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Fixed-price contracts, learning, and outsourcing: explaining the continuous growth of output and labour productivity in the German aircraft industry during the Second World War[1]

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In this article it is claimed that, at least in the aircraft industry, the development of German armament production and productivity was much more continuous than Wagenführ's armament index and both the *Blitzkrieg* thesis and the inefficiency thesis suggest. In order to prove this new thesis of continuity, we show on the basis of firm-level data, firstly, that investment in production capacities had already started before the war and was especially high in the early phase of the war, and secondly, that the regulatory setting of aircraft production management was rather constant and was not dramatically changed after 1941. In addition, we demonstrate that the driving forces of productivity growth were primarily learning-by-doing and outsourcing, the latter being generally neglected by economic historians.

In retrospect, no one denies that military success or failure in the materials-intensive Second World War was heavily dependent on the performance of the combatants' respective armament industries, which, during the war, had to be able to produce more and more units of weapons using a limited amount of raw materials, labour, and capital. Half a century after the Second World War ended, modern procurement theory recommends employing fixed-price contracts whenever a government primarily wants to motivate armament manufacturers to increase the productivity of their production processes.[2] Since under the regime of a fixed-price contract, a procurement agency and a private armament firm *ex ante* agree on a binding price of an armament good, the armament firm afterwards faces strong incentives to exploit all existing possibilities to reduce production costs, thereby increasing its productivity. An important source for productivity gains is blue-collar workers' and managers' learning-by-doing. In general, the more often a worker repeats a special task, the less time he or she will need to complete this task. Managers use the experience gained from previous production runs to organize future production processes more efficiently. They might realize, for example, that they can increase the final output considerably by outsourcing the

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[2] See, for example, Laffont and Tirole, *Theory of incentives*, p. 40.

production of standardized components which have previously been produced by their own firm. The resulting inter-firm division of labour allows both the producers of the final products and the suppliers of the components to concentrate on their respective core competences, thereby realizing economies of scale.

We will show for the case of the German aircraft industry that Nazi planners were well aware of the theoretical microeconomic considerations mentioned above before the development of modern procurement theory in the second half of the twentieth century. In preparation for the Second World War, they changed to fixed-price contracts for procuring bombers and fighters, initiated the division of labour between the different aircraft firms and their suppliers, and also took into consideration learning effects when estimating the cost and output of future aircraft production. At least in the case of the aircraft industry, the German armament industry's failure to match the production of the Allies was not caused by a belated change to a coherent procurement policy, but rather was the natural result of comparatively small production capacities. In 1944, for example, the Allies' GDP was 3.3 times higher than the GDP of the Axis powers, and the steel production of the former 3.5 times higher than that of the latter. Against this background, it may not be surprising that while the US alone produced 153,000 combat aircraft between 1942 and 1944, and the total production of the Allies reached 299,500, the German output and the total output of the Axis powers only came to 65,000 and 114,600 units respectively.[3]

In order to prove our main hypothesis that, at least in the aircraft industry, the development of German armament production and productivity was much more continuous than both the old *Blitzkrieg* thesis and the newer inefficiency thesis suggest, this article is arranged in five sections, as follows. In section I, we explain how our findings fit into the existing historiography of the German Second World War economy. In section II, we present data regarding production and factor endowment of a sample of seven German aircraft manufacturers during the Second World War. In section III, we calculate labour and total factor productivity growth of these firms. In section IV, we show that the observable labour productivity growth resulted from learning-by-doing and outsourcing, both motivated by fixed-price contracts used in the German aircraft industry. Section V concludes.

I

The history of German military campaigns in the Second World War can be divided into an early successful period and a later disastrous one. Hitler started the Second World War with the invasion of Poland on 1 September 1939. The German army won this war in only one month. The similarly fast victories over Norway, Belgium, the Netherlands, and France in spring and early summer of 1940 led Hitler and his military advisers to the believe that modern wars could be waged as so-called *Blitzkrieg* which consumed a comparatively small quantity of arms and ammunition. Consequently, it was the assault on Soviet Russia in June 1941 that was the first German military campaign that was actually planned in advance as a *Blitzkrieg*. Tooze stresses in his economic history of the Third Reich that Hitler intended to win the war in the east and get hold of Russian industrial capacities before the UK and the US (which was expected to be an enemy) had built up their

[3] Harrison, 'Economics of World War II', p. 10; Tooze, *Wages of destruction*, p. 641.

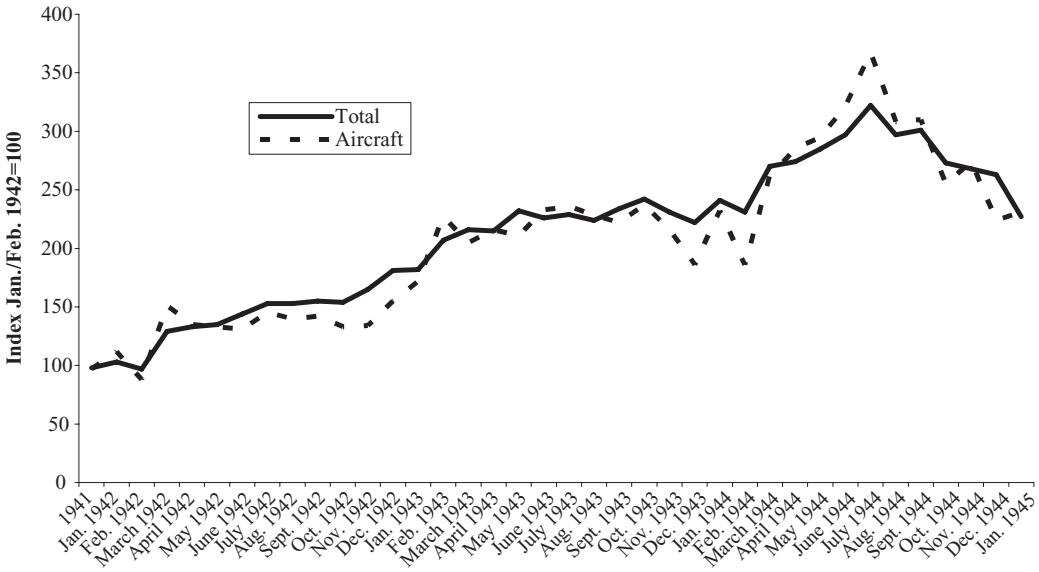

Figure 1. *German armament production, 1941–5*
Source: Wagenführ, *Industrie im Kriege*, pp. 178, 180. See n. 5.

own armament industry to full scale.[4] In December 1941, however, the Soviet army stopped the German army near Moscow. That, along with the entry of the US into the Second World War, brought the period of successful *Blitzkrieg* to a sudden end and Hitler's strategic nightmare to reality. The Third Reich was now confronted with the prospect of an enduring war against the US and the UK in the west and Soviet Russia in the east which could not be won in the longer run because of Germany's comparatively small-scale economic and human resources. The Allies re-conquered step by step all the countries occupied by the German army in 1941 and finally defeated Nazi Germany in May 1945.

To the surprise of early postwar observers, Germany's military development during the Second World War apparently did not go together with its economic development. Figure 1 shows that the index of German armament production, originally prepared on behalf of Albert Speer's armament department and published by Rolf Wagenführ in 1954, rather stagnated during the early period of successful military campaigns, but then more than tripled between early 1942 and July 1944 while the German army was gradually driven back by the Allies.[5]

In the first three decades following the Second World War, this discontinuous development of German armament production was usually explained by the so-called *Blitzkrieg* thesis. Scholars claimed that Hitler deliberately decided to under-mobilize the German armament industry in order to free up resources for producing consumption goods that were needed to maintain the German population's approval of the Nazi's antagonistic policies. Only after the military failures

[4] Tooze, *Wages of destruction*, p. 310.
[5] For the construction of the armament index, which includes, among other things, various armament goods such as warships, tanks, artillery, and ammunition, see Wagenführ, *Industrie im Kriege*, pp. 208–11.

at the end of 1941 did German military planners acknowledge that they had to increase weapons production considerably by assigning as many resources and workers to armament production as possible. This view was first expressed by the Final Report of the United States Strategic Bombing Survey (USSBS) published in October 1945: 'The Germans did not plan for a long war, nor were they prepared for it. Hitler's strategy contemplated a series of separate thrusts and quick victories'.[6] In the following two decades, Klein and Milward were the most influential advocates of the *Blitzkrieg* thesis.[7]

Since the 1980s, however, the validity of the *Blitzkrieg* thesis has been questioned by many scholars, for two main reasons.[8] On the one hand, historians failed to discover evidence which proves that Hitler went into war with a deliberate *Blitzkrieg* strategy. On the other hand, it became clear that the Nazis did not consciously under-mobilize the armament industry before 1942 but heavily invested in armament production in the early period of the Second World War.[9] However, rejecting the *Blitzkrieg* thesis meant that it was necessary to find another explanation for the apparent stagnation of German armament production before 1942. Overy and Müller therefore introduced the inefficiency thesis into the historiography of the German Second World War economy.[10] In Overy's view, it was the untimely outbreak of the Second World War, originally planned to start not earlier than 1942, that brought German mobilization into temporary disorder. Müller claims that the inefficiency of the armament industry resulted from the political incoherence (polycracy) of the Third Reich. Both authors share the opinion that first and foremost it was armament minister Albert Speer, who assumed office in February 1942, who was responsible for fostering German armament production by removing the major obstacles for productivity growth. This explanation was justified by an observation made by Eichholtz, an East German economic historian, who asserted that the development of labour productivity in German armament production was u-shaped during the war, first falling between 1939 and 1941 and then rising considerably during Speer's period of office.[11]

Speer is especially credited with making the following political decisions.[12] 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 express wishes 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 estab-

[6] United States Strategic Bombing Survey, Overall Economic Effects Division, ed., *Effects of strategic bombing*, p. 6.

[7] Klein, *Germany's economic preparations*; Milward, *German economy at war*.

