weser*) during war time.<sup>26</sup>

[Insert figure 4 here]

How can the development of the aircraft producers' capital-labor ratio depicted in figure 4 be explained? In the late 1930s, German aircraft producers had built up excess capacities with respect to plants and machinery. After World War II had started, the capital-labor-ratio shortly decreased since firms recruited many blue-collar workers in order to staff their newly built plants.<sup>27</sup> However, as the upward trend of the capital-labor ratio of most of the firms in our sample after 1940 indicates, the growth of their adjusted fixed assets soon exceeded the growth of their work force again. This unbalanced development seems to be caused by the shortage of labor that resulted from the increasing number of German male workers that were recruited by the army.<sup>28</sup> The fact that labor

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<sup>26</sup> The average annual growth rate of the capital-labor-ratio, calculated by weighting the seven firms' individual capital-labor-ratio by their share in the total adjusted capital stock of our sample, was 1.1 % in 1940, 7.9 % in 1941, 4.0 % in 1942 and -4.0 % in 1943.

<sup>27</sup> See Budraß, 1998, p. 674.

<sup>28</sup> 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).

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.<sup>29</sup> 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.<sup>30</sup> 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.<sup>31</sup>

The audit reports of the *Deutsche Revisions- und Treuhand AG* also shed light on whether these measures worked out at the firm level. The example of *Arado* demonstrates that at least some of the aircraft producers were not able to use German women to replace their male workers lost to the army.<sup>32</sup> In 1940, for example, 74 percent of all female blue-collar workers employed in *Arado*'s plant in Brandenburg-Neuendorf quit their job.<sup>33</sup> 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.<sup>34</sup> On the whole, the share of female blue-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.<sup>35</sup>

The audit reports also contain some remarks that imply that the aircraft producers were not 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

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<sup>29</sup> This observation was stressed by Kaldor, 1946, p. 35.

<sup>30</sup> 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.

<sup>31</sup> See Overy, 1994, pp. 291-303

<sup>32</sup> At *ATG*, the share of female workers in the total work force dropped from 13.2 percent in June 1940 to 12.1 percent in June 1941. See audit reports 1940 and 1941, BArch R 8135/2167, R 8135/7100.

<sup>33</sup> See audit report 1940, BArch R 8135/7084, p. 9.

<sup>34</sup> Married women received up to 85 percent of the former wages of their recruited husbands. See Winkler, 1977, p. 92.

<sup>35</sup> See audit report 1940, BArch R 8135/7084, p. 17; audit report 1941, BArch R 8135/7085, p. 7.

production.<sup>36</sup> *ATG*, for example, told the auditor that this type of worker needed extensive training before he could be deployed fruitfully.<sup>37</sup> The fact that, for example, *Arado* declared that in 1942 1,100 workers had to be fired for lack of aptitude,<sup>38</sup> leads us to the conjecture that the “forced” German workers tried hard to prove their incompetence to be released.<sup>39</sup> As a result, the aircraft producers more and more relied on foreign workers whose productivity was in despite of their poor living conditions apparently much higher than the propaganda made the German 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 their German counterparts.<sup>40</sup>

[Insert table 4 here]

Table 4 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 in 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 improve its capacity utilization by running more than one shift. The additional workers needed for this plan were taken from the nearby concentration camp.<sup>41</sup> In the following months *Heinkel* more and more depended on the labor of concentration camp prisoners

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<sup>36</sup> See *Verordnung zur Sicherstellung des Kräftebedarfs für Aufgaben von besonderer staatspolitischer Bedeutung*, Reichsgesetzblatt I, 1939, pp. 206 f.

<sup>37</sup> See audit report 1939/40, BArch R 8135/2167, p. 25.

<sup>38</sup> See audit report 1942, BArch R 8135/7085, p. 6.

<sup>39</sup> This conjecture is, for example, also confirmed by various complaints of the managers of the synthetic rubber plant in Hüls who criticized both the incompetence and the lack of discipline of the “forced” German workers. See Lorentz/Erker, 2003, pp. 307 f.

<sup>40</sup> 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. See also Spoerer, 2001, p. 186.

<sup>41</sup> See Budraß, 1998, p. 778 f.

whose share in the sum total of all blue-collar workers grew fast 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 representative of the situation in the German aircraft industry as a whole. *Heinkel*'s transformation into a firm that mainly exploited concentration camp prisoners was rather exceptional. The other aircraft producers relied more 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.<sup>42</sup>

The data presented in this section reveal that the boom in German aircraft production during World War II has not to be explained by increases in productivity alone but was obviously also caused by the growth of firms' factor endowment.

#### **4 Productivity growth**

Figure 5 shows that the aircraft producers' labor productivity calculated as value added per blue-collar worker generally rose during the period under consideration.<sup>43</sup> In 1940, *Heinkel* was the firm with the highest labor productivity followed by *Henschel*, *Junkers*, *Arado*, *Siebel*, *Weser* and finally *ATG*. This hierarchy changed in the following two years. In 1942, *Junkers* had taken over the lead while *Heinkel* had even fallen behind *Henschel*, *Arado*, *Weser* and *Siebel*.

[Insert figure 5 here]

At first glance, the fact that *Heinkel* was the only firm in our sample that had both a falling capital-labor-ratio and decreasing labor productivity might suggest that the latter was caused by the former. A detailed comparison of figure 4 and 5 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 only slightly

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<sup>42</sup> See audit report 1942/43, BArch R 8135/7560, p. 17; Budrass, 1998, p. 799.

<sup>43</sup> Since value added was measured by actual prices which rather decreased over time the real efficiency gains might be even underestimated.



growing capital-labor ratio, was able to improve its labor productivity steadily and to overtake *Heinkel* and *Siebel* in 1943,<sup>44</sup> while *Arado*, on the other hand, failed to increase efficiency despite a fast growing capital-labor-ratio. We will see in the next sub sections that, especially in the period between 1937 and 1941, the firms' growing labor productivity was most likely caused by learning-by-doing.