[8] Tooze, 'No room for miracles', pp. 440–1.

[9] Scherner, 'Preparation for war'.

[10] Overy, *War and economy*, pp. 233–56; Müller, 'Mobilisierung', pp. 364–9.

[11] Eichholtz, *Kriegswirtschaft*, pp. 265–6. Tooze, 'No room for miracles', and Scherner and Streb, 'Das Ende eines Mythos?', explain why Eichholtz's and Wagenführ's data might be misleading.

[12] Abelshauser, 'Germany', pp. 156–7; Overy, *War and economy*, pp. 356–63; Weyres-v. Levetzow, *Deutsche Rüstungswirtschaft*, pp. 47–9.

lished inter-firm committees in order to give less efficient firms the information considered necessary for imitating the technology of the superior firms. This might have especially accelerated the diffusion of flow production techniques in German industry.

All these rationalization measures had a common feature, in that they enabled firms to decrease their production costs. Overy, 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 the German procurement business until 1942.[13] Firms that delivered weapons on the basis of a cost-plus contract generally received 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.[14] That is why, under a cost-plus contract, an armament manufacturer had no incentive to reduce costs; quite the reverse, because he was motivated to increase them to get a higher premium. In order 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.[15] If the armament manufacturer was able to fabricate the good at a lower production cost than estimated, he was entitled to keep at least a part of this difference as an additional profit. As a result, firms now had an incentive to take the opportunities offered by Speer's rationalization programme to decrease their costs.

The fact that it was apparently during Speer's period of office when all these reforms were enforced and armament production boomed led many observers to believe that Speer may have been one of the few competent political managers in the Nazi ruling classes. The USSBS economist Nicholas Kaldor 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 [one] that will retain a more than historical interest'.[16]

However, recent studies suggest that the inefficiency thesis and the resulting very positive evaluation of Speer's managerial capability may also be misleading. First of all, the index of German armament production has serious shortcomings. Speer's administration intentionally chose the first two months of 1942, in which armament production was comparatively low, as the base of the index, in order to exaggerate its own achievements in the following years.[17] The decision to calculate the index only for the period when Speer was armament minister also hid the important fact that German armament production had already grown significantly between 1938 and 1940.[18] Another deficiency arises from the fact that the index also included armament goods that were produced in occupied countries.[19] As a result, the index of armament production depicted in figure 1 might considerably

[13] Overy, *War and economy*, p. 357.
[14] For more details, see Streb and Streb, 'Optimale Beschaffungsverträge'.
[15] See 'Anordnung über Einheits- und Gruppenpreise vom 19. Mai 1942', *Reichsanzeiger*, vol. 117.
[16] Kaldor, 'German war economy', p. 48.
[17] Wagenführ, *Industrie im Kriege*, p. 211.
[18] Ibid., p. 23. For more details about the role of statistics in German armament planning during Speer's period of office, see Tooze, *Statistics*, pp. 253–4.
[19] This fact is explicitly stated in 'Anmerkungen zum Text des Lageberichts 1943/44', Bundesarchiv, Berlin-Lichterfelde, Germany (hereafter BArch R), 3/1965, Blatt 67. See also 'Lagebericht 1943/44', R 3/1965, p. 82.

over-state the volume of new weapons produced within the traditional borders of Germany after 1941 and therefore also the discontinuity between the pre-1942 period and Speer's period of office.[20]

Even more important is the fact that many of the rationalization measures allegedly pushed through by Speer were actually implemented long before his appointment. Rauh-Kühne, for example, stresses that German firms were already opting for fixed-price contracts in spring 1940.[21] In the German aircraft industry, procurement agencies were already complaining in late 1936 about the fact that aircraft manufacturers that were given a cost-plus contract did nothing to increase productivity.[22] These considerations led the German aviation ministry to the early decision to change to fixed-price contracts in spring 1937.[23] From this time onwards, the unit price of the bombers or fighters in a certain batch was already fixed from the moment when the procurement agency ordered a firm to produce them. The calculation of this price was primarily based on the actual costs of earlier production runs, but also took into account expectations about the future development of the firm's cost. When an aircraft manufacturer 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 sale did not exceed a certain rate that was originally laid down at 10 per cent.[24] 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 updated information about the firm's productivity.

Reviewing the macroeconomic data with respect to German industrial investment, production, and productivity in the period from 1939 to 1944, Tooze rejects in a recent paper both the *Blitzkrieg* hypothesis and the inefficiency thesis. He claims instead that 'the German industrial performance during the early years of the war was in fact considerably better than has usually been thought'.[25] Consequently, Tooze sees no reason to draw a sharp distinction between the period before and after 1942, and therefore no reason to highlight the achievements under Speer. In this article, we support Tooze's interpretation on the basis of microeconomic data. We also claim that the development of German armament production during the Second World War was much more continuous than

[20] For more details, see Scherner and Streb, 'Das Ende eines Mythos?', pp. 176–82.

[21] See Rauh-Kühne, 'Hitlers Hehler?', p. 21. For the timing of other rationalization measures, see Scherner and Streb, 'Das Ende eines Mythos?', pp. 182–90.

[22] 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.

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

[24] The public procurement agencies, however, were encouraged by their guidelines to allow firms to transform that part of their profit per sale that exceeded 10% into hidden reserves. See 'Endgültige Fassung der Richtlinie über Preisbildung und Finanzierung vom 12.6.1937', BArch R 2/5475, p. 31. 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% of the salary 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.

[25] Tooze, 'No room for miracles', p. 444.

Wagenführ's armament index and both the *Blitzkrieg* thesis and inefficiency thesis suggest. In order to prove this continuity thesis, we will show, firstly, that investment in production capacities had already started before the war and was especially high in the early years of the war, and secondly, that the regulatory setting of aircraft production management was rather constant and not dramatically changed after 1941. In addition, we will demonstrate that the driving forces of productivity growth were primarily learning-by-doing and outsourcing. The latter has been generally neglected by economic historians. A notable exception is Fear, who points to inter-firm division of labour in the armament industry of Swabia during the Second World War.[26]

Finally, this article also contributes to the discussion about whether the Nazis directed German industry by means of the market or rather by hierarchical commands in a more and more centrally planned economy. Temin describes the economic system of the Third Reich as a certain 'brand of socialism', in which, 'instead of dispossessing private owners, the Nazis severely circumscribed the scope within which the nominal owners could make choices'.[27] Temin supposes that the Nazis degraded private ownership to a mere nominal provision which hardly covered the fact that private firms had no other alternative than to comply with the orders of the state's procurement agencies.[28] In a recent paper Buchheim and Scherner argue against this assessment. Supported by various historical examples, they come to the conclusion that 'the state normally did not use power in order to secure unconditional support of industry. Rather, freedom of contract was respected'.[29] Buchheim and Scherner infer, in contrast to Temin's view, that in Nazi Germany entrepreneurs preserved a good deal of their autonomy and could therefore even refuse to meet orders by the state without any harmful consequences. That is why, in their opinion, the relationship between state and industry in the Third Reich can be best understood in the market-oriented framework of a principal–agent model in which the state (principal) primarily relied on a set of different contract types to motivate the private firms (agents) to act in its interest. Our findings confirm this view in so far as we show that the introduction of fixed-price contracts in spring 1937 was the most important precondition for sustainable productivity growth in the German aircraft industry because this regulatory reform motivated armament manufacturers to increase their efficiency not by force but by self-interest.

II

Until now, German armament production during the Second World War has been mainly analysed on the basis of documents of the different state authorities, on macroeconomic data, and, last but not least, on Speer's autobiography, in which he

[26] Fear, 'Rüstungsindustrie'.

[27] Temin, *Lessons*, p. 111.

[28] 'The Nazis viewed private property as conditional on its use—not as a fundamental right. If the property was not being used to further Nazi goals, it could be nationalized'; Temin, 'Soviet and Nazi economic planning', p. 576.

[29] Buchheim and Scherner, 'Role of private property', p. 395; Scherner, 'NS-Regime und Industrieunternehmen'.

successfully built up his own myth.[30] Not much is known about the economic activity within the individual firms that had to produce the weapons represented by the armament index. In order to address this problem, we explore German armament firms' economic development on the basis of the annual audit reports of the Deutsche Revisions- und Treuhand AG, which have been widely ignored until now.[31]

The Federal Archives in Berlin possess a large collection of the audit reports of the Deutsche Revisions- und Treuhand AG for firms that were engaged in German armament production during the Second World War.[32] Most of the available audit reports cover the period from 1939 to 1943. Since the auditors needed at least one year to prepare their reports, most of the audits for the accounting years 1943/4 and 1944 are unfortunately missing and were probably never finished. 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 workforce. Sometimes the reports even include lists of every single machine bought during the accounting year and the most important suppliers of machines and intermediate goods. In general, both the quantity and the quality of the information delivered increased between 1939 and 1942, which might reflect the Nazis' desire to overcome the principal–agent problems of procurement by improving their knowledge about production technology and the actual costs of the private firms.[33]

We started our research project with a closer look at the German aircraft industry, on the grounds that its development might be representative of what was going on in other German war industries. This view was supported by two facts; first, that the aircraft industry's average share in armament production came to about 40 per cent;[34] and second, that the index of aircraft production represented by the broken line in figure 1 behaved very similarly to the index of total armament production. Note, however, that German aircraft production had grown considerably even before 1942. Figure 2, which is based on unpublished private files of Wagenführ himself, demonstrates that monthly aircraft production more than doubled in 1940 and then stagnated in 1941.[35]

In this article, we mainly concentrate on the seven German aircraft manufacturers presented in table 1.[36] Six of these firms were directly engaged in the

[30] Speer, *Erinnerungen*, pp. 219–28.

[31] 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, or for which the state stood surety. 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.

[32] The shelfmark of this collection is BArch R 8135.

[33] The Nazis 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, 'Ohne Rücksicht auf Kosten?', and Streb, 'Preisregulierung'.

[34] Wagenführ, *Industrie im Kriege*, pp. 30, 69.