The question remains why *Heinkel* was continuously losing efficiency. In our opinion, it was the comparatively discontinuous development of its production program which prevented *Heinkel* from keeping its high productivity level reached in 1940. 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.<sup>45</sup> 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. Figure 5 suggests that *Heinkel* was not able to adapt to these changes without a decrease in labor productivity. The next sudden about-turn of its production program again coincided with a considerable loss of efficiency. In 1942, *Heinkel* had to give up its production of Ju 88 wings and started to fabricate the new bomber type He 177.<sup>46</sup> As a result of this change the "regular" depreciation rate of *Heinkel's* capital stock soared to 28 % in 1942/43. 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. It took another two years until *Heinkel* was suddenly ordered to stop 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.<sup>47</sup>

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<sup>44</sup> The comparatively strong rise of *ATG's* labor productivity in 1943 was probably caused by a restriction of the own production program that resulted from the decision to move the production of engine suspension to *Opel* in Rüsselsheim and of tail units to *Württembergische Metallwarenfabrik* in Geisslingen. See audit report 1942/43, BArch R 8135/2168, p. 3.

<sup>45</sup> See audit report 1940, BArch R 8135/7498, p. 5.

<sup>46</sup> See audit report 1942/43, BArch R 8135/7500, p. 15.

<sup>47</sup> See audit report 1943/44, BArch R 8135/1916, p. 5.

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 Ju 88 bomber for at least the following time spans: *Arado* from October 1939 until the second half of 1942, *ATG* from January 1940 until June 1943, *Henschel* from September 1939 to September 1944, *Junkers* from February 1939 until September 1943, and *Siebel* from January 1940 until December 1943. *Weser* produced the Ju 87 bomber from 1938 to at least December 1942.<sup>48</sup>

Weighting the seven firms' individual labor productivity by their share in the total work force of our sample we also calculated the average annual growth rate of value added per blue-collar worker. It turned out that this growth rate was especially high in the early years of the Ju 88 and Ju 87 production. It came to 17.3 % both in 1938 and in 1939, to 9.2 % in 1940, to 6 % in 1941, and to only 3.5 % and 3.7 % in 1942 and 1943 respectively.<sup>49</sup> Surprisingly enough, labor productivity grew much faster in the period between 1937 and 1941 than under Speer's reign. We will explain this finding in the next section by learning effects.

#### **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 (1963) found 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.<sup>50</sup> 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

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<sup>48</sup> 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's* 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.

<sup>49</sup> Since prices for aircraft were falling during war time we under-rate the growth rate of labor productivity by using nominal value added to measure output. However, this measurement error is at least partly offset by the fact that the individual work load of the blue-collar workers increased in the period under consideration.

<sup>50</sup> See Hartley, 1965, p. 123.

repeats a special task the more efficient he or she will become. This effect might arise in all kinds of industries, but the expected increase in labor productivity is especially high when workers are given rather complex tasks, such as case in the World War II aircraft industry. 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 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.

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 (Sturmeijer, 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.

Before World War II, the German aviation department was already well aware of the existence of learning curves in the aircraft industry. In 1929, Wolfram von Richthofen, who later became the head of the department of aircraft development in the technical office of the aviation department, submitted his doctoral thesis to the Technical University of Berlin.<sup>51</sup> In this thesis Richthofen summed up his experiences in aircraft production which he had acquired as an expert of the ordnance office of the *Reichswehr* since 1925. Analyzing the production systems of the leading German aircraft producers he found in each case a negative correlation between working hours per ton of aircraft and accumulated output. Even though Richthofen could only observe very small

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<sup>51</sup> Richthofen, W. v., 1929. *Der Einfluß der Flugzeugbauarten auf die Beschaffung unter besonderer Berücksichtigung militärischer Gesichtspunkte*. Doctoral thesis, Technical University of Berlin. Wolfram von Richthofen was a cousin of the famous First World War fighter pilot Manfred von Richthofen.

production series presented in table 5, his findings on the learning curve became the basis for German armament planning since 1933.

[Insert table 5 here]

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.<sup>52</sup> Moreover, the Ju 88-program itself was explicitly designed to exploit “economies of learning”. *Junkers* had needed at the minimum 30,000 working hours to produce the bomber which preceded the Ju 88. Yet it was predicted that because of the learning effects occurring during a large production run *Junkers* would need only 25,000 working hours to complete the 1000<sup>th</sup> Ju 88. It was further assumed that learning effects could also be evoked in the smaller firms like *Siebel* and *ATG* which were therefore instructed to specialize in the production of certain parts of the Ju 88.<sup>53</sup>

[Insert figure 6 here]

The available data allow us to construct a curve depicted in figure 6 that shows the development of 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 working hours. Overall, average working hours dropped spectacularly from 100,000 in October 1939 to 15,317 in August 1941. This finding supports the observation stated above that learning effects are especially high in the early stage of a production run. Two details of figure 6 are especially noteworthy. 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 time. The decrease

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<sup>52</sup> See, for example, BArch MA RL 3/931, pp. 13, 34-36.

<sup>53</sup> See *Ju 88 Zentralsteuerung. Ein Schritt zur Rationalisierung der Fertigung in der Luftfahrtindustrie*, Archives of the German Museum in Munich (DMM/ASD) LRD LR 02621, p. 2.

in labor 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 months, as the firms returned to their long-term learning curve in June 1941.

[Insert figure 7 here]

The same learning effects are observable at *Henschel*, whose performance in the Ju 88-program can be studied over the whole span of production. Preparations for production started in January 1938, and final assembly began in November 1938. While *Henschel* needed more than 700 working hours to produce 1000 RM of production value (final assembly, fuselages, engine suspensions) in November 1938, this rate finally dropped to a minimum rate of 29 working hours in December 1943. As in the case of the other participants of the Ju 88-program, the largest increase in labor productivity occurred in the first year of the production run.

Learning at *Henschel* was interrupted by a governmental planning disaster. In mid 1943, the aviation department instructed *Henschel* to prepare for the production of a heavy fighter of the aircraft producer *Messerschmitt* (Me 410) which was supposed to replace the Ju 88. When the adaptation process was almost completed, this governmental order was withdrawn, and *Henschel* had to return to the production of Ju 88. As a result, in a period when Germany desperately needed new aircraft to fight the Allies, one of the most successful German aircraft producers wasted time with re-establishing the Ju 88 production that was nevertheless cancelled later in 1944.<sup>54</sup> As in the case of *Heinkel Oranienburg*, the drop in labor productivity at *Henschel* in 1944 was primarily caused by sudden changes in the production program.

[Insert table 6 here]

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<sup>54</sup> See *Zusammenstellung der Vorschläge zur Mobilisierung von Leistungsreserven (Mai 1944)*, BArch R 3/1813, p. 6.

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. This decrease in labor costs might have been 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.<sup>55</sup> Table 6 also shows that the increase in labor productivity depicted in figure 6 did not stop after 1941. At the end of the accounting year 1942/43 *Junkers* only needed about 7,000 working hours to build an aircraft the production of which had required 100,000 working hours four years ago.<sup>56</sup>

The precise timing of the Ju 88-program gives us some idea, why the concurrence of the German armament miracle and Albert Speer's reign might just have been 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.<sup>57</sup> 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. 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 broken in, and the Ju 88 producers were ready to take off. In February 1942 Albert Speer became armament minister, in the middle of a seasonal downturn. 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. This growth was not a sudden miracle made possible by Speer but the continuation of a development that started in 1938 and

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<sup>55</sup> See, for example, *Heinkel's* audit report 1942/43, BArch R 8135/7500, p. 49.

<sup>56</sup> See audit report 1942/43, BArch R 8135/7560, p. 76.

<sup>57</sup> See Budraß, 1998, p. 548 f.

was fuelled by the ongoing learning effects shown by table 6 and the growth of the firms' capital and labor endowment discussed in section 2.<sup>58</sup>

#### 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 or she stays long enough in the firm to do so. The available data imply that this precondition was not 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 for which we have data. This observation suggests that many employees only worked a few months in German aircraft plants,<sup>59</sup> and did not have, as a consequence, the time to learn enough to increase their productivity. This raises an important question: if individual worker turnover was so high that we cannot ascribe the learning-by-doing to worker learning, as the literature usually asserts, then who was responsible for the learning curves in the German aircraft industry documented above?

[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 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*

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<sup>58</sup> Milward (1965) already pointed out that the German armament miracle was not only caused by rationalization but also by a considerable growth of the firms' factor endowments.

<sup>59</sup> See also Budraß, 1998, p. 461.

*transferable, these facts undermine the learning-by-doing hypothesis that regards 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 were not 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.<sup>60</sup> 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.<sup>61</sup>

These examples support our conjecture that in the German aircraft industry 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 experience to improve the production system.

The managers’ goal to transfer learned knowledge among a fluctuating workforce might also help to explain why firm-specific employee suggestion systems ranging from the simple suggestion box to elaborated systems overseen by administrators and evaluators expanded in the aircraft industry and the German armament industry as a whole. In 1940,

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<sup>60</sup> See audit report 1941/42, BArch R 8135/7559, p. 95.

<sup>61</sup> See audit report 1943, BArch R 8135/7938, p. 10.



about 1,000 German companies possessed suggestion systems with which managers intended to motivate workers to reveal special skills, know-how, and innovative ideas acquired in the course of their employment. The number of suggestion systems rose from 3,000 in 1941 to 10,000 in 1942. By the end of 1943, some 35,000 companies had established workers' suggestion systems (Steinwarz, 1943). The aircraft producers were particularly eager to get a hold on the knowledge of their workers. Ernst Heinkel strongly encouraged the introduction of suggestion systems,<sup>62</sup> while a manager at *Junkers* led an inter-firm committee which had been specially founded to exchange workers' suggestions (Budraß, 1998, p. 817). In 1943, *Arado* and *Heinkel* organized large exhibitions of their workers' suggestions, not least to prove their ambitions in rationalizing production. Noteworthy, the suggestion systems were not restricted to German workers. The *Deutsche Arbeitsfront* (DAF) developed forms for workers' suggestions in a dozen languages. Even the concentration camp prisoners who worked at *Heinkel Oranienburg* were successfully asked to submit suggestions for technical improvements in production.<sup>63</sup> Though it is difficult to quantify the different effects of these suggestion systems on productivity, one important intention of the management was clearly to get the information which was necessary to accelerate the learning of green hands. When the former head of the committee for aircraft production under Speer, Karl Frydag, was asked in August 1945 to give his personal view on the reasons for the production miracle, he named for: rationalization, standardization of components, longer working hours and, last but not least, workers' suggestion systems.<sup>64</sup>

### 4.3 Incentives to learn

Under a regime of cost-plus contracts the managers of the German aircraft producers would not have been especially eager to realize cost reductions by improving the production system since lower production costs would have inevitably translated into lower profits. This problem was explicitly addressed by the German procurement agencies in late 1936. They complained that aircraft producers which were given a cost-

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<sup>62</sup> See Heinkel, 1943.

<sup>63</sup> See *Himmler an Göring*, 9.3.44, International Military Tribunal Vol. XXVII, Doc. 1584-PS, p. 357.

<sup>64</sup> See *Interrogation of Gen. Dir. K. Frydag and Prof. E. Heinkel. Some aspects of German aircraft production during the war*, 14/8/45, Combined Intelligence Objectives Subcommittee Evaluation Report #323, Imperial War Museum.

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 was to pay them prices which were independent from the actual costs.<sup>65</sup> These considerations led the German aviation department to the decision to change to fixed-price contracts in spring 1937.<sup>66</sup>

From this date on, the unit price of the bombers or fighters of a certain batch was fixed the moment the procurement agency ordered a firm to produce them. The calculation of the size of this price was based primarily 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, so long as his profit per sales did not exceed a certain rate that was originally laid down at 10 percent.<sup>67</sup> 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.

[Insert figure 8 here]

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<sup>65</sup> 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.

<sup>66</sup> See *LD I an LC II, Berlin, den 10. März 1937*, BArch MA RL 3/169.

<sup>67</sup> The managers had incentives to raise profits even when the firm was state-owned since the size of their salaries depended on the size of profits. See *Bezugsprüfung von Heinkel/Oranienburg 1942/43*, BArch R 8135/7500, p. 1. At Junkers, the profit-sharing bonus accounted for 20 to 50 percent of the payment of a member of the managing board. See *Sonderprüfung Junkers, Dessau betr. Aufteilung der vertraulichen Bezüge der leitenden Angestellten 1940/41*, BArch R 8135/7558, Anlage I; *Sonderprüfung Junkers, Dessau betr. Aufteilung der vertraulichen Bezüge der leitenden Angestellten 1941/42*, BArch R 8135/7559, Anlage p. 159; *Sonderprüfung Junkers, Dessau betr. Aufteilung der vertraulichen Bezüge der leitenden Angestellten 1942/43*, BArch R 8135/7560, p. 101.

Figure 8 demonstrates by the example of *Siebel's* wing set production in 1942 that the procurement agency was usually not able to update its estimates of a firm's labor costs as fast as the firm moved down its learning curve. This is especially true for the batches 23 to 26 of the wing set production. While the procurement agency apparently believed 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.<sup>68</sup>

[Insert figure 9 here]

The fact that the prices set by the procurement agency responded to the firms' cost reductions only after a time lag typically created a wave-like development of the aircraft producers' profits. Figure 9 illustrates the phenomenon with 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 that 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 sharp price cut of batch 54 with an appropriate cost reduction.