[35] These files are part of the empirical base of Wagenführ's famous book and are temporarily being held at the University of Hohenheim. Wagenführ, who was a professor at the University of Heidelberg after the Second World War, gave these files to the economic historian Eckart Schremmer, who in turn left them with Jochen Streb in 2003.

[36] See audit reports of the Deutsche Revisions- und Treuhand AG in the app. In addition, we use data from the company files of Henschel Flugzeug-Werke AG which partly survived in the archives of Zahnradfabrik Friedrichshafen (hereafter ZF) at Calden near Kassel.

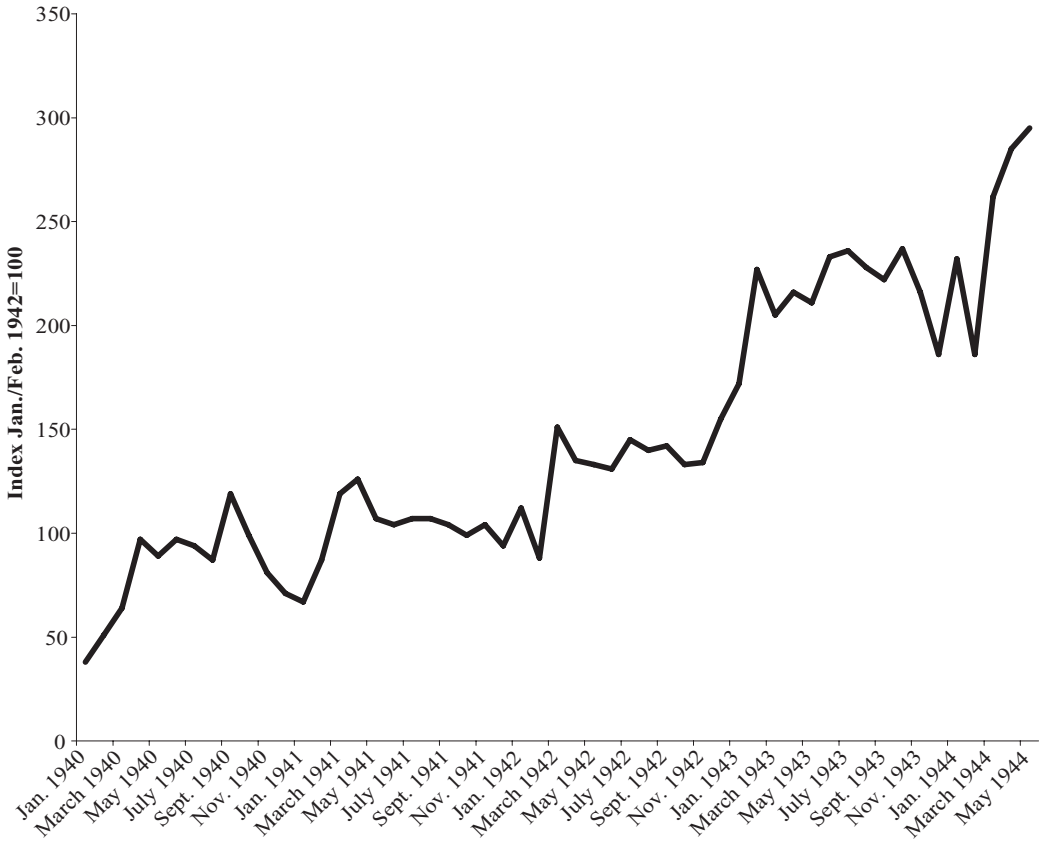

Figure 2. *Monthly German aircraft production, Jan. 1940–May 1944*
Source: Ha Planstatistik Index der industriellen Rüstungsproduktion, Rolf Wagenführ's private files, Univ. of Hohenheim (see n. 35).

production of the double-engine Ju 88 bomber, originally designed by the company Junkers Flugzeug- und Motorenwerke AG.[37] The so-called Ju 88-programme, which was established by Hermann Göring in mid-1938 and was aimed at exploiting economies of scale and increasing the technological standards of aircraft production, presented a major innovation in German procurement organization. The Ju 88-programme constituted one of the largest German armament projects. The firms that were involved in the original plan of 1938 employed more than half of the German aircraft production workforce. Even in 1943, when the focal point of air armament had already shifted to fighters, the participants in the Ju 88-programme still employed a third of the workforce. Between September 1938, when series production started at Junkers, and September 1944, when it was cancelled, some 14,000 Ju 88 bombers were built.[38]

[37] Interestingly enough, Junkers was one of the very few non-Jewish firms that were expropriated by the Nazis. See Budraß, *Flugzeugindustrie*, pp. 320–35.
[38] Ibid., p. 834.

The largest firm involved in this programme, Junkers, produced in its various plants all components of the Ju 88 aircraft, including the engines,[39] while ATG, Arado, Heinkel-Oranienburg, and Siebel, among others,[40] concentrated on specific components and tasks, such as wings, fuselages, engine suspension, tail units, and final assembly.[41] In contrast to those firms, the Mitteldeutsche Motorenwerke was not engaged in airframe manufacturing but only produced engines for the Ju 88 bomber.

In order to give Junkers the opportunity to boost its output of Ju 88 bombers, 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 labour to the different firms involved in the Ju 88-programme and was able to interfere in their spheres of production. In order to enable the other firms to imitate its design and production methods, Junkers shared production know-how and also gave them technological support when needed.[42] Interestingly enough, the firms in our sample started exchanging technological knowledge long before Speer ordered newly founded inter-firm committees to do exactly this.[43] There is some evidence, indeed, that Speer's reform was based on positive experiences with the Ju 88-programme.[44]

We now analyse the development of the factor endowment of our firm sample. Data about both fixed assets and the workforce will be needed later for productivity analysis. The official figures in the audit reports might considerably underestimate the firms' fixed assets 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.[45] On the other hand, firms often increased their production capacities not by investment in new plants but by leasing existing plants from other firms or the state, whose value then did not show up in their balance sheets.[46] In order to estimate the amount of capital stock that was actually employed by German aircraft manufacturers, we therefore adjusted the officially published figures by the following procedure. We re-added 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, $i = t, \ldots, t + n$, (regular depreciations in year i divided by officially published fixed assets in

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

[40] Henschel has already been mentioned. In addition, both the Dornierwerke in Friedrichshafen and the Norddeutsche Dornierwerke in Wismar were briefly engaged in the production of Ju 88 bombers, building 219 units (March 1940–Dec. 1940) and 467 units (Jan. 1940–Sept. 1941), respectively. See Bundesarchiv Military Archives, Freiburg, Germany, RL 3/976, p. 48.

[41] The German state owned Arado, Heinkel, Junkers, and Weser at least partly. See per 'Beteiligungsfirmen der Luftfahrtkontor GmbH', BArch R 2/5550, pp. 44–5.

[42] See audit report 1941/2, BArch R 8135/7559, p. 61.

[43] Due to the ambiguous role of Junkers, however, the Ju 88 programme initially met with strong resistance from the companies concerned. See Budraß, *Flugzeugindustrie*, p. 552.

[44] 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 and Schumann, eds., *Anatomie des Krieges*, pp. 245–6.

[45] See 'Endgültige Fassung der Richtlinie über Preisbildung und Finanzierung vom 12. Juni 1937', BArch R 2/5475, p. 31. For the particular write-off of capital in 1938, see BArch R 2 Anh./37, pp. 31–2. See also Budraß, *Flugzeugindustrie*, pp. 492–3.

[46] See audit report 1940 of Weser, BArch R 8135/5272, p. 2. See also Hopmann, *MONTAN*, pp. 123, 195–6.

Table 1. *Selected German aircraft manufacturers*

Firms	*Main product lines*	*Period*	*Annual growth rates*		
			Real output	*Adjusted fixed assets*	*Workforce*
Junkers	Ju 88 bombers and Jumo engines	1940–2	87%	18%	17%
Siebel	Ju 88 wings and final assembly	1939–43	74%	7%	22%
Mimo	Jumo engines	1938–43	71%	12%	29%
Weser	Ju 87 bombers	1939–42	50%	17%	22%
Arado	Ju 88 wings and final assembly	1940–2	38%	25%	14%
ATG	Ju 88 final assembly	1940–2	30%	30%	3%
Heinkel-Oranienburg	Ju 88 wings and final assembly	1941–3	23%	0%	23%

Note: Accounting years have been changed into calendar years.
Source: For data, see audit reports of the Deutsche Revisions- und Treuhand AG in the app.

year i) to depreciate them step by step in the actual and following years.[47] 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 as the rest of the production capacity or, when the audit reports contained this information, replaced by its updated value (P_{t+1}). As a result, the adjusted fixed assets (AFA) for the years t and t + 1, for example, are defined as:

$$\begin{aligned} AFA_t &= FA_t + (1 - r_t)\,SD_t + P_t \\ AFA_{t+1} &= FA_{t+1} + (1 - r_{t+1})(1 - r_t)\,SD_t + (1 - r_{t+1})\,SD_{t+1} + (1 - r_{t+1})\,P_t \end{aligned} \tag{1}$$

or

$$AFA_{t+1} = FA_{t+1} + (1 - r_{t+1})(1 - r_t)\,SD_t + (1 - r_{t+1})\,SD_{t+1} + P_{t+1} \tag{2}$$

Table 1 shows that in the period covered by the available audit reports not only the real output but also the adjusted fixed assets and the workforce of most firms in our sample increased, with two-digit annual growth rates. We do not observe a discontinuous growth path with stagnating production possibilities in the early war years and expanding factor endowments after 1941, but a rather continuous growth of both fixed assets and workforce during the whole period for which we have data. Two firms deviated from the general trend. ATG was for some reason not able to use the favourable conditions of the German war economy to augment its own workforce to the same extent as the other firms involved in the Ju 88-programme. Heinkel, which had the highest capital–labour ratio of all airframe manufacturers in 1939, increased only its workforce in the following years. The capital–labour ratio of the other firms increased (Arado, ATG), was u-shaped (Junkers, Weser), or decreased (Mimeo, Siebel) during war time (figure 3). The average capital–labour ratio (1,000 Reichsmarks per employee), calculated by weighting the seven firms' individual capital–labour ratios by their share in the

[47] In its book-keeping, Henschel explicitly distinguished between 'real' fixed assets actually employed and 'official' fixed assets decreased by special depreciation allowances.