[Insert table 8 here]

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<sup>68</sup> A similar misjudgment of the aviation department can be, for example, observed in the case of *Henschel*. Although the aviation department anticipated a sharp drop in production costs and reduced prices for fuselages accordingly both from 1940 to 1941 and from 1941 to 1942, it still considerably underestimated the achievements of *Henschel* in decreasing both labor and material costs. See *Report to the board of directors on the financial year of 1942, 13/10/43*, Henschel files, ZF, Calden.

Table 8 reveals that, while operating profits were generally increasing during the whole period covered by our data, aircraft producers realized their highest operating profits per sales volume in the year 1939. The rather downwards trend of the profit rates during World War II can be explained in two ways. First, as we have already seen in figures 6 or 7, 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 excessive 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.<sup>69</sup> 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 did not totally cease.

It is noteworthy that in the German aircraft industry fixed-price contracts were only used for aircraft producers' series production. 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, where the payment not only covered all costs but also included a premium calculated as a given percentage of these costs. Unfortunately, the audit reports did not reveal such an obvious mischief of the firms. In April 1943, Erhard Milch invited aircraft producers to repay excessive profits voluntarily.<sup>70</sup> This might indicate that the aviation department saw only a slight chance to reveal cheating by checking the firms' book-keeping.

In this section, we have shown that in the German aircraft industry the most substantial increases in labor productivity were already realized when Albert Speer became armament minister in 1942. Productivity growth resulted from learning-by-doing that was

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<sup>69</sup> See audit report 1940, BArch R 8135/7084, p. 15.

<sup>70</sup> See *Milch to Henschel-Flugzeug-Werke*, 30/4/43, Appendix to daily reports to the Board, #548, Henschel files, ZF, Calden.

made possible by the long production runs of the Ju 88 program established in 1938, and encouraged by the introduction of fixed-price contracts in 1937.

## **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 seven firms, which were engaged in the production of the Ju 88 and Ju 87 bombers, and which represented about the half of the German aircraft producers, 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 incentive 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. As a result, in the period before 1942 the growth rate of labor productivity was considerably higher than under Speer's reign. It came to 17.3 % both in 1938 and in 1939, to 9.2 % in 1940, to 6 % in 1941, and only to 3.5 % and 3.7 % in 1942 and 1943 respectively. After 1941, it was primarily the ongoing growth of the capital and labor endowment combined with a higher capacity utilization that enabled aircraft producers to raise their monthly production continually until summer 1944. We will have to analyze other war industries in greater detail before we can prove our hypothesis that this result is not an industry-specific exception but rather true for most of the German armament producers during World War II.<sup>71</sup>

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<sup>71</sup> Studies by Hirsch (1952) and Rapping (1965) reveal that both the American ship building and machine building industry realized substantial learning effects during and after World War II.

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## Appendix

### AUDIT REPORTS OF THE *DEUTSCHE REVISIONS- UND TREUHAND AG*

#### **Arado, Flugzeugwerke Potsdam**

Jan 1939-Dec 1939 BArch R 8135/7084  
Jan 1940-Dec 1940 BArch R 8135/7084  
Jan 1941-Dec 1941 BArch R 8135/7085  
Jan 1942-Dec 1942 BArch R 8135/7085

#### **ATG Allgemeine Transportanlagen-Gesellschaft Leipzig**

Jul 1937-Jun 1938 BArch R 8135/2167  
Jul 1938-Jun 1939 BArch R 8135/2167  
Jul 1939-Jun 1940 BArch R 8135/2167  
Jul 1940-Jun 1941 BArch R 8135/7100  
Jul 1941-Jun 1942 BArch R 8135/2166  
Jul 1942-Jun 1943 BArch R 8135/2168

#### **Heinkel-Werke Oranienburg**

Jan 1940-Dec 1940 BArch R 8135/7498  
Jan 1941-Dec 1941 BArch R 8135/7499  
Jan 1942-Mar 1942 BArch R 8135/7499  
Apr 1942-Mar 1943 BArch R 8135/7500  
Apr 1943-Mar 1944 BArch R 8135/1916

#### **Junkers Flugzeug- und Motorenwerke Dessau**

Oct 1939-Sep 1940 BArch R 8135/2548  
Oct 1940-Sep 1941 BArch R 8135/7588  
Oct 1941-Sep 1942 BArch R 8135/7559  
Oct 1942-Sep 1943 BArch R 8135/7560

#### **Siebel Flugzeugwerke Halle**

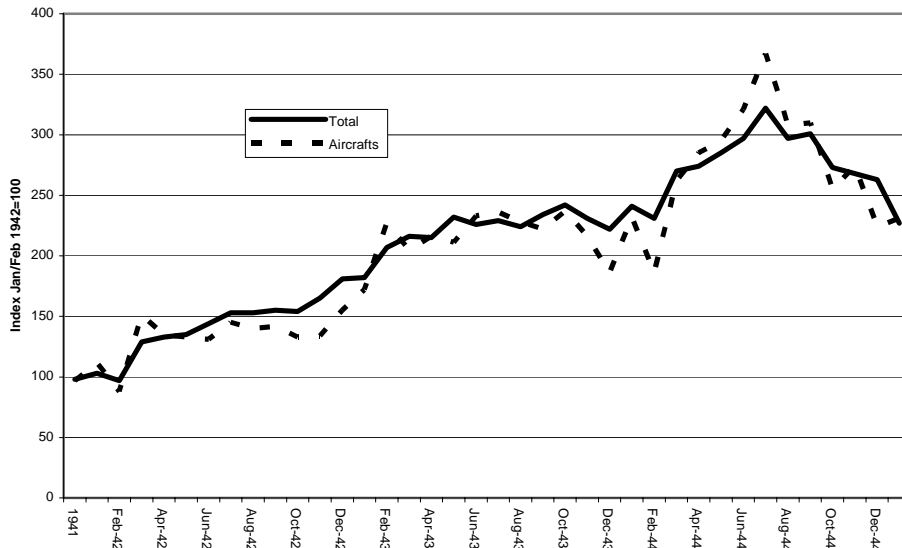
Jan 1937-Dec 1937 BArch R 8135/454  
Jan 1938-Dec 1938 BArch R 8135/454  
Jan 1939-Dec 1939 BArch R 8135/2518, 2172  
Jan 1940-Dec 1940 BArch R 8135/2172, 7938a  
Jan 1941-Dec 1941 BArch R 8135/7938  
Jan 1942-Dec 1942 BArch R 8135/2518, 7938  
Jan 1943-Dec 1943 BArch R 8135/7938

#### **Weser Flugzeugbau Bremen**

Jan 1938-Dec 1938 BArch R 8135/5271  
Jan 1939-Dec 1939 BArch R 8135/5271  
Jan 1940-Dec 1940 BArch R 8135/5272  
Jan 1941-Dec 1941 BArch R 8135/8132  
Jan 1942-Dec 1942 BArch R 8135/8133

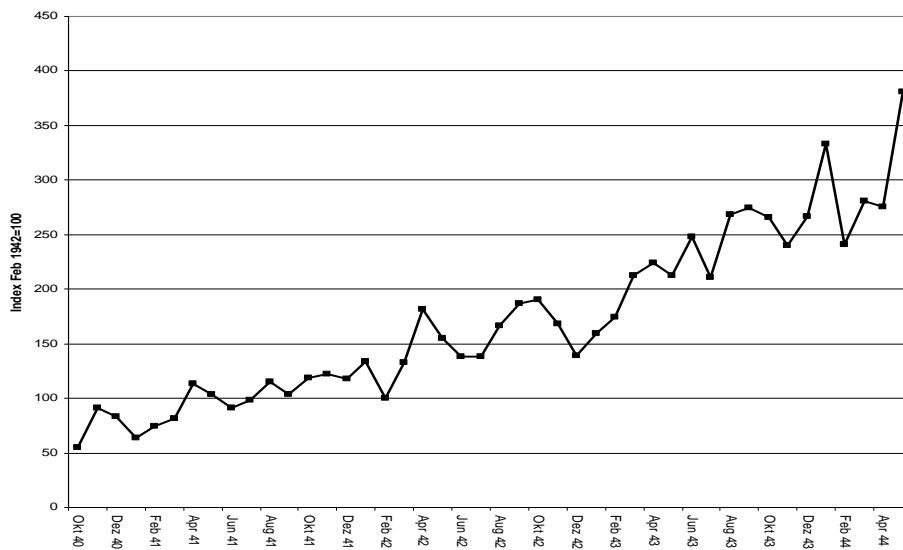


**Figure 1 German armament production 1941-1945<sup>a</sup>**



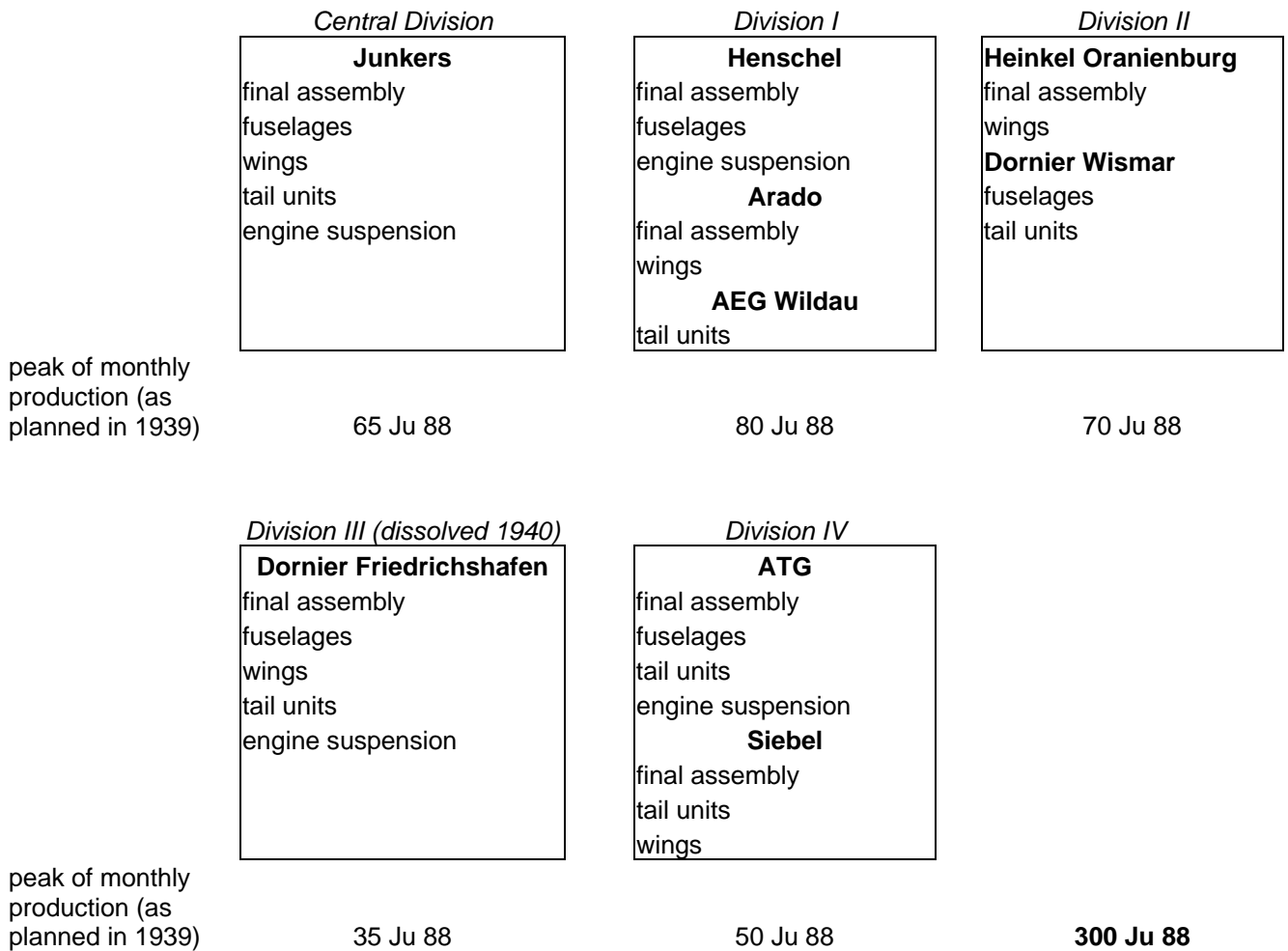
a Wagenführ, R., 1954. *Die deutsche Industrie im Kriege 1939-1945*. Berlin: pp. 178, 180.