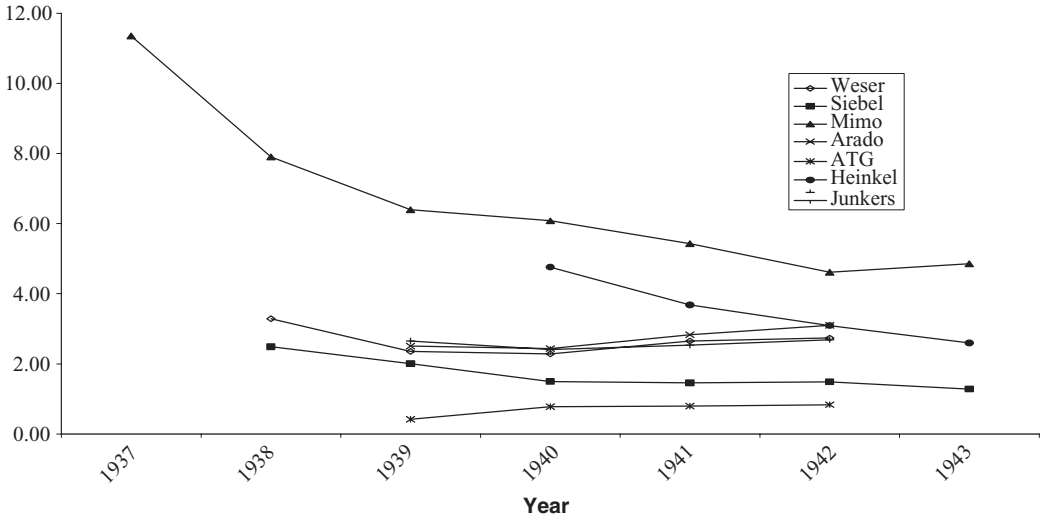

Figure 3. *Capital–labour ratio, 1937–43 (1,000 RM per employee)*
Source: For data, see audit reports of the Deutsche Revisions- und Treuhand AG in the app.

total adjusted capital stock of our sample, was 3.0 in 1939, 2.5 in 1940, 2.6 in 1941, and 2.7 in 1942 and 1943.[48]

How can the u-shaped development of the aircraft manufacturers' average capital–labour ratio be explained? In the late 1930s, German aircraft manufacturers had built up huge excess capacity with respect to plants and machinery. Immediately before and after the beginning of the Second World War, the capital–labour ratio sharply decreased as firms recruited many blue-collar workers in order to fill their newly built plants.[49] However, as indicated by the upward trend of the capital–labour ratio of the four firms Arado, ATG, Junkers, and Weser, the growth of their adjusted fixed assets soon exceeded the growth of their workforce again. This unbalanced development seems to have been caused by the shortage of labour that resulted from the increasing number of German male workers that were recruited by the army.[50] The fact that labour was probably the most important bottleneck in the German war industry explains why armament manufacturers were often not able to utilize their production capacity fully by running two or three shifts.[51] In the short run, firms instead increased the number of working hours per worker. At Junkers, for example, employees' effective weekly working time grew from 53 hours in 1938/9 to 56 hours in 1939/40 and 58 hours in 1940/1.[52] It is well known that the Nazis tried to overcome the labour shortage in

[48] We do not present the average capital–labour ratios of the years 1937 and 1938, which are dominated by the high capital–labour ratio of Mimo and are therefore misleading.
[49] See Budraß, *Flugzeugindustrie*, p. 674.
[50] The sum total of Germans drafted grew from 5.6 million in 1940, to 7.4 million in 1941, 9.4 million in 1942, 11.2 million in 1943, and 12.4 million in 1944 (Wagenführ, *Industrie im Kriege*, pp. 35, 45).
[51] This observation was stressed by Kaldor, 'German war economy', p. 35. See also Fear, 'Rüstungsindustrie', p. 208.
[52] See audit report 1939/40, BArch R 8135/2548, p. 15; audit report 1940/1, BArch R 8135/7558, p. 11. See also Budraß, *Flugzeugindustrie*, p. 675.

the German war industry first through women's employment and re-allocating the German workforce, and then by forcing foreign civilians, prisoners of war, and concentration camp prisoners to work.[53]

The audit reports of the Deutsche Revisions- und Treuhand AG give us some idea about whether these measures were successful at the firm level. The example of Arado demonstrates that aircraft manufacturers were not able to use German women to replace the male workers lost to the army. In 1940, for example, 74 per cent of all female blue-collar workers employed in Arado's plant in Brandenburg-Neuendorf left their jobs.[54] The audit report unfortunately mentioned no reason for this dramatic drop. We have to speculate as to whether the women were motivated to leave by poor working conditions in the armament industry combined with the increasing possibilities of better paid jobs in the service sector, or by the financial support given to soldiers' spouses by the government.[55] On the whole, the share of female blue-collar workers in the total workforce of Arado decreased from 19.9 per cent in 1939, via 15.6 per cent in 1940, to 15.1 per cent in 1941.[56]

As early as 1939, the German government had enacted the law on '*Dienstverpflichtung*', by which German workers in occupations not related to the war industry could be forced to move to the plants of armament manufacturers. The audit reports contain some remarks that imply that the aircraft manufacturers were not at all satisfied with the performance of these male German workers.[57] ATG, for example, told the auditor that this type of worker needed extensive training before he could be deployed fruitfully.[58] The fact that, for example, Arado declared that in 1942 1,100 workers had to be fired for lack of aptitude[59] leads us to the conjecture that the 'forced' German workers (*Dienstverpflichtete*) obviously tried to demonstrate incompetence in order to be released.[60] As a result, aircraft manufacturers relied more and more on foreign workers, whose productivity was apparently much higher than the racially prejudiced propaganda made the German people believe. Even a document from the Reich's aviation ministry, found in the military archives in Freiburg, stated that the productivity of female Russians and male Czech skilled workers came up to 90 to 100 per cent of the productivity of German workers.[61] The high level of productivity of young Russian women needs some explanation. They often arrived in Germany completely disoriented. As a result, they apparently did not withhold their labouring power and applied passive

[53] Overy, *War and economy*, pp. 291–303.

[54] See audit report 1940, BArch R 8135/7084, p. 9.

[55] Married women received up to 85% of the former wages of their recruited husbands. See Winkler, *Frauenarbeit*, p. 92.

[56] See audit report 1940, BArch R 8135/7084, p. 17; audit report 1941, BArch R 8135/7085, p. 7.

[57] See 'Verordnung zur Sicherstellung des Kräftebedarfs für Aufgaben von besonderer staatspolitischer Bedeutung', *Reichsgesetzblatt*, I (1939), pp. 206–7.

[58] See audit report 1939/40, BArch R 8135/2167, p. 25.

[59] See audit report 1942, BArch R 8135/7085, p. 6.

[60] This conjecture is, for example, also confirmed by various complaints made by 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 and Erker, *Chemie und Politik*, pp. 307–8. See also the complaints about '*dienstverpflichtete Arbeitskräfte*' in 'Die Probleme der deutschen Rüstungswirtschaft im Kriege, OKW WiRüAmt Stab, Bearb.: Reg.Rat Dr. Tomberg', Sept. 1940, BArch MA RW 19/1503, fol. 99.

[61] See BArch MA RL 3/976, p. 24. This document also claims that French and Belgians reached 80% to 95%; Russians 60% to 80%; Italians 70%; and Dutch, Danes, and workers from the Balkans 50% to 70% of the productivity of a German worker. See also Spoerer, *Zwangsarbeit*, p. 186.

resistance to a far lesser degree than their male counterparts. As this form of forced labour did not run out after the German retreat had begun, the German aircraft industry relied more and more on young Russian and Ukrainian women.

Table 2 shows the development of the workforce of Heinkel in Oranienburg, which is best documented by the audit reports that we reviewed. Between January 1940 and March 1941, Heinkel still increased its workforce by about 30 per cent by hiring mainly male German workers. After this period, however, the number of both male and female German workers steadily decreased. Between summer 1941 and summer 1942, it was the employment of foreign civilian workers in which female Russians played a prominent role that enabled Heinkel not only to replace its lost German workers but also to expand its workforce again by 40 per cent. In order to improve its capacity utilization by running more than one shift, the firm consented to participate in a joint experiment by the air ministry and the SS to make use of concentration camp labour in early 1942. The additional workers needed for this plan were taken from the nearby concentration camp in Sachsenhausen.[62] In the following months, Heinkel became increasingly dependent on the labour of concentration camp prisoners, whose share in the sum total of all blue-collar workers grew quickly from 11 per cent in September 1942, via 35 per cent in March 1943, to 53 per cent in March 1944. The development of Heinkel's workforce until the summer of 1942 may be quite representative of the situation in the German aircraft industry as a whole, but Heinkel's transformation into a firm that mainly exploited concentration camp prisoners was rather exceptional. The other aircraft manufacturers 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 per cent in September 1943, whereas more than a third of all employees were foreign civilian workers.[63]

The fact that Heinkel was the firm with the lowest increase in labour productivity in our sample is not explained only by the above-average employment of concentration camp prisoners.[64] The comparatively discontinuous development of its production programme also prevented Heinkel from maintaining the high productivity level it reached in 1940. Originally, Heinkel had produced the He 111 bomber in Oranienburg. In 1940, the firm was instructed to switch to the production of wings for the Ju 88 instead.[65] This change in the production programme involved a substantial reorganization of the production process. Workers who were used to assembling whole airplanes now had to learn how to fabricate a special component of another design. Old machines became useless and had to be replaced with new ones with which the workers were unfamiliar. Moreover, corporate culture at Heinkel bred some opposition against the Junkers design among the workforce. Heinkel was not able to adapt to these changes without a decrease in labour productivity. The next sudden about-turn of its production programme again coincided with a considerable loss of efficiency. As compensation for participating in the Air Ministry's experiment to assign concentration camp labour to aircraft production in early 1942, Heinkel was allowed to abandon production of

[62] Budraß, *Flugzeugindustrie*, pp. 776–8; Orth, *Konzentrationslager*, pp. 175–9.
[63] See audit report 1942/43, BArch R 8135/7560, p. 17; Budraß, *Flugzeugindustrie*, p. 799.
[64] See tab. 3.
[65] See audit report 1940, BArch R 8135/7498, p. 5.