**Figure 2 Armament production in occupied Poland (*Generalgouvernement*) 1940-1944<sup>a</sup>**



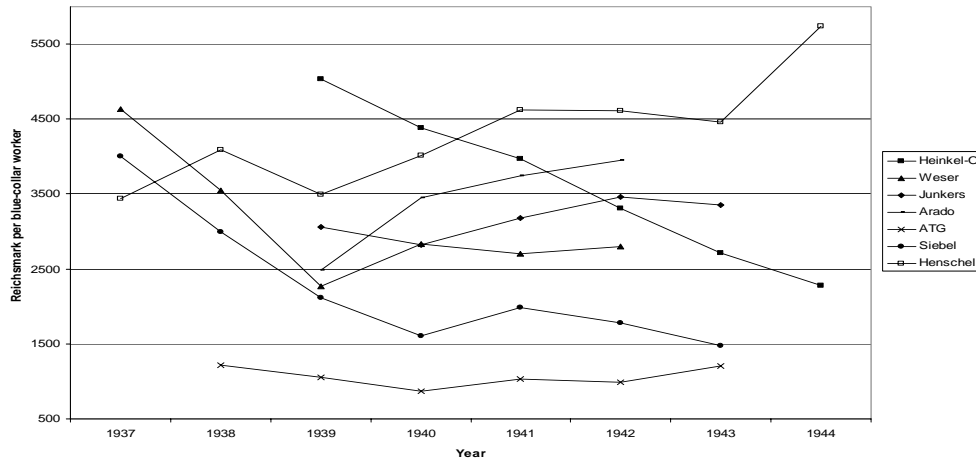
a See BArch R 3/506.

**Figure 3 The organization of the Junkers 88-program (1939)<sup>a</sup>**



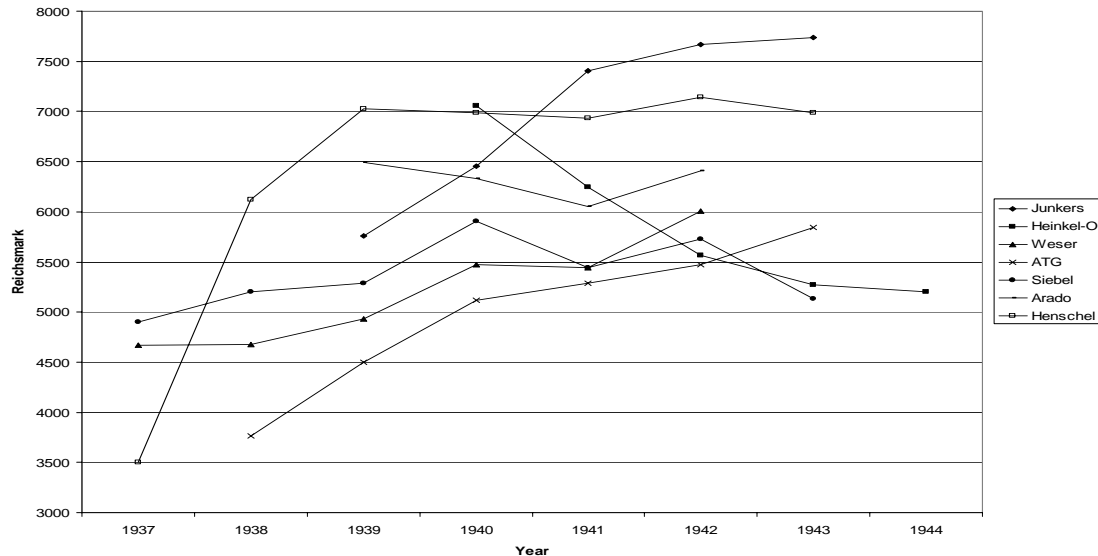
<sup>a</sup> See *Plan der Großserienfertigung Ju 88 mit Jumo 211B (1939)*, Archives of the German Museum Munich, *Sondersammlungen, Dokumentation*, (DMM/ASD) LR 02642.

**Figure 4 Capital-labor-ratio 1937-1943<sup>a</sup>**



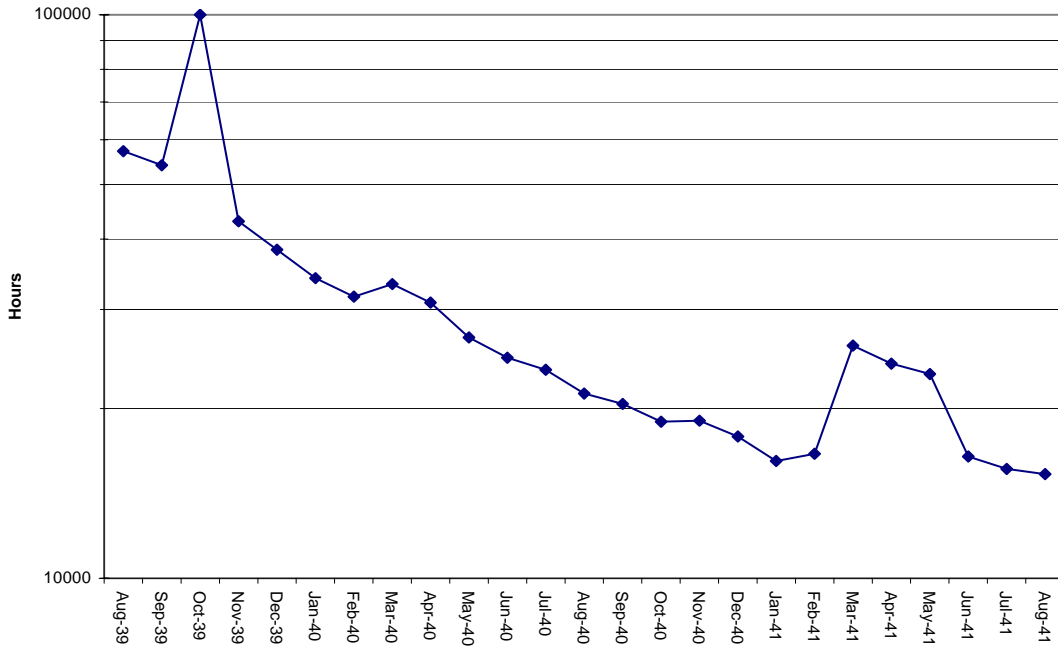
a For data see *Audit reports of the Deutsche Revisions- und Treuhand AG* in the appendix. For *Henschel* see charts *Gefolgschaftsstatistik* in *Statistische Übersichten betr. Kosten*; appendix to the 1938 volume of the monthly reports to the board; report to the board of directors on the financial year of 1943; monthly report to the board of November 1944, Henschel files, ZF Calden.

**Figure 5 Value added per blue-collar worker per calendar year<sup>a</sup>**



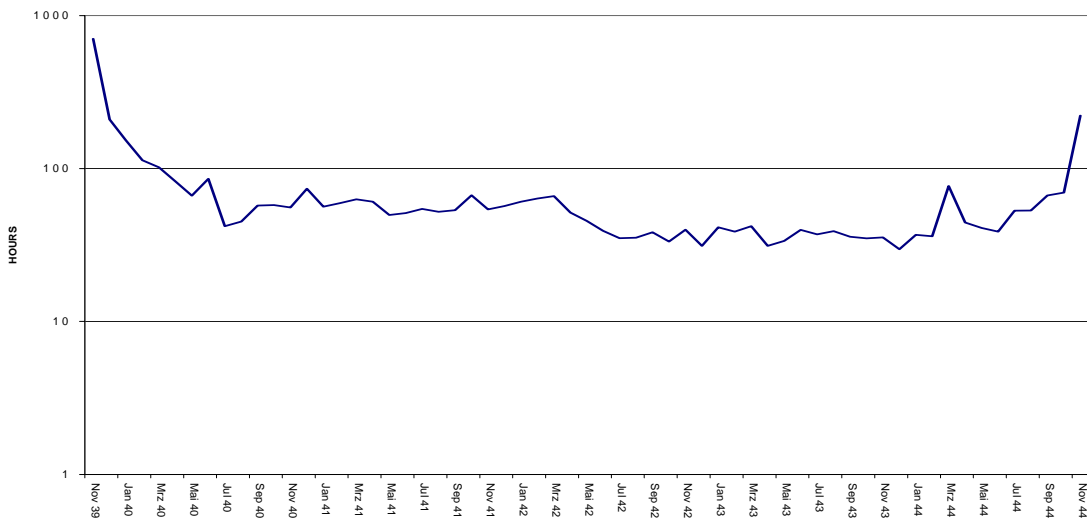
a Value added is defined as production output (*Fabrikationsleistung*) minus intermediate inputs. For the firms *ATG*, *Heinkel* and *Junkers* we interpolated value added per blue-collar per calendar year on basis of the respective figures per accounting year. For data see *Audit reports of the Deutsche Revisions- und Treuhand AG* in the appendix. For *Henschel* see charts *Gemeinkostenzuschläge*, *Fertigungsaufwand*, *Lagerbewegung* in *Statistische Übersichten betr. Kosten*; appendix to the 1938 volume of the monthly reports to the board; report to the board of directors on the financial year of 1943, Henschel files, ZF Calden.

**Figure 6** Average working hours per unit Ju 88 (ATG, Junkers, Siebel), log-linear<sup>a</sup>



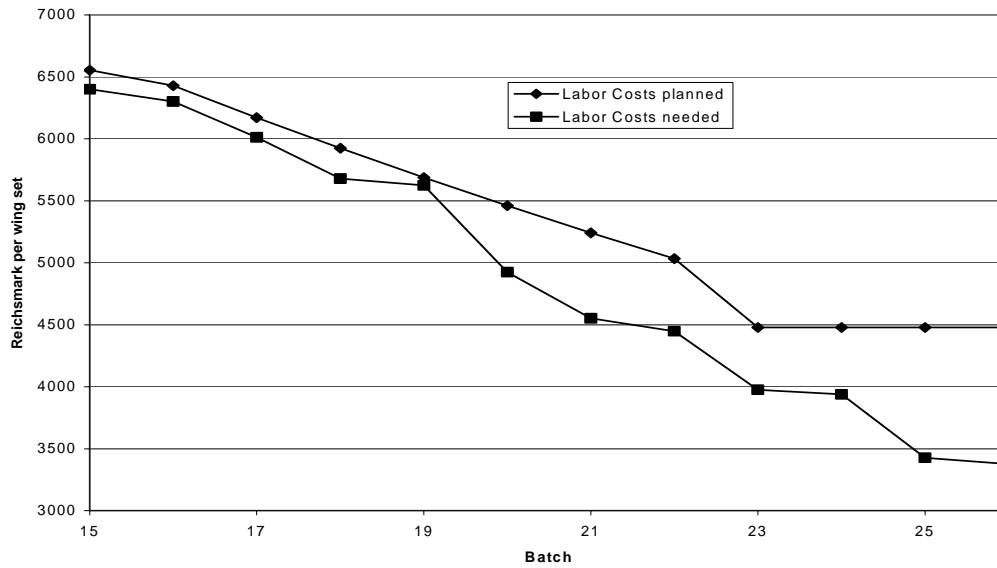
a BArch MA RL 3/976, p. 48, BArch MA RL 3/931, pp. 34-36.

**Figure 7** Direct working hours per 1000 RM production value at Henschel, log-linear<sup>a</sup>



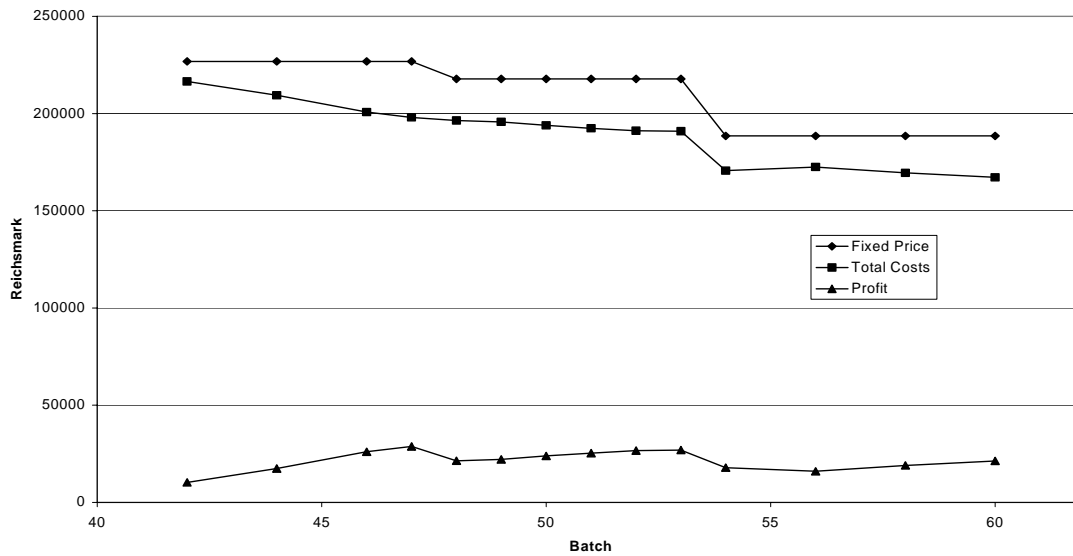
a See *Henschel Flugzeug-Werke*, monthly reports to the board, Henschel files at ZF, Calden.