Table 2. *Development of the workforce of Heinkel's plant in Oranienburg*

Groups	*Jan. 1940*	*Dec. 1940*	*March 1941*	*March 1942*		*June 1942*		*Sept. 1942*		*Dec. 1942*		*March 1943*		*July 1943*		*March 1944*
				Male	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*	
Germans				6,074	999	5,508	954	4,917	856	4,402	715	3,714	696	3,690	649	3,656
Russians				—	—	54	578	228	801	471	811	196	949	149	785	1,386
Other foreigners				1,391	53	2,203	289	1,705	247	1,460	196	1,422	206	1,011	191	
Prisoners of war		130	206	830	—	663	—	556	—	511	—	509	—	468	—	424
Concentration camp prisoners				—	—	—	—	1,144	—	2,226	—	4,107	—	5,676	—	6,240
Sum total male	4,868	5,734	6,265	8,295		8,428		8,550		9,070		9,948		10,994		10,768
Sum total female	851	1,043	1,136		1,052		1821		1,906		1,722		1,851		1,585	938
Sum total	5,719	6,777	7,401	9,347		10,249		10,456		10,792		11,799		12,579		11,706

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

Ju 88 wings and to fabricate an aircraft of its own design instead, the new heavy He 177 bomber.[66] As a result of this change, the 'regular' depreciation rate of Heinkel's capital stock soared to 28 per cent in 1942/3. This time the necessary adaptation process was made even more difficult by the fact that a large number of concentration camp prisoners had arrived at the firm at the same time, necessitating further adjustments to the firm's organization of production. It was another two years before Heinkel was ordered to stop the production of the He 177 bomber, when the bomber squadrons of the Luftwaffe were disbanded. It had to concentrate instead on the final assembly of the Fw 190 fighter, which was needed to fight the Allied bombers.[67]

In conclusion, the data presented in this section reveal that the growth in German aircraft production during the Second World War should not be explained by increases in productivity alone, but was partly caused by the ongoing growth of firms' endowment both with fixed assets and workers.

III

In this section, we quantify the impact of productivity growth on the growth of real output of the aircraft manufacturers in our sample. As a first step, we use a Cobb-Douglas production function to calculate total factor productivity growth. As a second step, we rearrange the equation needed to estimate total factor productivity to apportion labour productivity growth among the three factors: total factor productivity growth, increase in capital–labour ratio, and increase in intermediate goods–labour ratio.

Following Solow's seminal approach,[68] we estimate total factor productivity on the basis of firm-specific Cobb-Douglas production functions, explaining firms' output (O) with the help of the three material inputs labour (L), capital (C), and intermediate goods (I), and an index of Hicks-neutral technical progress (K):

$$O = K \cdot L^{\alpha} \cdot C^{\beta} \cdot I^{\gamma} \quad with\ \alpha + \beta + \gamma = 1 \tag{3}$$

Under the assumption of constant economies of scale, the production elasticities α, β, and γ add up to unity. Additionally assuming perfect competition, the traditional approach measures production elasticities by each material input's average share in output. The German aircraft market during the Second World War, however, cannot be characterized by perfect competition. Instead, the oligopolistic market structure may have allowed aircraft manufacturers to use their information advantages to push through prices that were considerably higher than their marginal cost. We therefore rely on an alternative approach, which does not require an assumption regarding perfect competition, and calculate production elasticities by each input's average share in total production cost.[69]

[66] See audit report 1942/3, BArch R 8135/7500, p. 15.
[67] See audit report 1943/4, BArch R 8135/1916, p. 5.
[68] See Solow, 'Technical change'.
[69] See Malley, Muscatelli, and Woitek, 'Business cycles and productivity growth', pp. 136–9. Since the firms in our sample concentrated on different tasks, we assumed firm-specific production functions and calculated the average production elasticities for α, β, and γ: Arado: 0.35, 0.13, 0.52; ATG: 0.21, 0.18, 0.61; Heinkel: 0.25, 0.1, 0.65; Junkers: 0.29, 0.08, 0.63; Mimo: 0.2, 0.18, 0.62; Siebel: 0.27, 0.12, 0.61; and Weser: 0.34, 0.22, 0.44.

Expressed in growth rates and transformed, equation (3) finally becomes

$$\hat{K} = \hat{O} - \alpha \cdot \hat{L} - \beta \cdot \hat{C} - \gamma \cdot \hat{I} \quad (4)$$

The growth of total factor productivity on the left-hand side of equation (4) is usually interpreted as technical progress, which might encompass, among other factors, the effects of Speer's alleged rationalization measures mentioned in section I. In addition, this residual captures all other impact factors on output that are not attributed to an increase in material input factors.[70] Among these are economies of scale, individual working hours, human capital, the composition of the workforce, and measurement error. Most of the variables on the right-hand side can be calculated on the basis of data that can be found in the annual audit reports. Total output, which comprises revenues, self-constructed assets, and increases in the inventory of finished goods and work in progress, is published in current prices. In order to transform nominal output into real output (O), we constructed an output price index of each firm's main products.[71] In contrast, we interpret the growth rates of firms' nominal adjusted fixed assets calculated in section II as an appropriate indicator for the growth rates of real capital (C) in equation (4) because the opportunity cost of capital (for example, the interest rates) were constant in the regulated capital market of the German war economy. Since we do not have data about the development of firm-specific weekly working hours during the whole period under consideration, we use the average annual number of blue-collar and white-collar workers as a measure for the firms' labour input (L).[72] The largest empirical problem is to assess the development of the price index of the various intermediate goods used by the aircraft manufacturers. The audit reports sometimes mention that the prices for intermediate goods were decreasing, but give no detailed information about either the amount or the prices of raw materials and standard components processed by the aircraft manufacturers.[73] We are therefore not able to construct a price index for intermediate goods. Instead, we use an upper-bound and a lower-bound estimate of this price index to transform nominal expenses for intermediate goods into two alternative measures of real intermediate goods input (I). The upper-bound estimate (case 1) assumes that the prices for intermediate goods were constant over time and leads to a minimum growth rate of real intermediate goods input. The lower-bound estimate (case 2) supposes that the prices for intermediate goods faced by an individual firm decreased at the same rate as this firm's output price index and results in a maximum growth rate of real intermediate goods input. Using the data for real output, labour, capital, and the minimum and maximum annual real amount of intermediate goods, we can use equation (4) to calculate a minimum (case 2) and a maximum (case 1) growth rate of total factor productivity shown in table 3.

[70] See Denison, *Why growth rates differ*, pp. 279–89.

[71] The main products were Ju 88 wings (Arado, Heinkel, and Siebel), Ju 52 and Ju 88 fuselages (ATG), Ju 87 (Weser), Ju 88 airframes and Jumo engines (Junkers), and Jumo engines (Mimo).

[72] As a result, a non-observed increase in working hours will result in an observable increase in total factor productivity.

[73] See Mimo's audit report 1941, BArch R 8125/7736, p. 28, and Junkers' plant Aschersleben's audit report 1941/2, BArch R 8135/7567, p. 60.

Table 3. *Explaining labour productivity growth (average annual growth rates)*

		Total factor productivity			*Weighted intermediate goods–labour ratio*	
Firm	*Labour productivity*	*Minimum (case 2)*	*Maximum (case 1)*	*Weighted capital–labour ratio*	*Minimum (case 1)*	*Maximum (case 2)*
Junkers	69.9%	11.9%	43.2%	0.0%	27.2%	58.4%
Siebel	52.3%	12.9%	36.4%	–1.8%	17.4%	41.4%
Mimo	33.1%	7.7%	20.6%	–2.1%	15.6%	28.2%
Weser	28.7%	7.9%	12.1%	–1.2%	16.6%	22.2%
ATG	26.4%	–2.8%	6.4%	5.8%	14.2%	22.7%
Arado	23.5%	7.3%	15.3%	1.5%	6.5%	14.6%
Heinkel	0.3%	–4.9%	4.4%	–2.3%	–2.3%	6.5%

Note: Notice that the growth rates of total factor productivity, capital intensity, and outsourcing do not always add up to the growth rate of labour productivity exactly because of rounding errors.

To evaluate the impact of total factor productivity, changes in capital intensity, and intermediate goods intensity on labour productivity, we subtract the growth rate of labour on each side of equation (4) and finally get:

$$\hat{O} - \hat{L} = \hat{K} + \beta \cdot \left(\hat{C} - \hat{L}\right) + \gamma\left(\hat{I} - \hat{L}\right) \tag{5}$$

Equation (5) demonstrates that the growth rate of labour productivity equals total factor productivity growth plus the weighted growth of both the capital–labour ratio and the intermediate goods–labour ratio.

Tables 1 and 3 show that most of the firms in our sample realized high annual growth rates with respect to both real output and labour productivity. What is more, there is obviously a positive correlation between these two economic variables: the higher the labour productivity growth, the higher generally was the increase in real output. Explaining the growth of output, therefore, means first and foremost explaining the growth of labour productivity.

First of all, it becomes clear that the labour productivity growth of the seven aircraft manufacturers analysed in this article cannot in general be attributed to an increase in capital intensity. Even in the outstanding case of ATG, increasing capital intensity explained only about 20 per cent of this firm's labour productivity growth. All aircraft manufacturers, except for ATG and Heinkel, realized high average annual growth rates of total factor productivity. The most surprising result is that a large part of aircraft manufacturers' labour productivity growth during the Second World War can be explained by an increasing intermediate goods–labour ratio, which until now has not been mentioned in the traditional explanations for the growth of German armament production. Even then, when we assume that intermediate goods prices were not decreasing over time (case 1), at least one-third of the labour productivity growth of the particularly successful firms Junkers, Siebel, Mimo, and Weser was caused by an increasing intermediate goods–labour ratio. On the other hand, it is obvious that Heinkel's low labour productivity growth primarily resulted from this firm's failure to outsource the production of standard components.

In the following section, we will explain in detail which factors caused the increase in both total factor productivity and intermediate goods–labour ratio and therefore the growth of labour productivity.

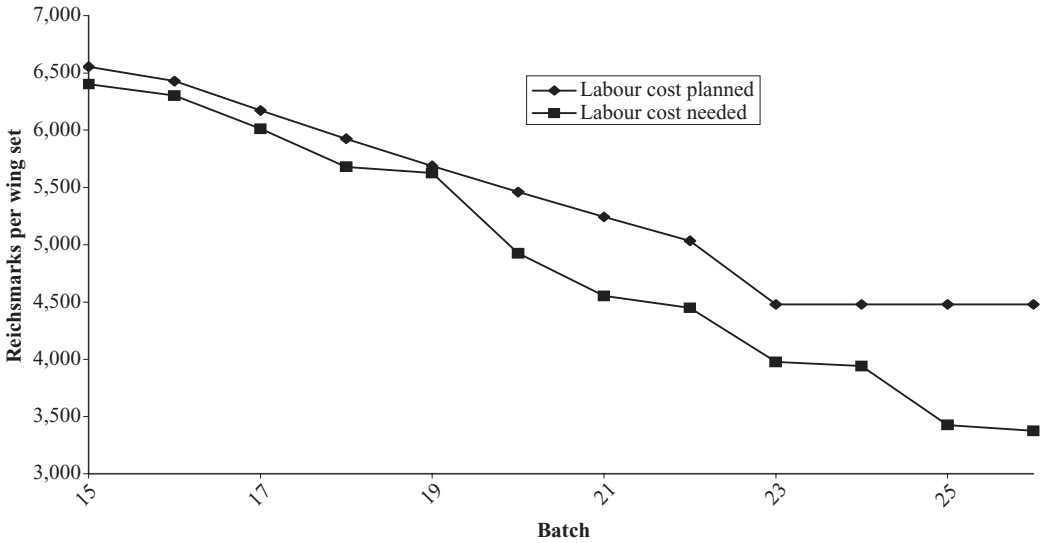

Figure 4. *Labour cost per Ju 88 wing set, planned in advance and actually needed, Siebel 1942*

Source: Siebel audit report 1942, BArch R 8135/2518, p. 18.

IV

We have already stressed that the introduction of fixed-price contracts in spring 1937 was the most important precondition for sustainable productivity growth in the German aircraft industry, because this regulatory reform motivated armament manufacturers to raise their profits by cost reduction. When an aircraft manufacturer was able to fabricate the aircraft at a lower production cost than estimated in the *ex ante* price agreement, he was entitled to keep this difference as an additional premium.

Figure 4 demonstrates, using the example of Siebel's wing set production in 1942, how this mechanism worked in practice. Usually, the longer fixed prices were kept constant, the higher the difference was between estimated and actual labour cost. This is especially true for batches 23 to 26 of the wing set production. While the procurement agency apparently believed that the possibilities to reduce costs were already being fully exploited, Siebel was still able to decrease its labour costs by about 25 per cent.[74]

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 manufacturers' profits, as depicted in figure 5, which shows the profits per unit of Junker's Ju 88 A-4 production during the two accounting years 1940/1 and 1941/2. During this two-year period, Junkers had to face only three price cuts, which occurred at the beginning of batches 42, 48, and 54

[74] A similar misjudgment of the aviation department can be observed in the case of Henschel, for example. Although the aviation ministry 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 labour and material costs. See ZF, Henschel files, 'Bericht an den Vorstand für das Wirtschaftsjahr 1942 [Report to the board of directors on the financial year of 1942]', 13 Oct. 1943.

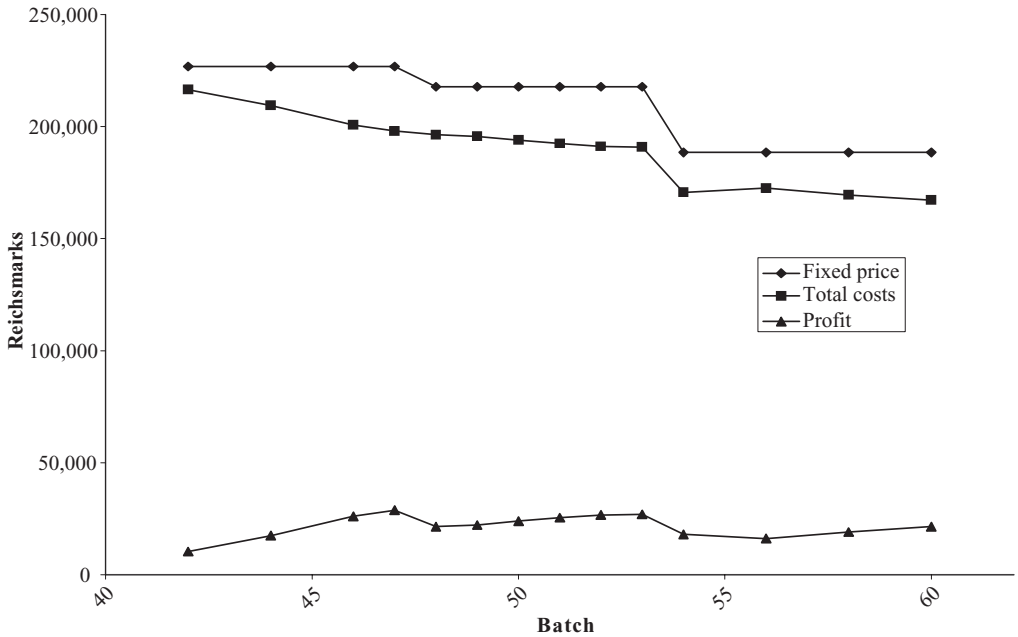

Figure 5. *Profit per unit of Junkers' Ju 88 A-4 production, 1940/1 to 1941/2*
Source: Audit report 1940/1, BArch R 8135/7558, p. 56; audit report 1941/2, BArch R 8135/7559, p. 94.

respectively. Each of these price adjustments, which were each calculated on the basis of the latest available production cost, decreased Junkers's profits considerably. Since each of the new prices was fixed for six batches, Junkers was then given both the time and the incentive to decrease its costs. As a result, Junkers's profits were generally 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 efficiency gains that were already possible into the period that followed the anticipated price reduction. Such behaviour would explain why Junkers was able to match the sharp price cut of batch 54 with an appropriate cost reduction.

Table 4 reveals that, while operating profits generally increased during the whole period covered by our data, aircraft manufacturers realized their highest operating profits per sales volume in 1939. The downward trend of the profit rates during the Second World War can be explained by two reasons. First, as we will see below, the learning effects of Ju 88 production were especially high in 1939 and 1940. Second, after 1939, the aviation ministry was no longer willing to tolerate the exceptional profits of the aircraft manufacturers and therefore often reduced the fixed prices after checking the book-keeping results.[75] In 1940, for example, Arado's operating profits per sales volume were decreased from 13.5 per cent to 9 per cent by later price adjustments.[76] The expectation that the state was going to

[75] On fixed price reductions in the aircraft industry and other armament industries, see Scherner and Streb, 'Das Ende eines Mythos?', pp. 187–9.
[76] See audit report 1940, BArch R 8135/7084, p. 15.

Table 4. *Operating profits of the aircraft manufacturers ATG, Heinkel-Oranienburg, Junkers, Siebel, and Weser by calendar year, 1938–43*

	Average monthly operating profits		
Year	*Index (1938 = 100)*	*Growth rate*	*Operating profits per sales volume*
1938[a]	100		8.3%
1939	161	61%	10.8%
1940	237	47%	9.6%
1941	278	18%	8.4%
1942	350	26%	7.5%
1943[b]	411	18%	7.0%

Notes: a Without Heinkel-Oranienburg.
b Without Weser, for ATG only up to June 1943, for Junkers only up to Sept. 1943.
Source: For data, see audit reports of the Deutsche Revisions- und Treuhand AG in the app.

cut profits *ex post* certainly lowered the firms' willingness to reduce costs.[77] Since the firms were still certain that they would be allowed to keep part of the additional profits, it seems reasonable to assume that the incentives provided by the fixed-price contracts did not totally cease.

Obviously, during the whole period of the Second World War and not just after 1941, the procurement regime of fixed-price contracts motivated profit-oriented aircraft manufacturers to strive for increases in productivity. We now analyse in detail how the firms of the Ju 88-programme actually managed to reach these goals. We will stress the importance of two sources of firms' productivity growth which are usually not mentioned in traditional explanations of the German armament miracle, namely, learning effects and outsourcing.

The idea of learning curves was introduced into economics by Alchian in 1963. Analysing the data of 22 different aircraft types produced by the US industry during the Second World War, Alchian found that the direct amount of labour required to produce a unit of a special aircraft type regularly declines when the total output of this type is expanded.[78] This relationship can be graphically expressed by the so-called learning curve.[79] 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 labour productivity is expected to be especially high when workers are given rather complex tasks, as was the case in the aircraft industry during the Second World War. Another general characteristic of the learning curve is that the absolute decrease in working time required to produce a special good will be less with each successive unit of output. This implies that aircraft manufacturers realize

[77] On the effort-reducing effects of ex post price adjustments in the construction industry, see Streb, 'Negotiating contract types'.
[78] Alchian, 'Progress curves'.
[79] Hartley, 'Learning curve', p. 123.