**Figure 8 Labor costs per Ju 88 wing set, planned in advance and actually needed, Siebel 1942<sup>a</sup>**



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

**Figure 9 Profit per unit of Junker's Ju 88 A-4 production, 1940/41 to 1941/42<sup>a</sup>**



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)<sup>a</sup>

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<sup>a</sup>**

Firm	Officially revealed fixed assets in 1939, million RM	Blue-collar workers in 1939	Main business in 1939
<b>Junkers</b> Flugzeug- und Motorenwerke, Dessau	110.6 (Sep 39)	47,200	Production of Ju 88 (wings, fuselages, engine suspension, tail units and final assembly)
<b>Arado</b> Flugzeugwerke, Potsdam	54.0 (Dec 39)	16,500	Production of Ju 88 (wings and final assembly)
<b>Henschel</b> Flugzeugwerke Schönefeld	30.1 (Dec 39)	7,256	Production of Ju 88 (fuselages, engine suspension and final assembly)
<b>Heinkel-Werke</b> , Oranienburg	21.5 (Dec 39)	5,719	Production of Ju 88 (wings and final assembly)
<b>Weser</b> Flugzeugbau, Bremen	16.2 (Dec 39)	11,428	Production of Ju 87
<b>ATG</b> Allgemeine Transportanlagen-Gesellschaft, Leipzig	6.5 (Jun 39)	5,820	Production of Ju 88 (fuselages, tail units, engine suspension and final assembly)
<b>Siebel</b> Flugzeugwerke, Halle	5.9 (Dec 39)	3,048	Production of Ju 88 (wings and final assembly)

a For data see *Audit reports of the Deutsche Revisions- und Treuhand AG* in the appendix. For *Henschel* see charts *Gefolgschaftsstatistik* in *Statistische Übersichten betr. Kosten*; appendix to the 1938 volume of the monthly reports to the board; report to the board of directors on the financial year of 1943; monthly report to the board of November 1944, Henschel files, ZF Calden.

**Table 3 Extensive growth of the selected German aircraft producers<sup>a</sup>**

Firm	Annual growth rate					
	Adjusted fixed assets			Blue-collar workers		
	Pre-1941 <sup>b</sup>	1941	Post-1941 <sup>b</sup>	Pre-1941 <sup>b</sup>	1941	Post-1941 <sup>b</sup>
Junkers, Dessau	27.8 % (39-40)	19.8 %	18.5% (41-43)	33.3 % (39-40)	19.8 %	10.5 % (41-43)
Arado, Potsdam	47.9 % ((39-40)	29.9 %	5.4 % (41-42)	31.3 % (39-40)	20.2 %	6.4 % (41-42)
Henschel, Schönefeld	29.0 % (37-40)	12.5 %	9.7 % (41-44)	17.1 % (37-40)	0.6 %	8.1 % (41-43)
Heinkel, Oranienburg	2.1 % (39-40)	-1.3 %	-3.2 % (41-44)	14.6 % (39-40)	9.0 %	18.4 % (41-44)
Weser, Bremen	15.1 % (37-40)	17.6 %	21.6 % (41-42)	27.8 % (37-40)	14.4 %	14.5 % (41-42)
ATG, Leipzig	4.0 % (38-40)	6.0 %	4.8 % (41-43)	16.4 % (38-40)	7.1 %	- 6.0% (41-43)
Siebel, Halle	2.3 % (37-40)	30.0 %	1.3 % (41-43)	30.7 % (37-40)	19.2 %	15.9 % (41-43)
<b>AVERAGE</b>	<b>18.3 %</b>	<b>16.3 %</b>	<b>8.3 %</b>	<b>24.5 %</b>	<b>12.9 %</b>	<b>9.7%</b>

a Data refer to the balance sheet date. See *Audit reports of the Deutsche Revisions- und Treuhand AG* in the appendix. For *Henschel* see charts *Gefolgschaftsstatistik* in *Statistische Übersichten betr. Kosten*; appendix to the 1938 volume of the monthly reports to the board; report to the board of directors on the financial year of 1943; monthly report to the board of November 1944, Henschel files, ZF Calden.

b Covered accounting years in parentheses.

**Table 5 Productive working hours per ton of aircraft (1929)<sup>a</sup>**

Production system	1 <sup>st</sup> aircraft	3 <sup>rd</sup> aircraft	12 <sup>th</sup> aircraft	50 <sup>th</sup> aircraft
Dornier	11,800	10,200	8,200	—
Junkers	21,400	14,100	10,300	3,600

a Richthofen, W. v., 1929. *Der Einfluß der Flugzeugbauarten auf die Beschaffung unter besonderer Berücksichtigung militärischer Gesichtspunkte*. Dissertation at Technical University of Berlin-Charlottenburg, table 19.

**Table 4 Development of the work force of Heinkel-Oranienburg<sup>a</sup>**

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	1386
Other foreigners				1391	53	2203	289	1705	247	1460	196	1422	206	1011	191	
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 6** Decreasing production costs at Junkers<sup>a</sup>

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 7** Employees recruited and dismissed, in percent of all employees at the end of the accounting year<sup>a</sup>

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      Operating profits of the aircraft producers ATG, Heinkel-Oranienburg, Junkers, Siebel and Weser per calendar year, 1938-1943<sup>a</sup>**

Year	Average monthly operating profits		Operating profits per sales volume
	Index (1938=100)	Growth rate	
1938 <sup>b</sup>	100		8.3%
1939	151	51.1%	10.7%
1940	199	31.9%	9.6%
1941	254	27.4%	8.2%
1942	360	41.8%	7.2%
1943 <sup>c</sup>	424	17.7%	7.3%

a      *und Treuhand AG* in the appendix.

b      Without *Heinkel-Oranienburg*.

c      Without *Weser*.

For data see *Audit reports of the Deutsche Revisions-*