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.

Given non-increasing wages, the learning curve obviously translates via falling labour 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 aircraft manufacture.[80] When workers become accustomed to a special production process, they also learn to avoid mistakes that cause materials to be wasted. As we have already assumed in case 2 in table 3, the prices of components bought from other firms may also 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 inexperienced workers, learning-by-doing also cuts fixed overhead costs per unit.

Before the Second World War, the German aviation ministry 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 ministry, submitted his doctoral thesis in which he found a negative correlation between working hours per ton of aircraft and accumulated output.[81] The aviation ministry understood the economic implications of Richthofen's observation and carefully kept track of the decreasing direct labour input, actually drew its own learning curves for different aircraft types and different aircraft manufacturers, and finally used the information delivered by these charts to predict the future development of labour productivity in the aircraft industry.[82] Moreover, the Ju 88-programme itself was explicitly designed to exploit economies of learning. Junkers had needed a minimum of 30,000 working hours to produce the type of bomber that preceded the Ju 88, and 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 thousandth Ju 88. It was further assumed that learning effects could also be initiated in smaller firms such as Siebel and ATG, which were therefore instructed to specialize in the production of certain parts of the Ju 88.[83]

The available data allow us to construct a curve, depicted in figure 6, which shows the development of working hours needed on average by the three firms ATG, Junkers, and Siebel to produce one unit of the Ju 88 bomber in the period from August 1939 to August 1941.[84] Notice that the vertical axis presents the logarithm of the working hours. Overall, the average working hours dropped spectacularly 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 stages of a production run. Two further details in figure 6 are

[80] Sturmey, 'Cost curves', pp. 961–3.

[81] Richthofen, *Einfluß der Flugzeugbauarten*. Wolfram von Richthofen was a cousin of the famous First World War fighter pilot Manfred von Richthofen.

[82] See, for example, BArch MA RL 3/931, pp. 13, 34–6.

[83] See Archives of the German Museum in Munich (DMM/ASD) LRD LR 02621, 'Ju 88 Zentralsteuerung. Ein Schritt zur Rationalisierung der Fertigung in der Luftfahrtindustrie', p. 2.

[84] Traditionally, learning curves show working hours as a function of cumulative output. We decided to present working hours in fig. 6 as a function of incremental time and therefore only indirectly as a function of cumulative output to demonstrate that absolute learning effects were higher in the pre-Speer period than afterwards. By contrast, figs. 4 and 5 show learning as a function of successive batches, in other words, of cumulative output.

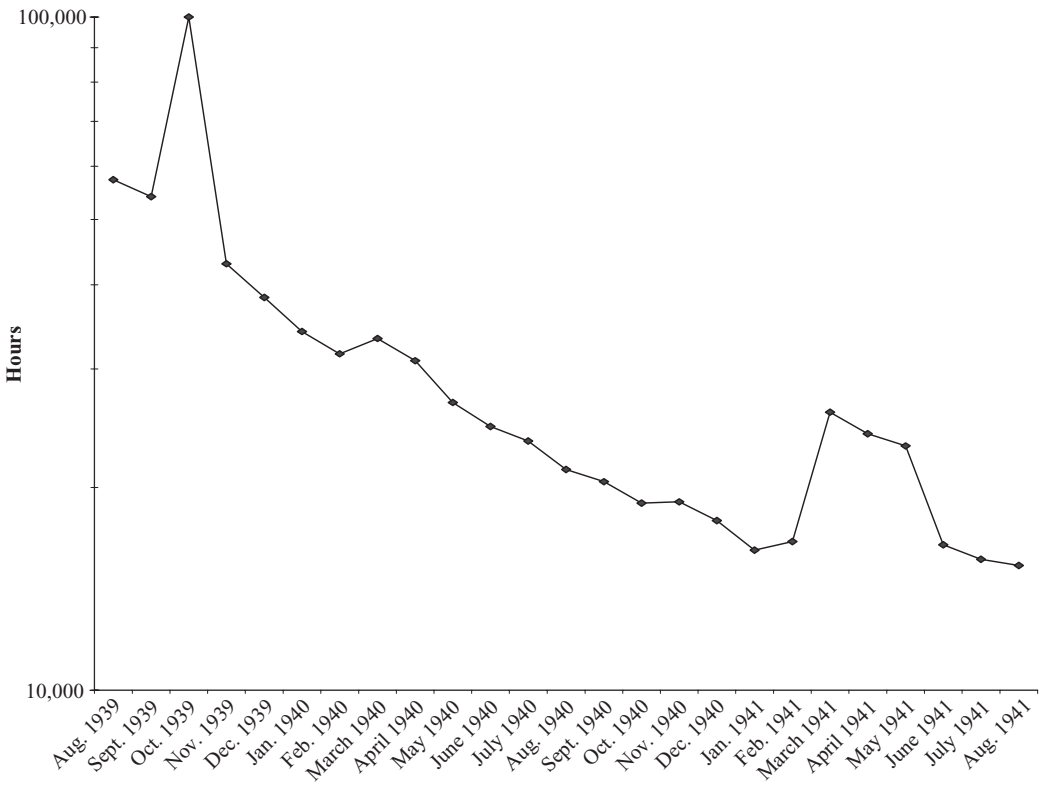

Figure 6. *Average working hours per unit of Ju 88 (ATG, Junkers, and Siebel), log-linear*

Source: BArch MA RL 3/976, p. 48; BArch MA RL 3/931, pp. 34–6.

noteworthy. The small decrease in labour productivity in spring 1940 was caused by the appearance of two new manufacturers, ATG and Siebel, which started their Ju 88 production later and were therefore less efficient than Junkers at this point in time. The sharp decrease in labour productivity in spring 1941 resulted from the adaptation costs that occurred because of the change to the new design, the 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.[85]

Table 5 demonstrates that learning effects translated into falling production costs for Junkers. In the two-year period between 1940/1 and 1942/3, the total costs of producing one unit of the Ju 88 bomber fell by 33 per cent, the direct material costs by 29 per cent, and the labour costs by 60 per cent. This decrease

[85] The same learning effects are observable at Henschel, whose performance in the Ju 88 programme can be studied over the whole span of production. Preparations for production started in Jan. 1938, and final assembly began in Nov. 1938. While Henschel needed more than 700 working hours to produce 1,000 Reichsmarks of production value (final assembly, fuselages, and engine suspensions) in Nov. 1938, this rate steadily dropped to a minimum rate of 29 working hours in Dec. 1943. As in the case of the other participants in the Ju 88 programme, the largest increase in labour productivity occurred in the first year of the production run. See ZF, Henschel files, Henschel Flugzeug-Werke, monthly reports to the board.

Table 5. *Decreasing production costs at Junkers*

Accounting year: type	*Production costs (Reichsmarks)*	*Labour costs (Reichsmarks)*	*Material costs (Reichsmarks)*
1939/40: Ju 88	523,385		
	210,648		
1940/1: Ju 88 A-5	196,825	14,998	141,996
	187,324	13,497	136,431
1940/1: Ju 88 A-4	216,523	21,481	143,479
	198,019	12,467	142,246
1941/2: Ju 88 A-4	170,605	12,211	128,160
	167,129	10,803	126,446
1941/2: Ju 88 A-4 trop.	173,143	12,114	129,680
	159,484	7,876	125,897
1941/2: Ju 88 D-1 trop.	156,807	8,580	122,844
	154,670	7,686	122,422
1942/3: Ju 88 A-4 trop.	141,246	6,876	107,966
	139,274	6,475	107,155
1942/3: Ju 88 D-1 trop.	137,204	6,592	104,515
	131,145	5,750	101,500

Notes and sources: For each accounting year both the highest (and simultaneously earliest) and the lowest (and simultaneously latest) production costs of a special design are reported. For more details, see audit report 1939/40, BArch R 8135/2548, p. 70; audit report 1940/1, BArch R 8135/7558, p. 56; audit report 1941/2, BArch R 8135/7559, p. 94; audit report 1942/3, BArch R 8135/7560, p. 76.

in labour costs might have been larger than the decrease in working hours, since wages were also decreasing during the Second World War because of the growing share of foreign civilian workers, prisoners of war, and concentration camp prisoners who were paid lower wages than German workers.[86] Table 5 also shows that the increase in labour productivity depicted in figure 6 did not stop after 1941. At the end of the accounting year 1942/3, Junkers only needed about 7,000 working hours to build an aircraft that had required 100,000 working hours in October 1939 and about 20,000 working hours in the autumn of the year 1940.[87] This decrease in working hours between 1940 and 1943 at Junkers corresponds to an average annual increase in productivity of about 41 per cent. Since this number comes very close to our upper-bound estimate of average annual total factor productivity growth at Junkers of about 43 per cent, shown in table 3, we are confident in assuming that the calculated total factor productivity growth first and foremost captures the learning effects in aircraft production.

It was claimed above that the increase in labour productivity portrayed by the learning curve generally results from blue-collar 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 in the firm long enough to do so. The available data imply that this precondition was not always realized in the German aircraft industry. During the Second World War, the fluctuation of the workforce was high. Every accounting year, Junkers, for example, lost between a fifth and a third of the employees recruited earlier. Since this firm nevertheless tried to increase its workforce, the number of newly recruited and mostly very inexperienced employees comprised about 40 per cent of the work-

[86] See, for example, Heinkel's audit report 1942/3, BArch R 8135/7500, p. 49.
[87] See audit report 1942/3, BArch R 8135/7560, p. 76.

force in every accounting year for which we have data.[88] This observation suggests that a lot of employees only worked for a few months in the plants of the German aircraft manufacturers and, as a consequence, did not have enough time to increase their labour productivity considerably through learning-by-doing.[89] As a result, it was apparently primarily the skilled long-term employees, who were always in danger of being drafted, who increased their efficiency by learning.[90]

However, reviewing B-17 production in Boeing's Plant No. 2 in Seattle, Washington, during the Second World War, Mishina observed that the management learned during the production run how to improve the workers' productivity by improving the production system.[91] 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 labour, and the reduction of rework thanks to greater interchangeability of components.

We found some evidence that in the German aircraft industry it was also often the production system that embodied learning effects and not the individual workers themselves. The auditor of Junkers, for example, pointed out that in the accounting year 1941/2 the firm's savings in labour costs were above all caused by technical rationalization measures, by the refining of the production methods and the introduction of assembly lines.[92] In Siebel's plants, the labour–output coefficient, calculated by dividing the average annual number of blue-collar workers by the number of aircraft assembled in the respective year, dropped from 9 in 1941 to 2.2 in 1943. This increase in labour productivity was again explained by the introduction of assembly lines. In addition, the audit report mentioned, however, that more frequent use of interchangeable components may also have improved efficiency.[93]

These examples support our conjecture that in the German aircraft industry both the managers and the workers learned. The managers' attempts to transfer learned knowledge to a fluctuating workforce might also help to explain why suggestion systems rapidly expanded in the aircraft industry and the German armament industry as a whole. In 1940, 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 in German industry 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.[94] Among them, the aircraft manufacturers were particularly eager to take advantage of the knowledge of their workers. Ernst Heinkel intensely propagated the introduction of suggestion systems,[95] while a manager at Junkers led an inter-firm committee which had been founded to

[88] For Arado, see audit report 1940, BArch R 8135/7084, p. 8; audit report 1941, BArch R 8135/7085, pp. 7–8; audit report 1942, BArch R 8135/7085, p. 6. For Junkers, see audit report 1940/1, BArch R 8135/75558, p. 22; audit report 1941/2, BArch R 8135/7559, p. 141.
[89] See also Budraß, *Flugzeugindustrie*, p. 461.
[90] See also Uziel, 'Industrial revolution and slavery'.
[91] Mishina, 'Learning by new experiences', p. 164.
[92] See audit report 1941/2, BArch R 8135/7559, p. 95.
[93] See audit report 1943, BArch R 8135/7938, p. 10.
[94] Steinwarz, *Vorschlagswesen*.
[95] Heinkel, *Erfahrungen*.

exchange workers' suggestions.[96] In 1943, Arado and Heinkel organized large exhibitions of their workers' suggestions, not least to prove their ambitions for rationalizing production. Interestingly, 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 responded to requests to submit suggestions for technical improvements in production.[97] Though it is difficult to quantify the different effects of these suggestion systems on productivity, one important intention of the management was clearly to find out the information that was necessary to accelerate the learning of inexperienced workers. 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 four: rationalization, standardization of components, longer working hours, and, last but not least, workers' suggestion systems.[98]

In his seminal book *The economic institutions of capitalism*, Williamson concludes that a firm's decision to make or buy a special component of its own final product depends on the comparison of the governance cost and production cost of internal production and market procurement respectively.[99] In Williamson's opinion, market procurement, later called outsourcing by the management literature of the 1990s, always decreases total production cost because it allows both the manufacturer of the final product and the supplier of the component to concentrate on their respective core competences, thereby realizing economies of scale and economies of learning. That is why a manager who intends to increase the productivity of his firm should outsource the production of those components that involve low asset specificity and therefore negligible external governance cost.

The *Wirtschaftsrüstungsamt* (the military-economic office of the supreme command of the German army) were already planning in November 1939 to use outsourcing as a means of increasing armament firms' output and productivity.[100] The firms in our sample also soon realized that they could increase their own output considerably by outsourcing the production of standardized components that they had originally planned to produce themselves.[101] Adam Opel AG, Rüsselsheim, Metallgußgesellschaft mbH, Leipzig, Vereinigte Deutsche Leichtmetallwerke, Hildesheim, and Kronprinz AG (in Solingen-Ohligs), among others, became important suppliers of standardized components.[102] Table 6 demonstrates that outsourcing was in fact substantial during the Second World War. In the case

[96] Budraß, *Flugzeugindustrie*, p. 817.

[97] See 'Himmler an Göring, 9.3.44', Trial of the Major War Criminals before the International Military Tribunal, Nuremberg 14 Nov.–1 Oct. 1946, vol. 27 (Nuremberg, 1948), pp. 355–7.

[98] See Imperial War Museum, London, Combined Intelligence Objectives Subcommittee evaluation report #323, 'Interrogation of Gen. Dir. K. Frydag and Prof. E. Heinkel. Some aspects of German aircraft production during the war, 14/8/45'.

[99] Williamson, *Economic institutions*, pp. 90–5.

[100] See 'Vortragsnotiz des WiRüAmt vom 11. November 1939', BArch MA RW 19/561, fos. 16–17.

[101] See, for example, Heinkel's audit report 1940, BArch R 8135/7498, p. 56. See also Junkers' audit report 1940/1, BArch R 8135/7558, p. 53; Mimo's audit report 1939, BArch R 8135/3625, p. 18; Siebel's audit report 1939, BArch R 8135/2518; Weser's audit report 1940, BArch R 8135/5271, app., p. 59. See also Budraß, *Flugzeugindustrie*, pp. 838–40, and Werner, *Kriegswirtschaft*, p. 50.

[102] See ATG's audit report 1943, R 8135/2168, p. 3; Mimo's audit report 1941, BArch 8135/3626, enclosure VI; Siebel's audit report 1941, BArch 8135/7938, enclosure V; Weser's audit report 1940, BArch R8135/5272, enclosure VIII.

Table 6. *Outsourcing: share of intermediate goods in total cost*

Year[a]	*Junkers*	*Siebel*	*Mimo*	*Weser*	*ATG*	*Heinkel*	*Arado*
1937			21%	36%			
1938		47%	47%	34%	52%		
1939	56%	53%	58%	41%	59%	62%	52%
1940	63%	66%	64%	47%	58%	67%	53%
1941	71%	63%	66%	43%	62%	64%	51%
1942	79%	69%	68%	54%	63%	66%	55%
1943	88%	72%	72%		71%	68%	

Note: a Accounting years have not been changed into calendar years.
Source: For data, see audit reports of the Deutsche Revisions- und Treuhand AG in the app.

of Mimo, the share of the expenses for intermediate goods in total production costs increased from just 21 per cent in 1937 to 72 per cent in 1943. ATG and Siebel reached a similar degree of outsourcing in the same year. The comparison of tables 3 and 6 reveals that Junkers realized both the highest degree of outsourcing and the highest annual growth rates of labour productivity. On the other hand, Heinkel and Arado, the two firms with the lowest labour productivity growth in our sample, hardly decreased their manufacturing penetration in the period covered by the available audit reports. These observations suggest that there was a strong positive relationship between outsourcing: an increasing intermediate goods–labour ratio depicted in table 3, labour productivity growth, and consequently also output growth in aircraft production during the Second World War. A full examination of German armament production during the Second World War would therefore involve taking a closer look at the many unknown suppliers of the more famous armament firms.

V

It is widely believed that it was the Speer administration that caused the alleged sudden upswing in German armament production after 1941 by introducing several rationalization measures and, probably most importantly, by replacing cost-plus contracts with fixed-price contracts. The sample of seven aircraft manufacturers analysed in this article suggests instead that, at least in the aircraft industry, which accounts for about 40 per cent of German armament production, the crucial changes in procurement policy occurred not in 1942 but before the Second World War started. In the spring of 1937, the aviation department chose to rely on fixed-priced contracts in order to give aircraft manufacturers an incentive to reduce costs. In summer 1938, it was decided that the aircraft manufacturers should concentrate on special tasks and outsource the production of most standard components. The resulting increase in the inter-firm division of labour allowed firms to run larger production series and exploit economies of scale. In addition, moving down the learning curve, the managers of the aircraft manufacturers increased their knowledge about how to deploy workers efficiently. Since we also found a steady increase in the firms' factor endowment during the war, we can be certain that the development of German aircraft production should not be subdivided into two distinct periods; in fact, it followed a rather continuous growth

path during the Second World War. We consequently reject both the old *Blitzkrieg* thesis and the new inefficiency thesis, at least for the aircraft industry—and the explosives industry, for which similar results have been found.[103] We will have to analyse other war industries in greater detail before we can be sure that the continuity thesis is true for the majority of German armament manufacturers during the Second World War.[104]

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[103] Scherner and Streb, 'Wissenstransfer'.
[104] Studies by Hirsch ('Manufacturing progress') and Rapping ('Learning') reveal that both the American ship-building and machine-building industries realized substantial learning effects during and after the Second World War.

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APPENDIX: AUDIT REPORTS OF THE DEUTSCHE REVISIONS- UND TREUHAND AG

BArch R: Bundesarchiv, Berlin-Lichterfelde, Germany.

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

July 1937–June 1938	BArch R 8135/2167
July 1938–June 1939	BArch R 8135/2167
July 1939–June 1940	BArch R 8135/2167
July 1940–June 1941	BArch R 8135/7100
July 1941–June 1942	BArch R 8135/2166
July 1942–June 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–March 1942	BArch R 8135/7499
April 1942–March 1943	BArch R 8135/7500
April 1943–March 1944	BArch R 8135/1916

Junkers Flugzeug- und Motorenwerke Dessau

Oct. 1939–Sept. 1940	BArch R 8135/2548
Oct. 1940–Sept. 1941	BArch R 8135/7588
Oct. 1941–Sept. 1942	BArch R 8135/7559
Oct. 1942–Sept. 1943	BArch R 8135/7560

Mitteldeutsche Motorenwerke GmbH Leipzig

Jan. 1937–Dec. 1937	BArch R 8135/7736
Jan. 1938–Dec. 1938	BArch R 8135/3625
Jan. 1939–Dec. 1939	BArch R 8135/3625
Jan. 1940–Dec. 1940	BArch R 8135/3626
Jan. 1941–Dec. 1941	BArch R 8135/7736
Jan. 1942–Dec. 1942	BArch R 8135/7736
Jan. 1943–Dec. 1943	BArch R 8135/7736

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